Scilab Textbook Companion for Turbomachinery Design and Theory by R. S. R. Gorla And A. A. Khan[1]

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Book Description

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

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Chapter 1

Introduction Dimensional Analysis Basic Thermodynamics and Fluid Mechanics

Scilab code Exa 1.1 Radial Flow Hydraulic

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 1, Example 1")
8  //Linear ratio L = Lp/Lm = Bp/Bm = Dp/Dm
9  // We know P1/(rho1*(N1)^3*(D1)^5) = P2/(rho2*(N2)
       ^3*(D2)^5)
10 //Pressure equation rho1 = rho2
11 //Hence, D2/D1 = 0.238(N1/N2)^(3/5)
12 //Also (g*H1)/(N1*D1)^2 = (g*H2)/(N2*D2)^2
13 //Therefore 0.238 (N1/N2)^(3/5) = (6/16)^(N1/N2)
```

```
14  //Hence, (N2/N1)^(2/5) = 2.57
15  disp ("Therefore Model Speed N2 in rpm, Model Scale
        Ratio RD and Volume flow rate(Q)in cubic meters
        per second are:")
16  N2 = 100 * 2.57^(5/2)
17  RD = 0.238 * (100/1059)^(3/5)
18  Q = 42 * 1000 / (0.92*1000*9.81*6)
```

Scilab code Exa 1.2 Centrifugal Pump Head

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 1, Example 2")
8  // While equating flow coefficients Q1 / (N1 * D1^3)
        = Q2 / (N2 * D2^30)
9  //Also the head equation we follow is g*H1/(N1^2*D1
        ^2) = g*H2/(N2^2*D2^2)
10 disp("Volume flow rate in cubic meters per second
        and Head in meters are:")
11 Q2 = 2.5*2210*(0.104)^3/(2010*(0.125)^3)
12 H2 = 9.81 * 14 * (2210*104)^2 /(((2010*125)^2)
        *(9.81))
```

Scilab code Exa 1.3 Air Compressor Speed

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
```

```
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 1, Example 3")
 8  //The Speed Parameter Equation (N1/T01^(1/2)) = (N2/
        T02^(1/2))
 9  //Also the mass flow Parameters m1 * (T01^2)/p01 =
        m2 * (T02^2)/p02
10  disp("The Compressor speed in rpm, mass flow rate in
         kg per s are: ")
11  N2 = 5000 * ((273+25)^(1/2)/(273+18)^(1/2))
12  m2 = 64 * (65/101.3) * (291/298)^0.5
```

Scilab code Exa 1.4 Pumping Power

```
 1  // Display mode
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 1, Example 4")
 8  disp ("Theoritical Question")
 9  //liquid discharge rate Q; head H;specific weight of
         the liquid is w.
10  disp("Expression for Pumping power is P = kwQH")
```

Scilab code Exa 1.5 Drag Force F

```
 1  // Display mode
 2  mode(0);
```

```
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 1, Example 5")
8  disp ("Theoritical Question")
9  //V is the velocity of the body, l is the linear
      dimension, rho is the fluid density, k is the rms
       height of surface roughness and g is the
      gravitational acceleration
10 disp("Functional Relationship for Force F  may be: F
      = V^2 * l^2 * rho * f(k/l , l*g/V^2)")
```

Scilab code Exa 1.6 Axial Pump Power

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 1, Example 6")
8  // Geometric and Dynamic similarity equations Q1 / (
      N1 * D1^2) = Q2 / (N2 * D2^2)
9  // Head coefficient W2 = W1 * N2^2 * D2^2 / (N1^2 *
      D1 ^2)
10 // Also Pressure Delta P = W2 * eta tt * rho
11 disp("Flow rate in cubic meters per minute , Head
      coefficient in J/kg, Change in Total Pressure in
      bar , Input Power P in kilowatt are : ")
12 Q2 = 2.5 * 2900 * 0.22^2 / (1450 * 0.32^2)
13 W2 = 120 * 2900 ^ 2 * 0.22 ^ 2 / ((1450)^2 * 0.32^2)
14 Pressure = 226.88 * 0.78 * 1000 /100000
```

```
15  P = 1000 * 2.363 * 0.22688 / 60
```

Scilab code Exa 1.7 Axial Gas Turbine

```
1   // Display mode
2   mode(0);
3   // Display warning for floating point exception
4   ieee(1);
5   clear;
6   clc;
7   disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 1, Example 7")
8   // Using isentropic P-T Relation T02' = T01 * (P02/
        P01) ^ (gamm - 1 / 2)
9   //Total to total Efficiency etta tt implies T01 -
        T02 = (T01 - T02") * ettatt
10  //Power input W1 = cp * delta To
11  //Power output W2 = W1 * N2 ^ 2 * D2 ^ 2 / (N1 * D2)
        ^2
12  ettatt = 0.85;
13  T01 = 1050;
14  gamm = 1.4;
15  T02 = T01 * (1/4)^((1.4-1)/2);
16  disp("Power input in KJ/Kg and Power output in KJ/Kg
        are :")
17  W1 = 1.005 * 292.13
18  W2 = 293.59 * 1000 * 12500 ^ 2 * .2 ^ 2 / (15500^2 *
        0.3^2)
19  disp("Therefore power output = ")
20  Power = W2/1000
```

Scilab code Exa 1.8 Wind Tunnel

```
1  // Display mode
2  mode (0) ;
3  // Display warning for floating point exception
4  ieee (1) ;
5  clear ;
6  clc ;
7  disp (" Turbomachinery Design and Theory ,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 1, Example 8")
8  //Let us suppose
9  //Velocity of the model, Vm
10 //Length of the model, Lm = 160mm
11 //Length of the prototype Lp = 1000mm
12 //Velocity of the prototype Vp = 40.5m/s
13 //According to (Re)m = (Re)p
14 //Also Vm*Lm/vm = Vp*Lp/vp
15 disp (" Velocity of wind(m/s) in the tunnel implies =
       ")
16 Vm = 40.5 * 1000 / 160
```

Scilab code Exa 1.9 Kinetic Energy

```
1  // Display mode
2  mode (0) ;
3  // Display warning for floating point exception
4  ieee (1) ;
5  clear ;
6  clc ;
7  disp (" Turbomachinery Design and Theory ,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 1, Example 9")
8  //Theoritical Question
9  //Kinetic Energy Equation
10 disp (" The Kinetic Energy => k V^2 m ")
11 disp (" Where k is a constant")
```

Scilab code Exa 1.10 Radial Inward Flow

```scilab
1  // Display mode
2  mode (0);
3  // Display warning for floating point exception
4  ieee (1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 1, Example 10")
8  //Given conditions
9  //r1 = 0.14m
10 //Cw1 = 340m/s
11 //r2 = 0.07m
12 //Cw2 = 50m/s
13 //Torque = r1*Cw1 - r2*Cw2
14 disp("Torque in Nm kg/s implies => ")
15 T = 0.14*340-0.07*50
```

Chapter 2

Hyraulic Pumps

Scilab code Exa 2.1 Centrifugal Pump Torque

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 1")
8  //Reference to the Fig 2.2 for zero slip beta2
       beta2'. Using Euler's pump equation , E=W/m=(U2*
       Cw2-U1*Cw1)
9  Cw1 = 0;
10 disp ("Euler head = H in meters , Power in Kilowatts
       , Torque in Newton meters are :")
11 //H=U2*Cw2/g = (U2/g)*(U2 - 1.5/tan(28))
12 H = (12/9.81)*(12 - 1.5 / tan(28*%pi/180))
13 //Power delivered = pho * g * Q * H joules/s
14 Power = 1000 * 9.81 * 3.8 * 11.23 /(60 * 1000)//
       Power will be in kilowatts
```

```
15 //Torque = power/angular velocity
16 Torque = Power* 1000 * 0.6/12
```

Scilab code Exa 2.2 Head Imparted

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
4 ieee(1);
5 clear;
6 clc;
7 disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 2, Example 2")
8 //Fluid is entering in radial direction
9 Cw1 = 0;
10 alpha1 = 90; //angle is in degrees
11 beta2 = 22; //angle in degress
12 Ca1 = 3.5; //velocity of flow in m/s
13 D= 0.22;
14 N=1250;
15 //Ca1 = Ca2
16 Ca2 = 3.5;
17 //Head developed H = Cw2*U2/g
18 //Impeller tip Speed U2 = pi*D*N/60
19 disp ("Impeller tip speed in m/s is : ")
20 U2 = %pi * D * N / 60
21 disp("Whirl velocity at impeller outlet, in m/s is :
      ")
22 Cw2 = (U2 - Ca2/tan(22*%pi/180))
23 disp("Head Imparted is H in meters : ")
24 H = Cw2 * U2 / 9.81
```

Scilab code Exa 2.3 Centrifugal Pump Impeller

```scilab
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 3")
8  D2 = 0.4;
9  N= 1400;
10 disp ("Impeller tip speed given by piDN/60 in m/s is
        : ")
11 U2 = %pi * D2 * N /60
12 disp("whirl velocity at tip in m/s is : ")
13 Cr2 = 2.6;
14 Cw2 = (U2 - Cr2 / tan(25*%pi/180))
15 //From velocity Triangle 2.3 tangent alpha2 = Cr2/
       Cw2 = 2.6/23.75 = 0.1095
16 disp("Alpha2 is in degrees")
17 alpha2 = atan(0.1095) *180/(%pi)
18 disp("Impeller velocity at inlet in m/s is : ")
19 D1 = 0.2;
20 U1 = %pi * D1*N /60
21 //From velocity Triangle 2.3 tangent beta1 = Cr1/U1
       = 2.6/14.67 = 0.177
22 disp("Beta1 is in degrees")
23 beta1 = atan(0.177) * 180 /(%pi)
24 disp("Work done per kg of water in Joules is : ")
25 W = Cw2 * U2
```

Scilab code Exa 2.4 Efficiency Lift Discharge

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 4")
8  //Q is discharge rate, beta2 is angle of vane at
       outlet, H is head, Diaratio is diameter ratio of
       external by internal dia, N is rpm, A is area of
       outer periphery
9  Q = 1550;
10 beta2 = 25;
11 H = 6.2;
12 Diaratio = 2;
13 D2 = 1.2;
14 N = 210;
15 A = 0.65;
16 disp("Velocity of flow at impeller tip in m/s is :")
17 Cr2 = Q/(A*1000)
18 disp("Impeller tip speed in m/s is :")
19 U2 = %pi * D2 * N / 60
20 Cw2 = U2 - Cr2 / tan(%pi*25/180)
21 disp("TheoH is theoritical head in m")
22 TheoH = Cw2 * U2/9.81
23 //Assuming slip factor sigma = 1, efficiency is
24 disp("efficiency is ")
25 etah = H * 100 / TheoH
26 //Power is denoted by P
```

19

```
27  disp("Power in kilowatts is : ")
28  P = Q * TheoH * 9.81 / 1000
29  disp("Centrifugal head is minimum head. Thus we get
        : ")
30  //U2^2-U1^2/2g = 6.2
31  //U1 = U2/2
32  U2 = (2 * 9.81 * 6.2 /(1-0.25))^(1/2)
33  disp("minimum speed in rpm is :")
34  minN = U2 * 60 / (%pi * D2)
```

Scilab code Exa 2.5 Horse Power Pump

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 5")
8  //H is head in m, Q is discharge m3/s, eta is
       efficiency , P is power
9  disp("Power P in Horse power is :")
10 H = 35;
11 Q = 0.045;
12 eta = 0.6;
13 //P = rho gQ/eta in joules per second
14 P = 9.81 * Q * H / (0.6 * 0.746)
```

Scilab code Exa 2.6 Impeller Vanes Angled

20

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 2, Example 6")
8  // Velocity of flow through impeller is constant so
      Cr1 = Cr2 = 3.5 m/s
9  disp("Tangential Velocity of impeller at inlet in m/
      s is :")
10 //Din and D2 are diameters in meters, N is in rpm,
      Cr2 in m/s
11 Din = 0.3;
12 D2 = 0.6;
13 N = 950;
14 Cr2 = 3.5;
15 U1 = %pi * Din * N / 60
16 //tanalpha1 = Cr1/U1 3.5/14.93 = 0.234
17 disp("vane inlet angle of pump alpha1 : ")
18 alpha1 = atan(0.234) * 180/ %pi
19 disp("Tangential velocity of impeller at outlet in m
      /s:")
20 U2 = %pi * D2 * N / 60
21 disp("Now For velocity of whirl at impeller outlet,
      using velocity triangle.in m/s is :")
22 Cw2 = U2 - Cr2 / tan(46*%pi/180)
23 //As c2^2 = Cw2^2 + Cw2^2 , Therefore
24 disp(" Velocity of water at outlet C2 in m/s is :")
25 C2 = (Cr2^2 + Cw2^2)^(1/2)
26 disp("alpha2 be the direction of water outlet, Thus
      we have :")
27 alpha2 = atan(Cr2/Cw2)*(180/%pi)
28 disp("Work Done in Newton meters is given by :")
29 W = Cw2*U2
```

Scilab code Exa 2.7 Vanes At 45 Degrees

```scilab
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 7")
8  //From Figure Ex26
9  //Finding Manometric Efficiency
10 //D2 is dia in meters, N in rpm, Head H in meters ,
       Cr2 and Cw2 in m/s
11 D2 = 0.5;
12 D1 = 0.25;
13 N = 500;
14 H = 10;
15 Cr2 = 2;
16 beta2 = %pi/4;
17 Cr1 = 2;
18 //etaman = H/(Cw2*U2/g)
19 disp("Outlet Velocity be U2 in m/s :")
20 U2 = %pi * D2 * N / 60
21 //To Find Cw2
22 Cw2 = 13-2/(tan(%pi/4))
23 disp(" Manometric Efficiency be etaman in %: ")
24 etaman = H*9.81/(Cw2*U2)  *100
25 disp("Vane Angle at inlet beta 1 in degrees is :")
26 //U1 = U2/2
27 beta1 = atan(Cr1/(U2/2))*(180/%pi)
28 disp("Minimum Starting speed N in rpm is :")
```

```
29  //(U2^2-U1^2/2g = H implies
30  Nmin = ((2*9.81*10)/((%pi*D2/60)^2 -(%pi*D1/60)^2))
        ^(1/2)
```

Scilab code Exa 2.8 Vanes Radially Exit

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 8")
8  //D2 is siameter in meter, N is rpm, Cr2 in m/s and
       Cw2=U2 in m/s , V velocity of flow in m/s
9  D2 = 0.6;
10  N = 550;
11  Cr2 = 3.5;
12  U2 = %pi*D2*N/60
13  Cw2 = U2
14  g = 9.81;
15  V=2.5;
16  disp("Head in meters from where water is being
       lifted is :")
17  H = Cw2 * U2/ g - (V^2)/(2*g)
18  //b2 is width
19  //Qis discharge Q=piD2b2Cr2 in m3/s
20  b2 = 0.082;
21  disp("Discharge Q is in m3/s:")
22  Q = %pi * D2 * b2 * Cr2
23  disp("Power P in Kilowatts is given as :")
24  rho = 1000; //density of water 1000kg/m3
```

23
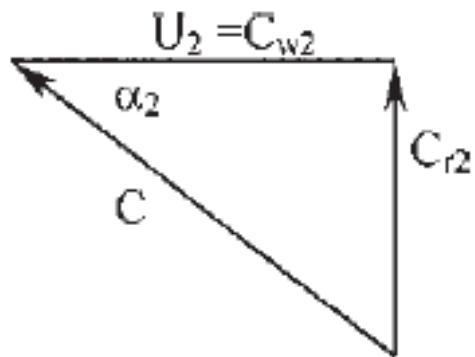
Figure 2.23 Velocity triangle for Example 2.8.
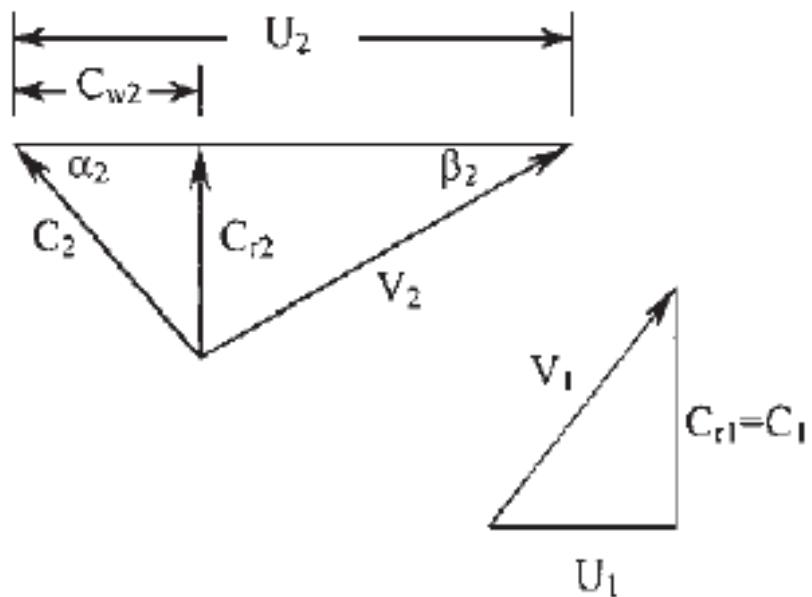
Figure 2.1: Vanes Radially Exit

24

```
25  P = rho*g*Q*H/1000
```

Scilab code Exa 2.9 Radial Component Water

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 9")
8  disp("The Given Data")
9  disp("The Following Data D2 is diameter in m, U2 and
        Cr2 in m/s, alpha1 and beta2 in degrees, Q is
       i9n m3/s")
10 D2 = 1
11 U2 = 11
12 alpha1 = 90
13 Cr2 = 2.5
14 beta2 = 32
15 Q = 5.5
16 rho = 1000;
17 disp("Outlet Velocity Cw2 in m/s is :")
18 Cw2 = U2 - (Cr2/tan(32*%pi/180))
19 disp("Power in pump in kilowatts is :")
20 P = rho*Q*Cw2*U2/(1000*60)
21 //H.P. = 2*pi*N*T/60
22 disp("Rpm and Torque T in Nm/s are :")
23 N = 60*U2/(%pi * D2)
24 T= P*1000*60/(2*%pi*N)
```

Scilab code Exa 2.10 Centrifugal Pump Running

```
1  // Display mode
2  mode (0) ;
3  // Display warning for floating point exception
4  ieee (1) ;
5  clear ;
6  clc ;
7  disp (" Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan , Chapter 2 , Example 10")
8  disp (" Given Data N in rpm , H in m, Q - discharge in
        litres /s :")
9  N1 = 590
10 Q1 = 1.83
11 H1 = 16
12 N2 = 390
13 //As H^1/2 / N = constant
14 H2 = N2^2* H1/( N1^2)
15 disp (" Head developed by the pump at 390 rpm = 6.98 m
        . In order to find discharge through the pump at
        390 rpm , We use Ns = N* Q^(1/2) /(H^3/4) .
        Therefore Discharge through pump in litres /s Q2
        is :")
16 x = N1*Q1^(1/2) /H1^(3/4) ;
17 Q2 = (x*H2^(3/4)/N2)^2
```

Scilab code Exa 2.11 Ideal Height Hydraulic Efficiency

```
1  // Display mode
2  mode (0) ;
3  // Display warning for floating point exception
4  ieee (1) ;
5  clear ;
6  clc ;
7  disp (" Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan , Chapter 2 , Example 11")
8  D2= 0.37; //in meters
```

```
9  N= 800;//in rpm
10 Q= 0.03;
11 Hgiven = 14;
12 disp("Impeller tip Speed U2 in m/s is :")
13 U2 = %pi *D2*N/60
14 disp("Radial velocity at the impeller exit Cr2 = 2.5
      m/s ")
15 Cr2 = 2.5;
16 disp("Therefore")
17 Cw2 = U2 - Cr2/tan(%pi/4)
18 disp("When there is no slip, the head H developed
      will be")
19 g =9.81;
20 H = Cw2*U2/g
21 disp("If there are no hydraulic internal losses, the
       power utilized by the pump will be: P")
22 P = 0.96*8 //given efficiency = 0.96 and Power = 8
      hp
23 disp("Theoretical flow rate Qtheo in m3/s :")
24 Qtheo = Q/0.97
25 disp("Ideal Height Hi :")
26 Hi = P * 0.746 / (g*Qtheo)
27 disp("The hydraulic efficiency is etah :")
28 etah =Hgiven/Hi *100
```

Scilab code Exa 2.12 Actual Work Absolute Velocity

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
4 ieee(1);
5 clear;
6 clc;
7 disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 2, Example 12")
```

```
8  disp("Exit blade angle beta2 =20 degres")
9  beta2 = 20;
10 U2 = 56;  //U2 in m/s
11 Cr2 = 7.5;  //in m/s
12 CW2 = U2 - Cr2/tan(20*%pi/180)
13 disp("Using slip factor :")
14 sigma = 0.88
15 disp("The velocity whirl at exit is :")
16 Cw2 = sigma*CW2
17 disp("Work input per kg of water flow in KJ/kg")
18 W = Cw2*U2/1000
19 disp("Absolute velocity at impeller tip C2 in m/s is
       :")
20 C2 = (Cr2^2 + Cw2^2)^(1/2)
```

Scilab code Exa 2.13 Theoritical Head

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 13")
8  disp("Assuming the blades are of infinitesimal
       thickness, the flow area is given by A in m2 =
       impeller periphery * blade depth")
9  D2 = 0.26  //in m
10 d = 0.02 //in m
11 N = 1400 //in rpm
12 g =9.81;
13 Q= 0.03 //m3/s
14 disp("Area A in m2")
15 A = D2*%pi*d
```

```
16  disp("Flow velocity Cr2 is given by")
17  Cr2 = Q/A
18  disp("Impeller tip speed, U2 in m/s is")
19  U2 = %pi*D2*N/60
20  disp("Absolute whirl component, Cw2 in m/s is given
        by")
21  Cw2 =  U2 - Cr2/tan(30*%pi/180)
22  disp("Using Euler s equation, and assuming Cw1 = 0
          (i.e., no whirl at inlet) Head H in m")
23  H = U2*Cw2/g
24  disp("Theoretical head with slip is Htheo in m")
25  Htheo = 0.78*H
26  disp("To find numbers of impeller blades, using
        Stanitz formula sigma = 1 - 0.63 pi/n")
27  disp("Slip factor, sigma = 0.78")
28  sigma = 0.78;
29  disp("Number of blades required")
30  n = (0.63*%pi)/(1-sigma)
31  disp("Therefore n = 9")
```

Scilab code Exa 2.14 Vanes 30 Degrees

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 2, Example 14")
8  disp("Given data D1 and D2 in meters, N in rpm, Cr2
        in m/s and beta2 in degrees")
9  D1 = 0.2
10  D2 = 0.4
11  N = 1500
```

```
12  Cr2 = 2.8
13  beta2 = 30
14  disp("Impeller tip speed, U2 in m/s, is")
15  U2 = %pi*D2*N/60
16  disp("Whirl component of absolute velocity Cw2 at
        impeller exit is")
17  Cw2 = U2 - Cr2/tan(30*%pi/180)
18  //As tan(alpha2)=2.8/26.58 = 0.1053
19  alpha2 = atan(0.1053) * 180 /%pi
20  disp("Impeller speed at inlet U1 in m/s is ")
21  U1 = %pi * D1*N/60
22  //tan(beta1) = 2.8/15.7 = 0.178
23  beta1 = atan(0.178)*180/%pi
24  disp("Work done per kg of water W in Nm :")
25  W = Cw2*U2
```

Scilab code Exa 2.15 Power Hub dia Angles

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 2, Example 15")
8  rho = 1000;//density in kg/m3
9  g = 9.81;//force of gravity in m/s2
10 H = 10;//head in m
11 Q = 1.3;//Discharge in m3/s
12 eta = 0.83;//efficiency
13 U2 = 22;//blade velocity
14 Ca = 4.5;//Flow velocity
15 N = 550;//rpm
16 disp("Power delivered to the water P in kW :")
```

```
17  P = rho*g*H*Q/1000
18  disp("Power input to the pump Pin in kW :")
19  Pin = P/eta
20  disp("Rotor tip diameter is given by D2 in m")
21  D2 = 60*U2/(%pi*N)
22  disp("Rotor Hub dia D1 in m :")
23  D1 = (D2^2 -Q/(%pi*Ca/4))^(1/2)
24  disp("Rotor velocity at hub is given by U1 in m/s :"
       )
25  U1 = D1*U2/D2
26  disp("Since, the axial velocity is constant, we have
        : rotor inlet angl at tip alpha1t in degrees")
27  alpha1t = atan(Ca/U1)*180/%pi
28  disp("Rotor outlet angle alpha2t in degrees :")
29  alpha2t = atan(Ca/U2)*180/%pi
```

Scilab code Exa 2.16 Mechanical Efficiency

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 16")
8  disp("Given Data:")
9  Qdel = 72//Discharge in l/s
10 rho = 1000
11 Di = 0.09//Inner Dia in m
12 Do = 0.28//Outer Dia in m
13 N = 1650//Revolution in min
14 H = 25//Head
15 bi = 0.02//Width at inlet in m
16 bo = 0.018//Width at outlet in m
```

```
17  Qleak = 2//in l/s
18  etap = 0.56//Efficiency of the pump
19  cf = 0.85//Contraction factor
20  g = 9.81//gravity in m/s2
21  Ploss = 1.41
22  disp("Total quantity of the water to be handled by
        the pump Qt in l/s")
23  Qt = Qdel + Qleak
24  disp("Total quantity of water per side Qw")
25  Qw = Qt/2
26  disp("Impeller speed at inlet U1 in m/s")
27  U1 = %pi*Di*N/60
28  disp("Flow area at inlet Af")
29  Af = %pi*Di*bi*cf
30  disp("Therefore, the velocity of flow at inlet Crl
        in m/s")
31  Crl = Qw/(Af*1000)
32  disp("From inlet velocity triangle beta1")
33  beta1 = atan(Crl/U1)*180/%pi//Crl/U1 = 7.708/7.78
34  disp("Area of flow at outlet Ao")
35  bo1 = bo / 2
36  Ao = %pi * Do * bo1* cf
37  disp("Therefore, the velocity of flow at outlet Cr2"
        )
38  Cr2 = Qw/(Ao*1000)
39  disp("The impeller speed at outlet U2")
40  U2 = %pi*Do*N/60
41  disp("Now using velocity triangle at outlet Cw2 in m
        /s")
42  Cw2 = U2 - Cr2/tan(35*%pi/180)
43  alpha2 = atan(Cr2/Cw2)*180/%pi
44  disp("The absolute velocity of water leaving the
        impeller C2 in m/s")
45  C2 = Cw2/cos(alpha2*%pi/180)
46  disp("The manometric efficiency etaman")
47  etaman =  g*H/(U2*Cw2)
48  disp("The volumetric efficiency etav")
49  etav = Qdel/Qt
```

```
50  disp("Water power Pw in kW")
51  Pw = rho*g*Qdel*H/1000000
52  disp("Shaft power Ps in kW")
53  Ps = Pw/etap
54  disp("Mechanical efficiency is etam")
55  etam = (Ps - Ploss)/Ps
```

Scilab code Exa 2.17 Single Stage Pump

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 17")
8  disp("Head generated by the pump H")
9  //H is directly proportionl to D^2
10 D = 0.32;
11 H = 21.5;
12 Hred = 20;
13 disp("Diameter to be reduced is Dred in cm")
14 Dred = D*(Hred/H)^(1/2) * 100
```

Scilab code Exa 2.18 Diameter of Impeller

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
```

```
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 2, Example 18")
8  disp("Specific speed N in rpm")
9  Ns = 38;
10 He = 70;
11 H = He/2;
12 Q = 55/1000;//in m3/s
13 rho = 1000;
14 g = 9.81;
15 N = Ns * (H)^(3/4)  /  Q^(1/2)
16 disp("Power Required P in kW")
17 P = rho*g*Q*He/(0.76*1000)
18 Hmano = 0.65*H;
19 beta2 = 28;
20 //Cr2 = 0.14*U2
21 disp("From velocity triangle at outlet")
22 disp("tan(beta2) = Cr2/(U2 - Cw2) or tan(28) = 0.14
       U2/ (U2 - Cw2)")
23 disp("U2/(U2 - Cw2) = 0.5317/0.14 = 3.798------(A)")
24 disp("As the flow at entrance is radial and alpha1 =
         90, the fundamental equation of pump would be")
25 disp("Hmano/etamano = U2*Cw2/g")
26 disp("Where etamano manometric efficiency of pump
       which is 65%.")
27 disp("Therefore, 35/0.65 = U2*Cw2/g")
28 disp("U2*Cw2 = 35 * 9.81/ 0.65")
29 disp("Cw2 = 528.23/U2------(B)")
30 disp("Substituting for Cw2 in Eq. (A) and solving U2
       ")
31 U2 = 26.78
32 D2 = U2 * 60 /(%pi *N)
33 disp("Where D2 is in meters")
```

Scilab code Exa 2.19 Two Multistage Pumps

```scilab
1  // Display mode
2  mode (0);
3  // Display warning for floating point exception
4  ieee (1);
5  clear;
6  clc;
7  disp(" Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan , Chapter 2, Example 19")
8  N = 1445//rpm
9  Q = 0.0352//m3/s
10 Ns = 14//rpm
11 g=9.81;
12 disp(" Head developed in each stage is H in m: ")
13 H = (N * (Q^(1/2))/Ns)^(4/3)
14 disp(" Total head required = 845m")
15 disp(" Number of stages needed = 845/52 = 16")
16 disp(" Number of stages in each pump = 8")
17 disp(" Impeller speed at tip is U2 in m/s")
18 U2 = 0.96*(2*g*H)^0.5
19 disp(" Impeller Diameter at tip D2")
20 //D2 = %pi*60*30.6*1445
21 disp(" But U2 = pi*D2*N/60 Therefore D2 real in m")
22 D2real = U2 *60/(%pi *1445)
```

Scilab code Exa 2.20 Pumps to be Connected

```scilab
1  // Display mode
2  mode (0);
3  // Display warning for floating point exception
4  ieee (1);
5  clear;
6  clc;
7  disp(" Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan , Chapter 2, Example 20")
8  disp(" Specific speed for a single impeller is given
```

```
        by")
 9  disp("Ns = N*Q^0.5/H^0.75")
10  Ns = 700
11  H = 105
12  N = 900
13  Q = 5500/60//l/s
14  H = (N*Q^0.5/Ns)^(4/3)
15  disp("Hence total number of stages :")
16  Ht = 105;
17  Stages = Ht/H
18  disp("Stages in series are 4")
```

Scilab code Exa 2.21 Specific speed 1150

```
 1  // Display mode
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 2, Example 21")
 8  disp("Given data")
 9  D2 = 0.9//m
10  D1 = 0.45//m
11  Ns = 1150//rpm
12  Cr = 2.5 //m/s
13  H = 5.5//m
14  disp("H,D2 and D1 are in meters, Ns in rpm, Cr in m/
        s")
15  Q = (%pi*(D2^2-D1^2)/4 )*Cr*1000
16  disp("Q in l/s")
17  N = Ns*H^0.75/Q^0.5
18  disp("Therefore N = 120")
19  disp("In order to find vane angle at entry, using
```

36

```
        velocity triangle at inlet ,U1 in m/s is:")
20  U1 = %pi*D1*N/60
21  alpha = atan(Cr/U1)*180/%pi
```

Chapter 3

Hydraulic Turbines

Scilab code Exa 3.1 Generator Pelton Wheel

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 1")
8  disp("Given data : Discharge rate Q = 145 l/s, Head
       H = 220m, U1 = U2 = 14m/s, beta2 = 180-160 =20
       degrees")
9  Q = 145;
10 H = 220;
11 U2 = 14;
12 U1 = U2;
13 beta2 = 20;
14 g = 9.81;
15 disp("Refering figure")
16 disp("Using Using Euler s equation, work done per
```

```
     weight  mass  of  water  per  sec.=  (Cw1U1 − Cw2U2).
         But  for  Pelton  wheel  Cw2  is  negative")
17  disp (" Therefore  Work  done  /  s  =  (Cw1U1 + Cw2U2) Nm /
         s .  From  inlet  velocity  triangle  Cw1 = C1  and  C1
         ^2/2g = H")
18  C1 = (2*g*H)^0.5
19  disp (" Relative  velocity  at  inlet  V1")
20  V1 = C1 -U1
21  disp (" From  outlet  velocity  triangle ")
22  V2 = V1
23  Cw2 = cos (20*%pi /180) *V2  -14
24  disp (" Hence ,  work  done  per  unit  mass  of  water  per
         sec .")
25  W = C1*U1+Cw2*U2
26  disp (" Power  in  kw")
27  P = W*Q /1000
```

Scilab code Exa 3.2 Pelton Wheel 725

```
 1  // Display  mode
 2  mode (0) ;
 3  // Display  warning  for  floating  point  exception
 4  ieee (1) ;
 5  clear ;
 6  clc ;
 7  disp (" Turbomachinery  Design  and  Theory ,Rama S.  R.
         Gorla  and  Aijaz  A.  Khan ,  Chapter  3,  Example  2")
 8  disp (" Overall  efficiency  etao = Power  developed/
         Power  available ")
 9  rho = 1000;
10  g = 9.81;
11  Q = 0.035;
12  H = 92;
13  etao = 0.82;
14  Cv = 0.95;
```

```
15  N = 725;
16  disp("Power in kw")
17  P = rho*g*Q*H*etao/1000
18  disp("Velocity coefficient Cv = C1/(2gH)^0.5")
19  C1 = Cv * (2*g*H)^0.5
20  disp("Speed of the wheel is given by U")
21  U = 0.45*C1
22  disp("If D is the wheel diameter, then")
23  D = 2*U*60/(N*2*%pi)
24  disp("Jet area A")
25  A = Q/C1
26  disp("Jet diameter, d, is given by")
27  d = (4*A/%pi)^0.5
28  disp("Diameter ratio D/d =")
29  R = D/d
30  disp("Dimensionless specific speed is given by Nsp =
        NP^0.5/rho^0.5*(gH)^1.25    in radians")
31  Nsp = (N/60)*(((P/rho)*1000)^0.5) * ((1/(g*H))^1.25)
        *2*%pi
```

Scilab code Exa 3.3 Pelton Speed 14

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 3")
8  disp("Refering Figure")
9  disp("Given Data")
10 U2= 14//m/s
```

```
11  U1=U2
12  Q = 0.82//m3/s
13  H =45//m
14  beta2 = 180-160
15  Cv = 0.98
16  g = 9.81
17  disp("Velocity of jet C1")
18  C1 = Cv*(2*g*H)^0.5
19  disp("Assuming beta1 = 180")
20  beta1 = 180;
21  Cw1 = C1
22  V1 = C1-U1
23  disp("From outlet velocity triangle ,U1 = U2(
        neglecting losses on buckets)")
24  V2 = V1
25  Cw2 = V2*cos(beta2*%pi/180) -U2
26  disp("Work done per weight mass of water per sec")
27  W = (Cw1+Cw2)*U1
28  disp("Power developed P in kw and horse power are
        Pkw,Php")
29  Pkw = W*Q
30  Php = Pkw*1000/746//in horse power
31  disp("Efficiency eta1")
32  eta1 = 1000*Pkw/(1000*g*Q*H)
```

Scilab code Exa 3.4 Pelton Wheel 12900kW

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 4")
```

```
8  disp("Given Data")
9  H = 505//Head in m
10 P = 12900//Power in kW
11 N = 425//Speed in rpm
12 etao = 0.84//Efficiency
13 g = 9.81//m/s2
14 disp("Let Q be the discharge of the turbine")
15 Q = P/(etao*g*H)
16 disp("Velocity of jet C")
17 Cv = 0.98;
18 C = Cv * (2*g*H)^0.5
19 disp("Tangential velocity of the wheel is given by "
       )
20 U = 0.46*C
21 disp("Diameter D")
22 D = 60*U/(%pi*N)
23 disp("Let d be the diameter of the nozzle. The
        discharge through the nozzle must be equal to the
         discharge of the turbine. Therefore")
24 d = (Q*4/(%pi*C))^0.5
```

Scilab code Exa 3.5 Double Overhung Pelton

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 5")
8  disp("Output Power")
9  Po = 12000
10 eta = 0.95
11 disp("Power generated Pin")
```

```
12  Pin = Po/eta
13  disp("Since there are two runners, power developed
        by each runner")
14  P = Pin/2
```

Scilab code Exa 3.6 Power Station

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory, Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 6")
8  disp("Refering Figure")
9  disp("Hydraulic Efficiency etah = Power output/
        Energy available in the jet = P/(0.5mC1^2)")
10 disp("At entry to nozzle")
11 H = 610-46//in m
12 Cv = 0.98;
13 g = 9.81;
14 disp("Using nozzle velocity coefficient C1")
15 C1 = Cv * (2*g*H)^0.5
16 disp("Now W/m = U1Cw1 - U2Cw2 =U {(U + V1)-[U-V2cos
        (180 -alpha)]}= U[(C1 - U)(1 - k cos (alpha))]
        where V2 = kV1")
17 disp("Therefore W/m")
18 Wm = 0.46*C1*(C1-0.46*C1)*(1-0.99*cos(165*%pi/180))
19 etah = Wm/(0.5*103*103)
20 disp("Actual hydraulic efficiency")
21 etaha = 0.91*etah
22 disp("Wheel bucket speed")
```

```
23  s = 0.46*C1
24  disp("Wheel rotational speed N")
25  N = s*60/(0.445*2*%pi)
26  disp("Actual hydraulic efficiency")
27  disp("    Actual power/energy in the jet = (1260 *
       10^3)/(0.5mC1^2)")
28  disp("Therefore")
29  m = 1260*1000/(0.882*0.5*103*103)
30  disp("For one nozzle ,m")
31  mone = m/2
32  disp("For nozzle diameter, using continuity equation
       , m")
33  disp("m = rho*C1*A = rho*C1*pi*d^2/4")
34  disp("Hence, d in mm")
35  d = (mone*4/(%pi*103*1000))^0.5 *1000
```

Scilab code Exa 3.7 Pelton Head 90

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 7")
8  disp("Refering Figure")
9  disp("Head = 90m")
10 disp("Head lost due to friction = 30m")
11 disp("Head available at the nozzle = 90 - 30 = 60m")
12 Q = 1//m3/s
13 disp("From inlet diagram")
14 Cv = 0.98;
```

```
15 g = 9.81;
16 H = 60;
17 C1 = Cv *(2*g*H)^0.5
18 U1 =12;
19 disp("Therefore")
20 V1 = C1-U1
21 disp("From outlet velocity triangle")
22 V2 = V1
23 alpha = 15;
24 disp("neglecting losses in m/s")
25 U2 = U1;
26 Cw2 = V2*cos(alpha*%pi/180)-U2
27 Cr2 = V2*sin(alpha*%pi/180)
28 C2 = (Cw2^2+Cr2^2)^0.5
29 disp("Work done in kJ/kg")
30 W = (C1^2-C2^2)/2
31 disp("Note Work done can also be found by using
      Euler s equation (Cw1U1 + Cw2U2)")
32 Power = W //kW
33 disp("Hydraulic Efficiency")
34 Efficiency = W*2/C1^2
```

Scilab code Exa 3.8 Single Jet Pelton Wheel

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
4 ieee(1);
5 clear;
6 clc;
7 disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 3, Example 8")
8 //Answers here are given by direct calculations and
```

```
        none  of  them  are  rounded ,  the  answers  are
        dependent  on  each  other .
 9  disp (" Refering  Figure  and  the  scientific
        calculations ")
10  disp (" Velocity  of  jet ,  C1")
11  Cv  =  0.98;
12  g=9.81;
13  H  =  515;
14  C1  =  Cv*(2*g*H)^0.5
15  disp (" Discharge ,  Q  is  given  by")
16  d=0.2;
17  Q  =  %pi*C1*d^2  /4
18  disp (" Water  power  is  given  by  in  kW")
19  rho  =  1000;
20  P  =  rho*g*Q*H/1000
21  disp (" Bucket  velocity ,  U1 ,  is  given  by")
22  Cv1  =  0.46;
23  U1  =  Cv1*(2*g*H)^0.5
24  disp (" Relative  velocity ,  V1 ,  at  inlet  is  given  by")
25  V1  =  C1-U1
26  V2  =  0.88*V1
27  disp (" From  the  velocity  diagram ")
28  U2  =  U1
29  Cw2  =  U2  -V2*cos (%pi *15/180)
30  disp (" Therefore  force  on  the  bucket  F  in  N")
31  Cw1  =  C1
32  F  =  rho*Q*(Cw1-Cw2)
33  disp (" Power  produced  by  the  Pelton  wheel  Pp  in  kW")
34  Pp  =  F*U2/1000
35  disp (" Taking  mechanical  loss ")
36  loss  =  0.04
37  disp (" Therefore ,  shaft  power  produced ")
38  Pshaft  =  Pp*(1-loss)
39  disp (" Overall  efficiency  etao ")
40  etao  =  Pshaft/P  *100
```
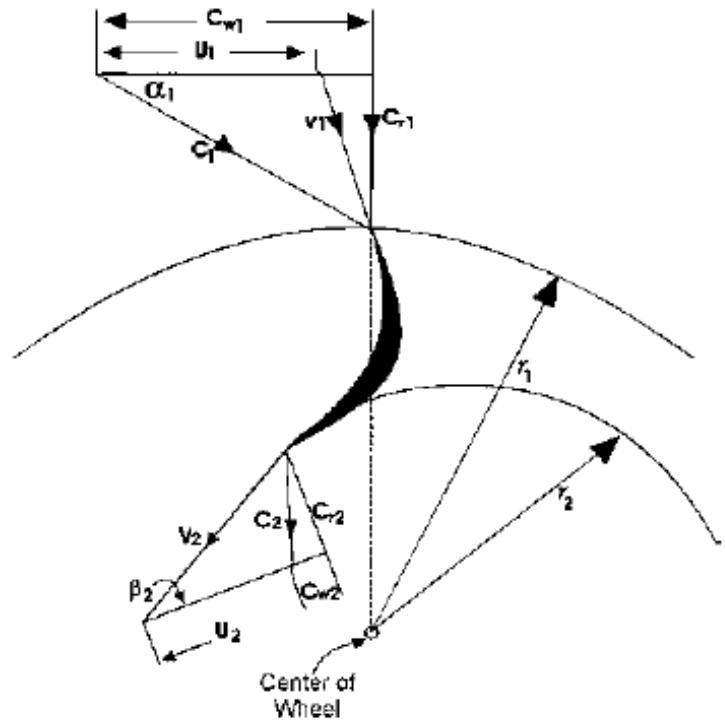
Figure 3.13 velocity triangles for inward flow reaction turbine.

Figure 3.1: Inward Flow Reaction Turbine

Scilab code Exa 3.9 Inward Flow Reaction Turbine

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
```

```scilab
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 9")
 8  disp("Refering Figure")
 9  disp("From inlet velocity triangle")
10  Cr1 = 3.8;//m/s
11  alpha1 = 16;//degree
12  Cw1 = Cr1/tan(alpha1*%pi/180)
13  disp("Absolute velocity of water at inlet, C1, is")
14  C1 = Cr1/sin(alpha1*%pi/180)
15  D1 = 1;//m
16  N = 240;//rpm
17  U1 = %pi*D1*N/60
18  x = Cr1/(Cw1-U1)
19  beta1 = atan(x) * 180/%pi
20  disp("Relative velocity of water at entrance")
21  V1 = Cr1/sin(beta1*%pi/180)
```

Scilab code Exa 3.10 Runner Axial Flow

```scilab
 1  // Display mode
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 10")
 8  disp("Refering Figures")
 9  disp("Since this is an impulse turbine, assume
        coefficient of velocity = 0.98")
10  disp("Therefore the absolute velocity at inlet is")
11  Cv = 0.98;
```

```
12  g = 9.81;
13  H = 35;
14  C1 = Cv*(2*g*H)^0.5
15  disp("The velocity of whirl at inlet")
16  alpha1 = 30;
17  Cw1 = C1*cos(alpha1*%pi/180)
18  disp("Since U1 = U2 = U")
19  disp("Using outlet velocity triangle")
20  disp("C2 = U2tan(beta2) = U tan(beta2) = U tan(22)")
21  disp("Hydraulic efficiency of turbine (neglecting
       losses)")
22  //etah = Cw1U1/gH = (H - C2^2/2g)/H
23  //22.24U + 0.082U^2 - 9.81H = 0
24  disp("As U is positive,")
25  U = (-22.24 + ((22.4)^2 + 4*0.082*g*H)^0.5)
       /(2*0.082) - 0.9
26  disp("Now using relation")
27  disp("U = %pi*D*N/60")
28  D = 1.5;
29  N = 60*U/(%pi*D)
30  disp("Hydraulic efficiency")
31  etah = Cw1*U/(g*H)
```

Scilab code Exa 3.11 Kaplan runner

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 11")
8  Cv = 2.08;
9  g = 9.81;
```

```
10  H = 5.5;
11  Cv1 = 0.68;
12  U1 = Cv*(2*g*H)^0.5
13  Cr1 = Cv1*(2*g*H)^0.5
14  N = 65;
15  disp("Now power is given by")
16  P = 9000;
17  eta = 0.85;
18  Q = P / (g * H * eta)
19  disp("If D is the runner diameter and, d, the hub
        diameter")
20  D = (Q*4*9/(%pi*Cr1*8))^0.5
21  disp("Solving")
22  Ns = N * P^0.5 / H^1.25
```

Scilab code Exa 3.12 Turbine 12000 HP

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 12")
8  disp("Mean diameter D")
9  D = (4+1.75)/2
10  N =145;
11  U1 = %pi*D*N/60
12  g = 9.81;
13  H = 20;
14  disp("Using hydraulic efficiency, etah")
15  etah = 0.93
16  Cw1 = etah*g*H/U1
17  Power = 12000*0.746
```

```
18  disp("Power = rho*g*Q*H*etao")
19  etao = 0.85
20  disp("Discharge, Q")
21  Q = Power/(g*H*etao)
22  Cr1 = Q*4/(%pi*(4^2-1.75^2))
23  beta1 = atan(Cr1/(U1-Cw1))*180/%pi
24  U2 =U1
25  Cr2 = Cr1
26  beta2 = atan(Cr2/U2)*180/%pi
```

Scilab code Exa 3.13 Speed angle reaction turbine

```
1  // Display mode
2  mode (0);
3  // Display warning for floating point exception
4  ieee (1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 13")
8  disp("Outer diameter, D2 = 1.4m")
9  disp("Inner diameter, D1 = 0.7m")
10 disp("Angle at which the water enters the vanes,
       alpha1 = 12 degrees")
11 disp("Velocity of flow at inlet,")
12 Cr2 = 2.8
13 Cr1 = Cr2
14 disp("As the vanes are radial at inlet and outlet
       end, the velocity of whirl at inlet and outlet
       will be zero, as shown in Fig. 3.21.")
15 disp("Tangential velocity of wheel at inlet,")
16 alpha1 = 12
17 U1 = Cr1/tan(alpha1*%pi/180)
18 D2 = 1.4
19 N = 60*U1/(%pi*D2)
```

```
20 disp ("Let beta2 is the vane angle at outlet")
21 D1 = 0.7
22 U2 = %pi*D1*N/60
23 disp ("From Outlet triangle ,")
24 beta2 = atan(Cr2/U2)*180/%pi
```

Scilab code Exa 3.14 Discharge 500

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
4 ieee(1);
5 clear;
6 clc;
7 disp ("Turbomachinery Design and Theory ,Rama S. R.
       Gorla and Aijaz A. Khan , Chapter 3, Example 14")
8 disp ("Discharge , Q")
9 Q = 0.5//m3/s
10 disp ("Velocity of flow at inlet , Cr1")
11 Cr1 = 1.5//m/s
12 disp ("Velocity of periphery at inlet , U1")
13 U1 = 20
14 disp ("Velocity of whirl at inlet , Cw1")
15 Cw1 = 15
16 disp ("As the velocity of flow is constant , Cr1 = Cr2
       ")
17 Cr2 = Cr1
18 disp ("Let beta1 = vane angle at inlet")
19 disp ("From inlet velocity triangle")
20 beta1 = 180 - atan(Cr1/(U1-Cw1)) *180/%pi
21 g = 9.81;
22 disp ("Since the discharge is radial at outlet , and
       so the velocity of whirl at outlet is zero.
       Therefore ,")
23 H = Cw1*U1/g + Cr1^2/(2*g)//m
```

Scilab code Exa 3.15 Rotation 290rpm

```scilab
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 15")
8  disp("Inner diameter of wheel,")
9  D1 = 1
10 disp("Outer diameter of wheel,")
11 D2 = 2
12 disp("Velocity of flow is constant")
13 Cr1 = 12//m/s
14 Cr2 =Cr1
15 disp("Speed of wheel,")
16 N = 290//rpm
17 disp("Vane angle at inlet = beta1")
18 disp("U1 is the velocity of periphery at inlet.")
19 U1 = %pi*D1*N/60
20 disp("From inlet triangle, velocity of whirl is
       given by")
21 Cw1 = Cr1/tan(20*%pi/180)
22 beta1 = atan(Cr1/(Cw1-U1))*180/%pi
23 disp("Let beta2 = vane angle at outlet")
24 disp("U2 = velocity of periphery at outlet")
25 U2 = %pi*D2*N/60
26 disp("From the outlet triangle")
27 beta2 = atan(Cr2/U2)*180/%pi
```

Scilab code Exa 3.16 Head 30

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 16")
8  disp("If D1 is the diameter of pipe, then discharge
        is Q = pi*D1^2*C2/4")
9  Q = 0.245
10 D1 = 0.28
11 C2 = 4*0.245/(%pi*0.28^2)
12 disp("But C2 = Cr1 = Cr2")
13 g =9.81;
14 H = 30;
15 disp("Neglecting losses , we have")
16 //x = Cw1*U1
17 x = g*H - C2^2 /2;
18 disp("Power developed")
19 Power = x*Q//kW
20 U1 = 16
21 Cw1 = x/U1
22 Cr1 = C2
23 alpha1 = atan(C2/Cw1)*180/%pi
24 beta1 = atan(Cr1/(Cw1-U1)) *180/%pi
```

Scilab code Exa 3.17 Power 12400

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
```

```
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 17")
8  disp("Velocity in casing at inlet to turbine")
9  Q = 7.8;
10 disp("Cc = Discharge/(Cross − sectional area of
       casing)")
11 Cc = Q/(%pi*1^2 /4)
12 disp("The net head on turbine")
13 disp(" = Pressure head + Head due to turbine
       position + (Cc^2 − C1^2)/2g")
14 PrHead = 164
15 TurbHead = 5.4
16 C1 = 1.6
17 g = 9.81;
18 Hnet = PrHead + TurbHead + (Cc^2-C1^2)/(2*g)
19 disp("Waterpower supplied to turbine = QgH kW")
20 P = Q * g * Hnet
21 disp("Hence overall efficiency,etao = Shaft Power/
       Water Power")
22 etao = 12400/P  * 100
```

Scilab code Exa 3.18 Francis Turbine 1250rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 18")
8  disp("For torque, using angular momentum equation")
9  disp("T = m(Cw2r2 − Cw1r1)")
```

```
10  disp("As the flow is radial at outlet, Cw2 = 0 and
        therefore")
11  Cw2 = 0;
12  disp("T = -mCw1r1")
13  disp(" - rQCw1r1")
14  disp("T = -225Cw1 Nm")
15  disp("If h1 is the inlet runner height, then inlet
        area, A, is")
16  h1 = 0.035;
17  r1 = 0.5;
18  A = 2*%pi*r1*h1
19  Q = 0.45;
20  Cr1 = Q/A
21  g = 9.81;
22  H = 125;
23  rho = 1000;
24  disp("From velocity triangle, velocity of whirl")
25  alpha = 70;
26  disp("Substituting Cw1, torque is given by")
27  Cw1 = Cr1 * tan(alpha *%pi/180)
28  T = -1 * 225* Cw1
29  disp("Negative sign indicates that torque is exerted
        on the fluid. The torque exerted by the fluid is
        +2534Nm")
30  Ta = -1*T;
31  disp("Power exerted")
32  N = 1250;
33  omega = 2*%pi*N/(60*1000)
34  P = Ta * omega
35  disp("Hydraulic efficiency is given by")
36  disp("etah = Power exerted/Power available")
37  etah = P * 1000/ (rho * g * H * Q ) * 100
```

Scilab code Exa 3.19 Turbine 130kW

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 3, Example 19")
8  disp("Hydraulic efficiency is")
9  disp("etah = Power deleloped/Power available")
10 disp(" =m(Cw1U1 - Cw2U)/rhogQH")
11 disp("Since flow is radial at outlet, then Cw2 = 0
      and m = rhoQ, therefore")
12 disp("etah = Cw1U1/gH")
13 g = 9.81;
14 H= 5;
15 U1 = 9.6;
16 etah = 80;//%
17 Cw1 = etah *g*H/(9.6*100)
18 disp("Radial velocity Cr1 = 4m/s")
19 Cr1 = 4;
20 disp("tan(alpha1) = Cr1/Cw1 (from velocity triangle)
      ")
21 alpha1 = atan(Cr1/Cw1)*180/%pi
22 disp("i.e., inlet guide vane angle alpha1 = 44.38")
23 disp("tan(beta1) = Cr1/(Cw1 - U1 )")
24 beta1 = 180+atan(Cr1/(Cw1-U1))*180/%pi
25 disp("Runner speed is")
26 N = 230;
27 D1 = 60*U1/(%pi*N)
28 disp("Overall efficiency")
29 disp("etao = Power output/Power available")
30 rho = 1000;
31 Q = 130*1000/(0.72*rho*g*H)
32 disp("But Q = pi*D1h1Cr1 (where h1 is the height of
      runner)")
33 h1 = Q/(%pi*D1*Cr1)
```

Scilab code Exa 3.20 Blade tip hub dia

```scilab
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 20")
8  disp("Mean diameter, Dm, is given by")
9  disp("Dm = (Dh + Dt)/2")
10 Dh = 2;
11 Dt = 4.5;
12 Dm = (Dh + Dt)/2
13 disp("Overall efficiency, etao, is given by")
14 disp("etao = Power develpoed/Power available")
15 disp("Power available = 22/0.84 = 26.2 MW")
16 P = 26.2*10^6;
17 disp("Also, available power = rho *gHQ")
18 disp("Hence flow rate, Q, is given by")
19 rho = 1000;
20 g = 9.81;
21 H = 22;
22 Q = P / (rho * g * H)
23 disp("Now rotor speed at mean diameter")
24 N = 150;
25 Um = %pi*Dm*N/60
26 disp("Power given to runner = Power available * etah
       in MW")
27 etah = 0.92;
28 Prun = P *etah / (10^6) // in MW
29 disp("Theoretical power given to runner can be found
       by using")
```

```
30 disp("P = rho*QUmCw1 (Cw2 = 0)")
31 Cw1 = Prun * 10^6  / (rho * Q * Um)
32 disp("Axial velocity is given by")
33 disp("Cr = Q * 4/(%pi *(Dt^2 - Dh^2)")
34 Cr = Q*4/(%pi*(Dt^2 - Dh^2))
35 disp("Using velocity triangle")
36 disp("tan (180 -beta1) = C/(Um - Cw1)")
37 disp("Inlet angle,")
38 beta1 = 180 - atan(Cr/(Um-Cw1))*180/%pi
39 disp("At outlet")
40 disp("But Vcw2 equals to Um since Cw2 is zero. Hence
     ")
41 Vcw2 = Um
42 beta2 = atan(Cr/Vcw2) * 180/%pi
```

Scilab code Exa 3.21 Overall Efficiency 75

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
4 ieee(1);
5 clear;
6 clc;
7 disp("Turbomachinery Design and Theory,Rama S. R.
     Gorla and Aijaz A. Khan, Chapter 3, Example 21")
8 disp("Hydraulic efficiency, etah, is given by")
9 disp("etah = Power given to runner/Water Power
     available")
10 disp(" = m (U1Cw1 - U2Cw2)/rho*gQH")
11 disp("Since flow is radial at exit, Cw2 = 0 and m =
     rho*Q. Therefore")
```

```
12  Cw2 = 0;
13  etah = 0.82;
14  U1 = 10.6;
15  g = 9.81;
16  H = 6;
17  Cw1 = etah*g*H/U1
18  Cr1 = 4;
19  alpha1 = atan(Cr1/Cw1)*180/%pi
20  disp("From Figures")
21  disp("Blade angle, beta1, is given by")
22  beta1 = 180 - atan(Cr1/(U1-Cw1)) * 180/%pi
23  disp("Runner speed at inlet")
24  N = 235;
25  D1 = U1*60/(%pi*N)
26  disp("Overall efficiency")
27  disp("etao = Power output/Power available")
28  etao = 0.75
29  rho = 1000;
30  P = 128000
31  disp("From which flow rate")
32  Q = P/(0.75*rho*g*H)
33  disp("Also, Q = rho*D1hCr1")
34  disp("where h1 is the height of runner. Therefore,")
35  h1 = Q/(%pi*D1*Cr1)
```

Scilab code Exa 3.22 Kaplan 10000kW

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 22")
```

```
8  disp("Head, H = 8 m, Power, P = 10,000kW")
9  disp("Overall efficiency, etao = 0.86")
10 P = 10000;
11 g = 9.81;
12 H = 8;
13 rho = 1000;
14 U1 = 2*(2*g*H)^0.5
15 disp("Flow ratio Cr1/(2gH)^0.5")
16 Cr1 = 0.6*(2*g*H)^0.5
17 disp("Hub diameter, D1 = 0.35 D2")
18 disp("Overall efficiency,etao = P/rho*gQH")
19 etao = 0.86;
20 Q = P/(rho*g*H*etao) * 1000
21 disp("Now using the relation")
22 disp("Q = Cr1 * pi*(D1^2- D2^2)/4")
23 D1 = (Q*4/(Cr1*%pi*(1-0.35^2)))^0.5
24 disp("The peripheral velocity of the turbine at
       inlet")
25 N = U1*60/(%pi*D1)
```

Scilab code Exa 3.23 Vanes 12 degrees

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 23")
8  disp("Inner Diameter,")
9  D2 = 0.45
10 disp("Outer Diameter,")
```

```
11  D1 = 0.9
12  disp("Radial Discharge")
13  alpha2 = 90
14  Cr2 = 2.8
15  Cr1 = Cr2
16  disp("From velocity triangle at inlet, The
        peripheral velocity of the wheel at inlet")
17  alpha1 = 12
18  U1 = Cr1/tan(alpha1*%pi/180)
19  N = 60*U1/(%pi*D1)
20  disp("Considering velocity triangle at outlet
        peripheral velocity at outlet")
21  U2 = %pi*D2*N/60
22  beta2 = atan(Cr2/U2)*180/%pi
```

Scilab code Exa 3.24 Inward Flow 70kW

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 3, Example 24")
8  Q = 0.545//m3/s
9  D1 = 0.8//m
10 D2 = 0.4//m
11 H =14//m
12 alpha2 = 90//degrees
13 N = 370
14 //beta1 = beta2
15 disp("Peripheral velocity of the wheel at inlet")
16 U1 = %pi*D1*N/60
17 disp("Velocity of flow at the exit,")
```

```
18  Cr2 = 2.8 //m/s
19  alpha2 = 90
20  C2 = Cr2
21  g = 9.81;
22  disp("Work done/s by the turbine per kg of water =
        Cw*U1/g")
23  disp("But this is equal to the head utilized by the
        turbine, i.e.")
24  disp("Cw1U1/g = H - C2/2g")
25  disp("(Assuming there is no loss of pressure at
        outlet)")
26  Cw1 = (H - C2/(2*g) )*g/U1
27  disp("Work done per second by turbine")
28  rho = 1000;
29  W = rho*Q*Cw1*U1/(1000) //kW
30  disp("Available power or water power")
31  Pav = rho*g*Q*H /1000 //kW
32  disp("Actual available power")
33  Pac = 70 //kW
34  disp("Overall turbine efficiency is")
35  etat = Pac/Pav  * 100
36  disp("This is the actual hydraulic efficiency as
        required in the problem. Hydraulic Efficiency is"
        )
37  etah = W/Pav  * 100
38  disp("This is the theoretical efficiency")
39  disp("Q = pi*D1b1Cr1 = pi*D2b2Cr2")
40  disp("(Neglecting blade thickness)")
41  Cr1 = Cr2 * D2/D1
42  disp("Drawing inlet velocity triangle")
43  //Cr1/(U1-Cw1) = 0.203
44  beta1 = atan(0.203)* 180/%pi
45  C1 = (Cw1^2+Cr1^2)^0.5
46  //Cw1/C1 = 0.995
47  aplha1 = acos(0.995)*180 /%pi
```

Scilab code Exa 3.25 Francis Turbine 500kW

```scilab
1  // Display mode
2  mode (0);
3  // Display warning for floating point exception
4  ieee (1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 3, Example 25")
8  P = 5000//kW
9  alpha1 = 30//degrees
10 H= 30//m
11 g = 9.81;
12 Ns = 270
13 etah = 0.9
14 etao = 0.86
15 disp("Specific speed of the turbine is")
16 N = Ns* H^1.25 / (P^0.5)
17 disp("Velocity of Flow:")
18 Cr1 = 0.28* (2*g*H)^0.5
19 disp("From inlet velocity triangle Cr1 = C1sin(
       alpha1)")
20 C1 = Cr1 / sin(alpha1*%pi/180)
21 Cw1 = C1 * cos(alpha1*%pi/180)
22 disp("Work done per (sec) (kg) of water")
23 //W = Cw1*U1/g
24 W = etah*H
25 disp("Peripheral Velocity,")
26 U1 = W*g/Cw1
27 disp("But U1 = pi*D1N/60")
28 D1 = 60*U1/(%pi*N)
29 disp("Power, P = rho*gQH*etao")
30 rho = 1000;
```

```
31  Q = P/(rho*g*H*etao) * 1000
32  disp("Also Q = k*pi*D1b1Cr1 (where k is the blade
         thickness coefficient and b1 is the breath of the
           wheel at inlet) or")
33  k = 0.95
34  b1 = Q/(k*%pi*D1*Cr1)
35  disp("From inlet velocity triangle")
36  beta1 = atan(Cr1/(U1-Cw1)) * 180/%pi
```

Scilab code Exa 3.26 35MW Generator

```
1   // Display mode
2   mode(0);
3   // Display warning for floating point exception
4   ieee(1);
5   clear;
6   clc;
7   disp("Turbomachinery Design and Theory,Rama S. R.
         Gorla and Aijaz A. Khan, Chapter 3, Example 26")
8   disp("In this case, the generator is fed by two
         Pelton turbines.")
9   disp("Power developed by each turbine,")
10  PT = 35000/2
11  disp("Using Pelton wheel efficiency in order to find
           available power of each turbine")
12  P = PT / 0.84
13  disp("But, P = rho*gQH")
14  rho = 1000;
15  g = 9.81;
16  H = 350
17  Q = P/(rho*g*H) * 1000
18  disp("Velocity of jet,Cj")
19  Cv = 0.96;
20  Cj = Cv*(2*g*H)^0.5
21  disp("Area of jet, A")
```

```
22  A = Q/Cj
23  disp("Diameter of jet , d")
24  d = (4*A/%pi)^0.5
25  disp("Diameter of wheel D = d * jet ratio")
26  r = 12;
27  D= d*12
28  disp("Peripheral velocity of the wheel")
29  U = 0.45*(2*g*H)^0.5
30  disp("But U = pi*DN/60 or")
31  N = 60*U/(%pi*D)
32  disp("Specific speed ,")
33  Ns = N*PT^0.5 / H^1.25
```

Chapter 4

Centrifugal Compressors and Fans

Scilab code Exa 4.1 Air leaving impeller

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 4, Example 1")
8  disp("From the velocity triangle")
9  disp("Refering Figure")
10 beta2 = 25.5//degrees
11 Cr2 = 110//m/s
12 U2 = 475//m/s
13 Cw2 = U2 - tan(25.5*%pi/180)  * Cr2  //m/s
14 sigma = Cw2/U2
15 disp("The overall pressure ratio of the compressor:"
       )
```

```
16  //r = P03/P04
17  etac = 0.8
18  psi = 1
19  Cp = 1005
20  T01 = 298
21  gamma = 1.4
22  r = (1 + etac * sigma * psi * U2^2 /(Cp*T01))^(gamma
        /(gamma-1))
23  disp("The theoretical power required to drive the
        compressor:")
24  m = 3
25  P = (m*sigma*psi*U2^2  /1000)
26  disp("Using mechanical efficiency, the actual power
        required to drive thecompressor is:")
27  Power = P / 0.96
```

Scilab code Exa 4.2 Speed Centrifugal Compressor270

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 2")
8  disp("Slip factor: sigma = Cw2/U2")
9  U2 = 370;
10 sigma = 0.9;
11 Cw2 = sigma * U2
12 disp("The absolute velocity at the impeller exit:")
13 Cr2 = 35; //m/s
14 C2 = (Cr2^2+Cw2^2)^0.5
15 disp("The mass flow rate of air: m = rho2 *A2*Cr2")
16 rho2 = 1.57;//kg/m3
```

```
17  A2 = 0.18; //m2
18  m = rho2*A2*Cr2
19  disp("The temperature equivalent of work done (
        neglecting c):")
20  disp("Therefore, T02 − T01 =sigma*U2^2/Cp")
21  T01 = 290;
22  Cp = 1005;
23  T02 = T01 + sigma*U2^2/Cp
24  disp("The static temperature at the impeller exit, "
        )
25  T2 = T02 - C2^2/(2*Cp)
26  disp("The Mach number at the impeller tip:")
27  gamma = 1.4;
28  R = 287; //
29  M2 = C2 / (gamma *R*T2)^0.5
30  disp("The overall pressure ratio of the compressor (
        neglecting psi): P03/P01")
31  etac = 0.88; //efficiency
32  psi = 1; //neglected
33  ratio = (1+etac*sigma*psi*U2^2  /(Cp*T01))^3.5
```

Scilab code Exa 4.3 Centrifugal Compressor 16000rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 3")
8  disp("Impeller tip speed is given by: U2")
9  D = 0.58 //m
```

```
10  N = 16000//rpm
11  U2 = %pi* D* N/60
12  disp("Assuming isentropic flow between impeller
        inlet and outlet, then T02a")
13  T01 = 293;//K
14  stagratio = 4.2
15  T02a = T01*(stagratio)^0.286
16  disp("Using compressor efficiency, the actual
        temperature rise T02a-T01")
17  etac = 0.82
18  rise = (T02a-T01)/etac
19  disp("Since the flow at the inlet is axial, Cw1 = 0"
        )
20  disp("W = U2Cw2 = Cp (T02 - T01)")
21  Cp = 1005
22  W = Cp*(rise)
23  Cw2 = W/U2
24  Slip = U2-Cw2
25  disp("Slip factor:")
26  sigma = Cw2/U2
```

Scilab code Exa 4.4 Adiabatic Efficiency

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 4")
8  //Impeller tip diameter = 1m
9  //Speed = 5945 rpm
10 //Mass flow rate of air = 28 kg/s
11 //Static pressure ratio p3/p1 = 2.2
```

```
12  //Atmospheric  pressure  =  1  bar
13  //Atmospheric  temperature  =  25  degree  Celcius
14  //Slip  factor  =  0.90
15  disp("Neglect  the  power  input  factor .")
16  disp("The  impeller  tip  speed  is  given  by:")
17  D  =  1;
18  N  =  5945;
19  U2  =  %pi*D*N/60
20  disp("The  work  input:")
21  sigma  =  0.9;
22  W  =  sigma  *  U2^2  /  1000
23  disp("Using  the  isentropic  P  T  relation  and
        denoting  isentropic  temperature  by  T3a,  we  get:")
24  T1  =  298;
25  r  =  2.2;
26  T3a  =  T1  *  (r)^  0.286
27  disp("Hence  the  isentropic  temperature  rise:  T3a  -
        T1")
28  rise  =  T3a  -T1
29  disp("The  temperature  equivalent  of  work  done:  T3  -
        T1")
30  Cp  =  1.005
31  Weq  =  W/Cp
32  disp("The  compressor  adiabatic  efficiency  is  given
        by:")
33  etac  =  rise/Weq   *  100
34  disp("The  air  temperature  at  the  impeller  exit  is:")
35  T3  =  T1  +  Weq
36  disp("Power  input:")
37  m  =  28;
38  P  =  m  *  W
```

Scilab code Exa 4.5 Centrifugal Compressor 9000rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 5")
8  disp("Impeller tip speed is given by")
9  D = 0.914;
10 N = 9000;
11 U2 = %pi*D*N/60
12 disp("Since the exit is radial and no slip, Cw2 = U2
        = 431 m/s")
13 disp("From the velocity triangle,")
14 alpha2 = 20;
15 Cw2 = U2;
16 Cr2 = U2*tan(alpha2 *%pi/180)
17 disp("For radial exit, relative velocity is exactly
        perpendicular to rotational velocity U2. Thus the
         angle beta2 is 90 degrees for radial exit.")
18 disp("Using the velocity triangle")
19 C2 = (U2^2 + Cr2^2)^0.5
```

Scilab code Exa 4.6 Centrifugal Compressor No prewhirl

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 6")
8  disp("The pressure ratio is given by r = P03/P01")
```

```
 9  etac = 0.88;
10  sigma = 0.95;
11  U2 = 457;
12  Cp = 1005;
13  T01 = 288;
14  r = (1+etac*sigma*U2^2/(Cp*T01) )^3.5
15  disp("The work per kg of air")
16  Cw2 = 0.95*U2;
17  W = U2*Cw2 / 1000//kJ/kg
18  disp("The power for 29kg/s of air")
19  m = 29;
20  P = W * m   //kW
```

Scilab code Exa 4.7 Centrifugal Compressor 10000rpm

```
 1  // Display mode
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 7")
 8  disp("Temperature equivalent of work done:")
 9  disp("Weq = T02 - T01")
10  T02 = 440;//kelvin
11  T01 = 290;//kelvin
12  sigma = 0.88;
13  psi = 1.04;
14  Cp = 1005;
15  N = 10000;//rpm
16  U2 = ((T02-T01)*Cp/(sigma*psi))^0.5//m/s
17  D = 60*U2/(%pi*N)//m
18  disp("The overall pressure ratio is given by: P03/
        P01")
```

73

```
19  etac = 0.85;
20  ratio = (1+etac*sigma*psi*U2^2 /(Cp*T01))^3.5
21  disp("Power required to drive the compressor per
        unit mass flow:")
22  m = 1;
23  P = m*psi*sigma*U2^2  / 1000//kW
```

Scilab code Exa 4.8 Centrifugal Compressor 19 vanes

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 8")
8  disp("Since the vanes are radial , using the Stanitz
        formula to find the slip factor:")
9  n = 19;
10 sigma = 1-0.63*%pi/n
11 disp("The overall pressure ratio r = P03/P01")
12 etac = 0.84;
13 psi = 1.04;
14 r = 4.5;
15 Cp = 1005;
16 T01 = 293;
17 U2 = ((r^(1/3.5) - 1) *Cp*T01 /(etac*sigma*psi) )
        ^0.5
18 disp("The impeller diameter")
19 N = 17000;
20 D = 60*U2/(%pi*N)
21 disp("The work done on the air")
22 W = psi*sigma*U2^2 /1000
23 disp("Power required to drive the compressor:")
```

```
24  m = 2.5;
25  P = m*W
```

Scilab code Exa 4.9 Problem 8 repeat

```
1  // Display  mode
2  mode(0);
3  // Display  warning  for  floating  point  exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery  Design  and  Theory,Rama  S.  R.
       Gorla  and  Aijaz  A.  Khan,  Chapter  4,  Example  9")
8  sigma = 0.8958;
9  U2 = 449.9;
10 Cw2 = sigma*U2
11 disp("Using  the  continuity  equation,")
12 disp("m=rho2*A2Cr2 = rho2*2*pi*r2b2Cr2")
13 disp("where:  b2 = axial  width,r2 = radius.  Therefore
       :")
14 m = 2.5;
15 rho2 = 1.8;
16 r2 = 0.25;
17 b2 = 0.012;
18 Cr2 = m / (rho2*2*%pi*b2*r2)
19 disp("Absolute  velocity  at  the  impeller  exit")
20 C2 = (Cr2^2+Cw2^2)^0.5
21 disp("The  temperature  equivalent  of  work  done:Weq =
       T02 − T01")
22 Cp = 1.005;
23 Weq = 188.57/Cp
24 T02 = 293+Weq
25 disp("Hence  the  static  temperature  at  the  impeller
       exit  is:")
26 T2 = T02 - C2^2 / (2*Cp*1000)
```

```
27  disp("Now, the Mach number at the impeller exit is:"
        )
28  gamma = 1.4;
29  R = 287;
30  M2 = C2 / (gamma*R*T2)^0.5
```

Scilab code Exa 4.10 Compressor 15000rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 10")
8  disp("Inlet stagnation temperature:")
9  R = 287;
10  Ta = 298;
11  C1 = 145;
12  Cp = 1005;
13  T01 = Ta + C1^2 /(2*Cp)
14  disp("Using the isentropic P  T relation for the
        compression process,")
15  disp("x = P03/P01")
16  x = 4;
17  T03a = T01 * (4)^0.286
18  disp("Using the compressor efficiency,")
19  disp("T02-T01 = y")
20  T02a = T03a;
21  etac = 0.89;
22  y = (T02a-T01)/etac
23  disp("Hence, work done on the air is given by: in kJ
```

```
      /kg")
24  W = Cp * y / 1000
25  U2 = (W*1000/0.89)^0.5 //m/s
26  disp("Hence, the impeller tip diameter")
27  N = 15000; //rpm
28  D = 60*U2/(%pi*N) //m
29  disp("The air density at the impeller eye is given
        by:")
30  P1 = 1*100;
31  rho1 = P1/(R*Ta)* 1000
32  disp("Using the continuity equation in order to find
          the area at the impeller eye,")
33  m = 8; //kg/m
34  A1 = m/(rho1*C1)  //m2
35  disp("The power input is: in kW")
36  P = m*W
```

Scilab code Exa 4.11 Double sided compressor

```
 1  // Display mode
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 11")
 8  disp("Let Uer be the impeller speed at the eye root.
          Then the vane angle at the eye root is:")
 9  disp("alphaer = atan(Ca/Uer)")
10  Der = 0.14; //m
11  N = 15000; //rpm
12  Uer = %pi*Der*N/60
13  disp("Hence, the vane angle at the impeller eye root
        :")
```

```scilab
14  Ca = 145; //m/s
15  alphaer = atan(Ca/Uer)*180/%pi
16  disp("Impeller velocity at the eye tip")
17  Det = 0.28;
18  Uet = %pi*Det*N/60
19  disp("Therefore vane angle at the eye tip:")
20  alphaet = atan(Ca/Uet)*180/%pi
21  disp("Work input:")
22  m = 10;
23  psi = 0.89;
24  sigma = 1.03;
25  D2 = 0.48;
26  U2 = %pi*D2*N/60
27  W = m*psi*sigma*U2^2   /1000
28  disp("The relative velocity at the eye tip:")
29  V1 = (Uet^2+Ca^2)^0.5
30  disp("Hence, the maximum relative Mach number at the
        eye tip:")
31  disp("M1 = V1/(gamma*R*T1)")
32  disp("where T1 is the static temperature at the
      inlet")
33  T01 = 290;
34  C1 = 145;
35  Cp = 1005;
36  T1 = T01 - C1^2 / (2*Cp)
37  disp("The Mach number at the inlet then is:")
38  gamma = 1.4;
39  R = 287;
40  M1 = (V1)/(gamma*R*T1)^0.5
```

Scilab code Exa 4.12 Recalculating 412

```scilab
1  // Display mode
```

```
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 4, Example 12")
8  disp("Figure shows the velocity triangle with the
       prewhirl angle. From the velocity triangle:")
9  Ca = 145;//m/s
10 C1 = Ca/cos(20*%pi/180)//m/s
11 disp("Equivalent dynamic temperature: Eq = C1^2/2Cp"
       )
12 Cp = 1005;
13 Eq = C1^2 / (2*Cp)
14 Cw1 = Ca*tan(20*%pi/180)
15 disp("Relative velocity at the inlet:")
16 Ue = 220;//m/s
17 V1 = (Ca^2 +(Ue - Cw1)^2)^0.5
18 disp("Therefore the static temperature at the inlet:
       ")
19 T01 = 290;//K
20 T1 = T01-Eq
21 gamma = 1.4;
22 R = 287;
23 M1 = V1/(gamma*R*T1)^0.5
24 disp("Note the reduction in Mach number due to
       prewhirl.")
```

Scilab code Exa 4.13 Centrifugal Compressor 16500rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
```

```scilab
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 13")
 8  disp("Let: rh = hub radius")
 9  disp("     rt = tip radius")
10  disp("The flow area of the impeller inlet annulus is
        :")
11  rh = 0.0625;
12  rt = 0.125;
13  A = %pi*(rt^2-rh^2);
14  A1 = A + 0.0012
15  disp("Axial velocity can be determined from the
        continuity equation but since the inlet density (
        rho1) is unknown a trial and error method must be
         followed.")
16  disp("Assuming a density based on the inlet
        stagnation condition,")
17  P01 = 1; //in bars
18  R = 287;
19  T01 = 288;//K
20  rho1 = P01*10^5  /(R*T01)
21  disp("Using the continuity equation,")
22  m = 5.5;
23  Ca = m/(rho1*A1)
24  disp("Since the whirl component at the inlet is zero
        , the absolute velocity at the inlet is C1 = Ca."
        )
25  C1 = Ca;
26  disp("The temperature equivalent of the velocity is:
         Eq")
27  Cp = 1005;
28  Eq = C1^2 /(2*Cp)
29  T1 = T01 - Eq
30  disp("Using isentropic P T relationship,")
31  P1 = P01*10^5 * (T1/T01)^3.5 /1000//kPa
32  rho1a = P1*1000/(R*T1) * 1.004
33  Caa = m/(rho1a * A1)
```

```
34  Eqa = Caa^2 /(2*Cp) * 1.003
35  T1a = T01 - Eqa
36  P1a = P01*10^5 *(T1a/T01)^3.5 /1000  //kPa
37  rho1b = P1a*1000/(R*T1a)
38  disp("Further iterations are not required and the
        value of rho1b = 1.13kg/m3 may be taken as the
        inlet density and Ca = C1 as the inlet velocity.
        At the eye tip:")
39  N = 16500;//rpm
40  Uet = 2*%pi*rt*N/60//m/s
41  disp("The blade angle at the eye tip:")
42  betat = atan(Uet/Caa)*180/%pi
43  disp("At the hub,")
44  Ueh = 2*%pi*rh*N/60//m/s
45  disp("The blade angle at the hub:")
46  betah = atan(Ueh/Caa)*180/%pi
47  disp("The Mach number based on the relative velocity
        at the eye tip using the inlet velocity triangle
        is:")
48  U1 = 216;
49  V1 = (Caa^2+U1^2)^0.5
50  disp("The relative Mach number")
51  gamma = 1.4;
52  M1 = V1/(gamma*R*T1a)^0.5
53  disp("A very small factor is multiplied to make
        approximity")
```

Scilab code Exa 4.14 ToT Efficiency 88

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
```

```
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 14")
 8  disp("The absolute Mach number of the air at the
        impeller tip is:")
 9  disp("M2 = C2/(gamma*R*T2)^0.5")
10  disp("where T2 is the static temperature at the
        impeller tip. Let us first calculate C2 and T2.")
11  U2 = 364;
12  sigma = 0.89;
13  Cw2 = sigma*U2
14  disp("From the velocity triangle,")
15  Cr2 = 28;
16  C2 = (Cr2^2+Cw2^2)^0.5
17  disp("With zero whirl at the inlet")
18  disp("W/m = sigam*U2^2 = Cp (T02 - T01)")
19  T01 = 288;
20  Cp = 1005;
21  T02 = T01 + sigma*U2^2 / Cp
22  disp("Static Temperature")
23  T2 = T02 - C2^2 /(2*Cp)
24  gamma = 1.4;
25  R = 287;
26  M2 = (C2^2/(gamma*R*T2))^0.5
27  disp("Using the isentropic P  T relation:")
28  disp("Ratioa = P02/P01 ")
29  etac = 0.88;
30  Ratioa = (1+etac * (T02/T01  - 1))^3.5
31  disp("Ratiob = P2/P02")
32  Ratiob = (T2/T02)^3.5
33  P01 = 1*100;
34  disp("Static Pressure in kPa")
35  P2 = Ratiob*Ratioa*P01
36  rho2 = P2*1000/(R*T2)
37  disp("Mass flow: in kg/s")
38  A = 0.085; //m2
39  m = rho2*Cr2*A
```

Scilab code Exa 4.15 Centrifugal Compressor 15500rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 4, Example 15")
8  disp("Impeller tip speed")
9  D2 = 0.56;//m
10 N = 15500;//rpm
11 U2 = %pi*D2*N/60 + 0.188
12 R = 287;
13 disp("Overall stagnation temperature rise Stagr =
       T03-T01")
14 psi = 1.04;
15 sigma = 0.9;
16 Cp =1005;
17 Stagr = psi*sigma*U2^2 /Cp
18 disp("Since T03 = T02")
19 T01 = 290;
20 T02 = Stagr + T01
21 disp("Now pressure ratio for impeller rat = P02/P01"
       )
22 rat = (T02/T01)^3.5
23 P01 = 101 //kPa
24 P02 = rat * P01
25 Cw2 = sigma*U2
26 disp("Let Cr2 = 105 m/s")
27 Cr2 = 105;
28 disp("Outlet area normal to periphery")
29 disp("A2 = pi*D2 * impeller depth")
```

```
30  A2 = %pi*D2*0.038
31  disp("From outlet velocity triangle")
32  C2 = (Cr2^2 +Cw2^2)^0.5
33  T2 = T02 - C2^2 /(2*Cp)
34  disp("Using isentropic P T relations")
35  P2 = P02*(T2/T02)^3.5
36  disp("From equation of state")
37  rho2 = P2/(R*T2) * 1000
38  disp("The equation of continuity gives")
39  m = 16;
40  Cr2a = m/(A2*P2) * 100
41  disp("Thus, impeller outlet radial velocity = 81.63
        m/s")
42  disp("Impeller outlet Mach number")
43  gamma = 1.4;
44  M2 = C2/(gamma*R*T2)^0.5
45  disp("From outlet velocity triangle")
46  alpha2 = acos(Cr2/C2)*180/%pi
47  disp("Assuming free vortex flow in the vaneless
        space and for convenience denoting conditions at
        the diffuser vane without a subscript (r = 0.28 +
        0.043 = 0.323)")
48  r = 0.323;
49  r2 = 0.28;
50  Cw = Cw2*r2/r
51  disp("The radial component of velocity can be found
        by trial and error. Choose as a first try, Cr =
        105 m/s")
52  Cr = 105;
53  C = (Cw^2+Cr^2)^0.5
54  x = C^2 /(2*Cp)
55  disp("T = 482.53 - 68 (since T = T02 in vaneless
        space)")
56  T = T02-x
57  P = P02*(T/T02)^3.5
58  rho = rho2/(R*T2) * 10^5 * 1.132
59  disp("The equation of continuity gives")
60  A = 2*%pi*r*0.038
```

```
61 Cra = m/(rho*A)
62 disp("Next try Cra = 79.41 m/s")
63 Cra = 79.41;
64 x1 = (Cra^2 + Cw^2)/(2*Cp)
65 Ta = T02 -x1
66 Px = P02*(Ta/T02)^3.5//Pa
67 rhox = P/(Ta*R) * 1000  + 0.1
68 Crb = m/(rhox*A)
69 disp("Try Crb = 68.1m/s")
70 x2 = (Crb^2+Cw^2)/(2*Cp)
71 Tb = T02-x2
72 Py = P02*(Tb/T02)^3.5
73 rhoy = Py/(Tb*R)* 1000
74 Crc = m/(rhoy*A)
75 disp("Taking Crc as 68.63 m/s, the vane angle")
76 alpha = atan(Cw/Crc)*180/%pi
77 disp("Mach number at vane")
78 M = (2*Cp*x1/(gamma*R*Tb))^0.5
79 //I have gone through all the answer there is a
       printing mistake in book with two answers
```

Scilab code Exa 4.16 Double sided compressor 15500

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
4 ieee(1);
5 clear;
6 clc;
7 disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 4, Example 16")
8 disp("At eye root, Ca = 150 m/s")
9 Ca = 150;
```

```
10  C1 = Ca / cos(20*%pi/180)
11  Cw1 = Ca*tan(20*%pi/180)
12  disp("Impeller speed at eye root")
13  Der = 0.18;
14  N = 15500; //rpm
15  Uer = %pi*Der*N/60 //m/s
16  disp("From velocity triangle")
17  betaer = atan(Ca/(Uer-Cw1))*180/%pi
18  disp("At eye tip from Figure")
19  Det = 0.3175;
20  Uet = %pi*Det*N/60
21  alphaet = atan(Ca/(Uet-Cw1))*180/%pi
22  disp("Mach number will be maximum at the point where
        relative velocity is maximum.")
23  disp("Relative velocity at eye root is:")
24  Ver = Ca/sin(betaer*%pi/180)
25  disp("Relative velocity at eye tip is:")
26  Vet = Ca/sin(alphaet*%pi/180)
27  disp("Relative velocity at the tip is maximum.")
28  disp("Static temperature at inlet:")
29  T01 =288;
30  Cp = 1005;
31  T1 = T01-Vet^2 /(2*Cp)
32  gamma = 1.4;
33  R = 287;
34  Mmax = Vet/(gamma*R*T1)^0.5
```

Scilab code Exa 4.17 Vanes 17 stagnation T and P

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
```

```
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 4, Example 17")
 8  disp("Pressure is in bar and temperature in Kelvin")
 9  disp("Mechanical efficiency is")
10  disp("etam = Work transferred to air/Work supplied
        to shaft")
11  disp("or shaft power = W/etam")
12  disp("for vaned impeller, slip factor, by Stanitz
        formula is")
13  disp("sigma = 1 - 0.63*pi/n")
14  n = 17;
15  R = 287;
16  sigma = 1-0.63*%pi/n;
17  disp("Work input per unit mass flow")
18  disp("W = psi*sigma*U2Cw2")
19  psi = 1.04;
20  U2 = 475;//m/s
21  W = psi*sigma*U2^2 /1000
22  disp("Work input for 2.5 kg/s")
23  Wi = W*2.5
24  disp("Shaft Power")
25  etam = 0.96;
26  Pshaft = Wi/etam
27  disp("The overall pressure ratio is pRatio = P03/P01
        ")
28  P01 = 1.01;
29  etac = 0.84;
30  Cp = 1005;
31  T01 = 288;
32  pRatio = (1+etac*psi*sigma*U2^2 /(Cp*T01))^3.5
33  disp("Stagnation pressure at diffuser exit")
34  P03 = P01*pRatio
35  m = 2.5;
36  T03 = Wi*1000/(m*Cp) +T01
37  T02 = T03;
38  disp("Static temperature at diffuser exit")
39  C3 = 90;
40  T3 = T03 - C3^2 /(2*Cp)
```

```
41  disp("Static pressure at diffuser exit")
42  P3 = P03*(T3/T03)^3.5
43  disp("The reaction is 0.5 = (T2 - T1)/(T3 - T1)")
44  disp("x = T3 - T1")
45  C1 = 150;
46  x = Wi*1000/(m*Cp) + (C1^2 - C3^2)/(2*Cp)
47  disp("y = T2-T1")
48  y = 0.5*x
49  disp("Substituting T2 - T1")
50  T2 = T01 - C1^2 /(2*Cp) + y
51  disp("At the impeller exit")
52  disp("T02 = T2 + C2^2/2Cp")
53  disp("T03 = T2 + C2^2/2Cp (Since T02 = T03)")
54  C2 = (2*Cp*((T03-T01)+(T01-T2)))^0.5
55  disp("Mach number at impeller outlet")
56  M2 = C2/(1.4*R*T2)^0.5
57  disp("Radial velocity at impeller outlet")
58  Cw2 = sigma*U2;
59  Cr2 = (C2^2 - Cw2^2)^0.5
60  disp("Diffuser efficiency is given by")
61  disp("etaD = (h3a - h2)/(h3 - h2)")
62  disp(" = isentropic enthalpy increase/actual
          enthalpy increase")
63  disp(" = (T3a - T2)/(T3 - T2)")
64  disp(" z = P3/P2 implies")
65  etaD = 0.821;
66  z = (1+etaD *(T3-T2)/T2)^3.5
67  P2 = P3/z
68  disp("From isentropic P T relations in bars")
69  P02 = P2*(T02/T2)^3.5
70  disp("Impeller efficiency is")
71  etai = T01*((P02/P01)^0.286 -1)/(T03-T01) * 100
72  rho2 = P2/(R*T2) * 10^5//in kg/m3
73  disp("m = rho2A2Cr2")
74  disp(" = 2pi*r2*rho2*b2")
75  m = 2.5;
76  b2 = 0.0065;
77  N = U2*2.27*246.58*b2*60/m
```

Chapter 5

Axial Flow Compressors and Fans

Scilab code Exa 5.1 Work of compression

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
4 ieee(1);
5 clear;
6 clc;
7 disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 5, Example 1")
8 T01 = 292;//K
9 P01 = 1;//bar
10 etac = 0.85;
11 disp("Using the isentropic P T relation for
    compression processes,")
12 disp("Ratio = P02/P01 = (T02a/T01)^(gamma/(gamma-1))
    ")
13 disp("where T02a is the isentropic temperature at
    the outlet. Therefore,")
```

```
14  Ratio = 9.5;
15  T02a = T01*(Ratio)^0.286//Kelvin
16  disp("Now, using isentropic efficiency of the
        compressor in order to find the actual
        temperature at the outlet ,")
17  T02 = T01 + (T02a - T01)/etac
18  disp("Work of compression: in kJ/kg")
19  Cp = 1.005;
20  Wc = Cp*(T02-T01)
```

Scilab code Exa 5.2 One stage compressor

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 2")
8  disp("The stage pressure ratio is given by:")
9  disp("Rs = (1+etas*deltaT0s/T01)^(gamma/(gamma-1))")
10  Rs = 1.22;
11  DeltaT0s = 21;
12  T01 = 288;//Kelvin
13  etas = (Rs^(1/3.5) - 1)*T01/DeltaT0s *100
14  disp("The rotor speed is given by:")
15  U = 200;//m/s
16  N = 4500;//rpm
17  D = 60*U/(%pi*N)
```

Scilab code Exa 5.3 Compressor 5000rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 5, Example 3")
8  disp("Rotor speed is given by:")
9  D = 0.95; //m
10 N = 5000; //rpm
11 U = %pi*D*N/60
12 disp("Blade speed at the hub:")
13 Dh = 0.85;
14 Uh = %pi*Dh*N/60
15 disp("From the inlet velocity triangle (Figure)")
16 disp("tanalpha1 = Cw1/Ca and tanbeta1 = (U - Cw1)/Ca
       ")
17 disp("Adding the above two equations:")
18 disp("U/Ca = tanalpha1 + tanbeta1")
19 alpha1 = 28;
20 beta1 = 56;
21 Ca = U/(tan(alpha1*%pi/180) + tan(beta1*%pi/180))
22 disp("Therefore, Ca = 123.47 m/s (constant at all
       radii)")
23 disp("The mass flow rate: in kg/s")
24 disp("m = pi*(rt^2 - rh^2)rho*Ca")
25 rt = 0.475;
26 rh = 0.425;
27 rho = 1.2;
28 m = %pi*rho*Ca*(rt^2 -rh^2)
29 disp("The power required per unit kg for compression
        is:")
30 disp("Wc = lambda*U*Ca*(tan(beta1) - tan(beta2)) in
       kJ/kg")
31 lambda = 1;
```

```
32  beta2 = alpha1;
33  Wc = lambda*U*Ca*(tan(beta1*%pi/180) - tan(beta2*%pi
       /180)) /1000
34  disp("The total power required to drive the
       compressor is: in kW")
35  P = m*Wc
36  disp("At the inlet to the rotor tip:")
37  Cw1t = Ca*tan(alpha1*%pi/180)//m/s
38  disp("Using free vortex condition, i.e., Cwr =
       constant, and using h as the subscript for the
       hub,")
39  Cw1h = Cw1t*rt/rh//m/s
40  disp("At the outlet to the rotor tip,")
41  alpha2 = beta1;
42  Cw2t = Ca *tan(alpha2*%pi/180)
43  Cw2h = Cw2t*rt/rh
44  disp("Hence the flow angles at the hub:")
45  alpha1a = atan(Cw1h/Ca)*180/%pi
46  beta1a = atan((Uh/Ca) - tan(alpha1a*%pi/180))*180/
       %pi
47  alpha2a = atan(Cw2h/Ca)*180/%pi
48  beta2a = atan((Uh/Ca)  - tan(alpha2a*%pi/180)) *180/
       %pi
49  disp("The degree of reaction at the hub is given by:
       ")
50  A = Ca*(tan(beta1a*%pi/180)+tan(beta2a*%pi/180))/(2*
       Uh) * 100
```

Scilab code Exa 5.4 Stage air angles for vortex

```
1  // Display mode
```
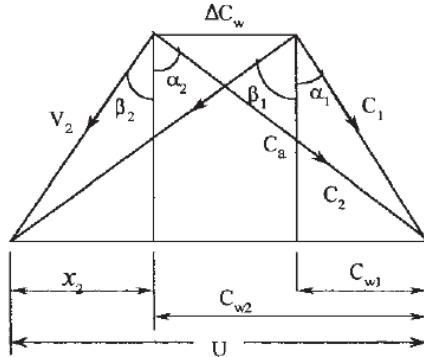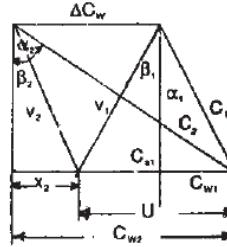
Figure 5.1: Stage air angles for vortex

```
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 5, Example 4")
8  disp("Calculation at mean radius:")
9  disp("Wc = U(Cw2 - Cw1) = U*DeltaCw")
10 disp("or")
11 disp(" Cp(T02 - T01) = CpDeltaT0s = lambda*U*DeltaCw
       ")
12 Cp = 1005;
13 DeltaT0s = 15;
14 lambda = 0.85;
15 Um = 185;
16 DeltaCw = Cp*DeltaT0s/(lambda*Um)
17 disp("Since the degree of reaction (Fig. 5.14) at
       the mean radius is 50%, alpha1 = beta2, and
       alpha2 = beta1. From the velocity triangle at the
        mean,")
18 disp("Um = DeltaCw + 2Cw1")
19 disp("Cw1 in m/s alpha1 in degrees")
```

```
20  Cw1 = (Um - DeltaCw)/2//m/s
21  Ca = 140;
22  alpha1 = atan(Cw1/Ca)*180/%pi
23  beta2 = alpha1
24  beta1 = atan((DeltaCw + Cw1)/Ca)*180/%pi
25  alpha2 = beta1
26  disp("Calculation at the blade tip: Using the free
        vortex diagram (Fig. 5.15), Velocity in m/s")
27  disp("(DeltaCw * U)t = (DeltaCw * U)m")
28  Ut = 240;
29  DeltaCwt =DeltaCw*Um/Ut
30  Cwt = Cw1*Um/Ut
31  alpha1t = atan(Cwt/Ca)*180/%pi
32  disp("From the velocity triangle at the tip, x2 +
        DeltaCwt + Cwt = Ut")
33  x2 = Ut-DeltaCwt - Cwt
34  beta1t = atan((DeltaCwt+x2)/Ca)*180/%pi
35  alpha2t = atan((Cwt+DeltaCwt)/Ca)*180/%pi
36  beta2t = atan(x2/Ca)*180/%pi
37  disp("Calculation at the blade root: (DeltaCwr * U)r
        = (DetaCw * U)m")
38  Ur = Ca;
39  DeltaCwr = DeltaCw*Um/Ur
40  Cwr = Cw1*Um/Ur
41  Cw2tip = Ca*tan(alpha2t*%pi/180)
42  Cw2root = Cw2tip*Ut/Ur
43  alpha1r = atan(Cwr/Ca)*180/%pi
44  x3 = Cw2root-Ur
45  beta1r = atan((Ur-Cwr)/Ca)*180/%pi
46  alpha2r = atan(Cw2root/Ca)*180/%pi
47  beta2r = -atan(x3/Ca)*180/%pi
```

Scilab code Exa 5.5 Degree of reaction for Ex54

```
1  // Display mode
```

```
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 5")
 8  disp("DOF -> Degree of Freedom")
 9  disp("Reaction at the blade root:")
10  Ca = 140;
11  beta1r = 30.08;
12  beta2r = -18;
13  Ur = 140;
14  DOFroot =Ca*(tan(beta1r*%pi/180)+tan(beta2r*%pi/180)
        )/(2*Ur) *100
15  disp("Reaction at the blade tip:")
16  Ut = 240;
17  beta1t= 55.75;
18  beta2t = 43.26;
19  DOFtip =Ca*(tan(beta1t*%pi/180)+tan(beta2t*%pi/180))
        /(2*Ut)*100
```

Scilab code Exa 5.6 Temperature rise in first stage

```
 1  // Display mode
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 6")
 8  disp("Since the degree of reaction is 50%, the
```

```
      velocity  triangle  is  symmetric  as  shown  in  Figure
         Ex56")
 9  disp("Using  the  degree  of  reaction  equation")
10  disp("DOF = Ca(tanbeta1 + tanbeta2)/2U")
11  disp("phi = Ca/U")
12  disp("Now, for  the  relative  Mach  number  at  the  inlet
         :")
13  DOF = 0.5;
14  phi = 0.56;
15  beta1 = atan(2*DOF/phi - tan(32*%pi/180))*180/%pi
16  disp("Mr1 = V1/(gamma*RT1)^0.5")
17  disp("V1^2 = gamma*R*Mr1^2*(T01 - C1^2/2Cp)")
18  disp("From  the  velocity  triangle ,")
19  disp("V1 = Ca/cosbeta1; and C1 = Ca/cosalpha1")
20  disp("alpha1 = beta2(since DOF = 0.5)")
21  disp("C1 = Ca/cos32 = Ca/0.848")
22  disp("V1 = Ca/cos 49.24 = Ca/0.653")
23  disp("Hence: C1^2/ = Ca^2/0.719; and V1^2 = Ca
         ^2/0.426")
24  disp("Substituting  for  V1  and  C1,")
25  Ca = ((104.41*295*1445)/(1445+104.41))^0.5
26  disp("The  stagnation  temperature  rise  may  be
         calculated  as:  Rise  in  Kelvin = T02-T01")
27  Cp = 1005;
28  Rise = Ca^2*(tan(beta1*%pi/180)- tan(32*%pi/180))/(
         Cp*phi)
```

Scilab code Exa 5.7 Rpm 152 rps

```
1  // Display  mode
2  mode(0);
3  // Display  warning  for  floating  point  exception
4  ieee(1);
5  clear;
6  clc;
```

```
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 7")
8  disp("The following equation provides the
        relationship between the temperature rise and the
         desired angles:")
9  disp("T02 - T01 = lambda*U*Ca*(tan(beta1) - tan(
        beta2))/Cp")
10 disp("T02-T01 = Rise")
11 Rise = 24;
12 lambda = 0.93;
13 U = 205;
14 Ca = 155.5;
15 Cp = 1005;
16 disp("Dif = tan(beta1) - tan(beta2)")
17 Dif = Rise*Cp/(U*lambda*Ca)
18 disp("Using the degree of reaction equation:")
19 disp("DOF = Ca*(tan(beta1) + tan(beta2))/(2*U)")
20 disp("tan(beta1) + tan(beta2) = Add")
21 DOF = 0.5;
22 Add = DOF*2*U/Ca
23 beta1 = atan((Add+Dif)/2)*180/%pi
24 alpha2 = beta1
25 beta2 = atan(Add - tan(beta1*%pi/180))*180/%pi
26 alpha1 = beta2
27 disp("The mean radius, rm, is given by: in m")
28 N = 152;//rpm
29 rm = U/(2*%pi*N)
30 disp("The blade height, h in m, is given by: m = rho
        *ACa, where A is the annular area of the flow.")
31 C1 = Ca/cos(alpha1*%pi/180)
32 T01 = 290;
33 disp("Static temperature in kelvin")
34 T1 = T01- C1^2 /(2*Cp)
35 disp("Using the isentropic P T relation:")
36 disp("Static pressure: P1 in bars")
37 P01 = 1;
38 P1 = P01*(T1/T01)^3.5
39 R = 287/1000;
```

```
40  disp("Density rho1 in kg/m3")
41  rho1 = P1/(R*T1) * 100
42  disp("From the continuity equation:")
43  m = 22;
44  A = m/(rho1*Ca)
45  disp("and the blade height:")
46  rm = 0.215;
47  h =A/(2*%pi*rm)
```

Scilab code Exa 5.8 polytropic efficiency 87

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 8")
8  disp("Since the degree of reaction at the mean
        radius is 50%, alpha1 = beta2 and alpha2 = beta1.
         From the velocity triangles, the relative outlet
         velocity component in the x-direction is given
        by:")
9  Ca = 158;
10 beta2 = 30;
11 Vx2 = Ca*tan(beta2*%pi/180)
12 disp("V1 = C2 = (U - Vx2)^2 + Ca^2)^1/2")
13 U = 245;
14 Vx2 = 91.22;
15 Ca = 158;
16 C2 = ((U - Vx2)^2 + Ca^2)^0.5
17 V1 = C2
18 beta1 = acos(Ca/V1)*180/%pi
19 disp("Stagnation temperature rise in the stage, in
```

```
        Kelvin")
20  disp("DeltaT0s = UCa(tanbeta1 - tanbeta2)/Cp")
21  Cp = 1005;
22  DeltaT0s = U*Ca*(tan(beta1*%pi/180) - tan(beta2*%pi
        /180))/Cp
23  disp("n /(n-1) = inf * gamma/(gamm-1 = 3.05)")
24  disp("Number of stages")
25  N = (4.5^(1/3.05) -1)*290/DeltaT0s
26  disp("implies N = 12 stages")
```

Scilab code Exa 5.9 Rotor speed 200

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 9")
8  disp("For 50% degree of reaction at the mean radius
        (Fig. Ex59), alpha1 = beta2 and alpha2 = beta1.")
9  disp("From the inlet velocity triangle,")
10  Ca = 180;
11  C1 = 185;
12  Cp = 1005;
13  alpha1 = acos(Ca/C1)*180/%pi
14  beta2 = alpha1
15  disp("From the same velocity triangle,")
16  Cw1 = (C1^2 - Ca^2)^0.5
17  U = 200;
18  beta1 = atan((U-Cw1)/Ca)*180/%pi
19  alpha2 = beta1
```

```
20  disp(" Static temperature at stage inlet may be
        determined by using stagnation and static
        temperature relationship as given below: in
        Kelvin")
21  T01 = 290;
22  T1 = T01 - C1^2/(2*Cp)
23  disp(" Stagnation temperature rise of the stage is
        given by")
24  lambda = 0.86;
25  DeltaT0s = lambda*U*Ca*(tan(beta1*%pi/180)-tan(beta2
        *%pi/180))/Cp
26  disp(" Stage pressure ratio is given by")
27  etas = 0.86;
28  Rs = (1+ etas*DeltaT0s/T01)^3.5
```

Scilab code Exa 5.10 Isentropic Efficiency

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp(" Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 10")
8  disp(" Using the isentropic P T relation for the
        compression process ,")
9  disp("P02/P01 = r,   T02a in Kelvin is")
10 r = 6
11 T01 = 285;
12 gam = 1.4;
13 x = (gam-1)/gam;
14 T02a = T01*r^x
15 disp(" Using the polytropic P T relation for the
        compression process :")
```

```
16  etainf = 0.85;
17  disp(" (n-1)/n = R")
18  R = (gam-1)/(gam*etainf)
19  disp("Actual temperature rise:")
20  T02 = T01*r^R
21  disp("The compressor isentropic efficiency is given
        by:")
22  etac = (T02a-T01)/(T02-T01) *100
```

Scilab code Exa 5.11 Rotation 5500rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 11")
8  disp("As no inlet guide vanes alpha1 = 0; Cw1 = 0")
9  disp("Stagnation temperature, T01 in Kelvins, is
        given by")
10 T01 = 290;
11 C1 = 145;
12 Cp = 1005;
13 Ca = C1;
14 T1 = T01 - (C1/(2*Cp)) - 1
15 disp("The Mach number relative to tip is")
16 M = 0.96;
17 gam = 1.4;
18 R = 287;
19 V1 = M*(gam*R*T1)^0.5 *1.04
20 disp("i.e., relative velocity at tip = 340.7 m/s.
```

```
              From  velocity  triangle  at  inlet  Fig  511")
21  Ut = (V1^2 - C1^2)^0.5
22  disp("Radius in m")
23  N = 5500;
24  rt = Ut*60/(2*%pi*N)
25  beta1 = atan(Ut/Ca)*180/%pi
26  DeltaT0s = 22;
27  Tau = 0.92;
28  disp("tan(beta1) - tan(beta2) = Dif")
29  Dif = DeltaT0s*Cp/(Tau*Ut*Ca)
30  beta2 = atan(1.588)*180/%pi
31  h = 0.268;
32  rm = 0.402;
33  A = 2*%pi*rm*h//m2
34  P01 = 1;//bar
35  P1 = P01*(T1/T01)^3.5
36  R = 287;
37  rho1 = P1/(R*T1) * 10^5
38  m = rho1*A*Ca
39  disp("Stage pressure ratio is")
40  etas = 0.9;
41  Rs = (1+etas*DeltaT0s/T01)^3.5
42  W = Cp*DeltaT0s//kJ/kg
43  disp("Power required by the compressor in kW")
44  P = m*W/1000
45  disp("In order to find out rotor air angles at the
        root section, radius at the root can be found as
        given below.")
46  rr = rm - h/2
47  disp("Impeller speed at root is")
48  Ur = 2*%pi*rr*N/60
49  disp("Therefore, from velocity triangle at root
        section")
50  beta1 = atan(Ur/Ca)*180/%pi
51  disp("tanbeta1 - tanbeta2 = R")
52  R = DeltaT0s*Cp/(Tau*Ur*Ca)
53  beta2 = atan(tan(46.695*%pi/180)-1.078)*180/%pi
```

Scilab code Exa 5.12 Number of stages

```scilab
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 5, Example 12")
8  disp("If N is the number of stages, then overall
       pressure rise is:")
9  disp("R = (1+(N*DeltaT0s)/T01)^((n-1)/n)")
10 disp("Exp=(n-1)/n = etaac *gam/(gam-1)")
11 disp("(where hac is the polytropic efficiency)
       substituting values")
12 etaac = 0.87;
13 gam = 1.4;
14 Exp = etaac *gam/(gam-1)
15 R=4.5;
16 Cp = 1005;
17 DeltaTs = 22;
18 T01 = 290;
19 N = ((R^(1/3.05)) -1)*T01/DeltaTs
20 disp("Hence number of stages = 8")
21 disp("Stagnation temperature rise, DeltaTs, per
       stage = 22K, as we took 8 stages, therefore")
22 DeltaT0s = DeltaTs*N/8
23 disp("From velocity triangle cos(a8) = Ca8/C8")
24 alpha8 = 20;
25 C8 = 160;
26 Ca8 = C8*cos(alpha8*%pi/180)
```

104

```scilab
27  disp("Using degree of reaction , DOF = 0.5")
28  disp("0.5 = Ca8(tanbeta8 + tanbeta9)/(2U)")
29  disp("0.5 = 150.35(tanbeta8 + tanbeta9)/2U -------(A
        )")
30  disp("DelTaT0s = TauUCa8*(tanbeta8 - tanbeta9)/Cp")
31  disp("23.1 = 0.85*U*150.35(tanbeta8 - tan20)/1005
        -----(B)")
32  Tau = 0.85;
33  beta9 = alpha8;
34  disp("From Eq. (A) U = 150.35(tanbeta8 - 0.364)
        -----(C)")
35  disp("From Eq. (B) U = 181.66/(tanbeta8 - 0.364)
        -----(D)")
36  disp("Comparing Eqs. (C) and (D), we have")
37  disp("150.35(tanbeta8 + 0.364)= 181.66/(tanbeta8 -
        0.364)")
38  disp("(tan(beta8))^2 = p")
39  p = 181.66/150.35 + 0.364^2
40  beta8 = atan(p^0.5)*180/%pi
41  disp("Substituting in Eq. (C)")
42  U = Ca8*(tan(beta8*%pi/180) + tan(beta9*%pi/180))
43  disp("The rotational speed is given by N in rps")
44  N = U/(2*%pi*0.0925)
45  disp("In order to find the length of the last stage
         rotor blade at inlet to the stage, it is
        necessary to calculate stagnation temperature and
         pressure ratio of the last stage.")
46  disp("Stagnation temperature of last stage: Fig.
        Ex512")
47  T08 = T01 + 7*DeltaT0s
48  disp("Pressure ratio of the first stage is: Rat =
        P09/P08")
49  Rat = 1.1643
50  disp("Rat1 = P09/P01")
51  Rat1 = 4
52  P01 = 1;//in bars
53  P09 = Rat1*P01//bars
54  P08 = P09/Rat
```

```
55  T8 = T08 - C8^2 /(2*Cp)
56  disp("Using stagnation and static isentropic
        temperature relationship for the last stage, we
        have pressure in bars")
57  P8 = P08*(T8/T08)^(3.5)
58  R = 287;
59  rho8 = P8/(R*T8)*100000 //in kg/m3
60  disp("Using mass flow rate m = rho8*A8*Ca8")
61  m = 3.5;
62  A8 = m/(rho8*Ca8)
63  r = 0.0925;
64  h = A8/(2*%pi*r)
65  disp("i.e., length of the last stage rotor blade at
        inlet to the stage, h = 16.17 mm.")
```

Scilab code Exa 5.13 10 stage axial

```
 1  // Display mode
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 13")
 8  disp("No. of stages = 10")
 9  disp("The overall stagnation temperature rise is:")
10  T01 = 290;
11  R = 4.5;
12  etac = 0.88;
13  T1 = (290*(4.5^0.286 - 1))
14  disp("The stagnation temperature rise of a stage")
15  T0s = T1/10
16  disp("The stagnation temperature rise in terms of
        air angles is:")
```

```scilab
17  disp("T0s = TauUCa(tanalpha2 - tanalpha1)/Cp")
18  disp("(tanalpha2 - tanalpha1) = T0s * Cp/(TauUCa)")
19  disp("(tanalpha2 - tanalpha1)= Dif -------(A)")
20  Tau = 0.87;
21  Cp = 1005;
22  U = 218;
23  Ca = 165;
24  Dif = T0s*Cp/(Tau*U*Ca)
25  disp("From degree of reaction DOF")
26  disp("DOF = (1 - Ca*(tanalpha2 + tanalpha1)/2U)")
27  disp("0.76 = (1 - 165(tanalpha2 + tanalpha1)/(2*218)
        )")
28  disp("(tanalpha2 + tanalpha1) = Add -------(B)")
29  Add = (1-0.76)*(2*U)/Ca
30  disp("Adding (A) and (B), we get")
31  alpha2 = atan((Add+Dif)/2)*180/%pi
32  alpha1 = atan((Add-Dif)/2)*180/%pi
33  disp("Similarly, for beta1 and beta2, degree of
        reaction")
34  disp("Add1 = tanbeta1 + tanbeta2 = 2.01")
35  Add1 = 2.01;
36  disp("and Dif1 = tanbeta1 - tanbeta2 = 0.501")
37  Dif1 = 0.501;
38  beta1 = atan((Add1+Dif1)/2)*180/%pi
39  beta2 = atan((Add1-Dif1)/2)*180/%pi
```

Scilab code Exa 5.14 Rotation 5400rpm

```scilab
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
```

```scilab
          Gorla and Aijaz A. Khan, Chapter 5, Example 14")
 8  disp("Impeller speed is U in m/s")
 9  rt = 0.45;//m
10  N = 5400;//rpm
11  U = 2*%pi*rt*N/60
12  disp("From velocity triangle")
13  disp("U = Ca*(tanalpha1 + tanbeta1)")
14  alpha1 = 28;
15  beta1 = 58;
16  Ca = U/(tan(alpha1*%pi/180)+tan(beta1*%pi/180))
17  disp("Flow area is A in m2")
18  rtip=rt;//m
19  rroot=0.42;//m
20  A = %pi*(0.45^2 - 0.42^2)
21  disp("Mass flow rate is m in kg/s")
22  rho = 1.5;//kg/m3
23  m = rho*A*Ca
24  disp("Power absorbed by the compressor P in kW")
25  disp(" = Tau*U(Cw2 - Cw1)")
26  disp(" = Tau*U*Ca*(tanalpha2-tanalpha1)")
27  alpha2 = beta1;
28  Tau = 0.93;
29  P = Tau*U*Ca*(tan(alpha2*%pi/180)-tan(alpha1*%pi
        /180))*1.001
30  disp("Total Power in kW")
31  Pt = m*P/1000*1.017
32  disp("and whirl velocity at impeller tip Cwt in m/s
        ")
33  Cwt = Ca*tan(alpha1*%pi/180)
34  disp("Now using free vortex condition")
35  disp("r Cw = constant")
36  disp("[ rhCw1h = rtCw1t (where subscripts h for hub
        and t for tip)")
37  rh = 0.4;
38  Cw1h = rt*Cwt/rh
39  Cw2t = Ca*tan(alpha2*%pi/180)
40  Cw2h = Cw2t*rt/rh
41  disp("Therefore, the flow angles at the hub are")
```

```
42  alpha1h = atan(Cw1h/Ca)*180/%pi
43  Uh = 2*%pi*rh*N/60
44  beta1h = atan((Uh-Ca*tan(alpha1h*%pi/180))/Ca)*180/
        %pi
45  alpha2h = atan(Cw2h/Ca)*180/%pi
46  beta2h = atan((Uh-Ca*tan(alpha2h*%pi/180))/Ca)*180/
        %pi
47  disp("Finally, the degree of reaction at the hub is
        DOF in %")
48  DOF = Ca*(tan(beta1h*%pi/180)+tan(beta2h*%pi/180))
        /(2*Uh) *100
```

Scilab code Exa 5.15 Rotation 8000rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 5, Example 15")
8  disp("Angles are in degrees, lengths in meters,
        velocities in m/s, temperatures are in Kelvins")
9  disp("Using Equation at the mean radius")
10  disp("Wc = Cp(DeltaTA + DeltaTB) =DeltaTS")
11  disp("Dif = T02-T01")
12  Dif = 20;
13  tau = 0.94;
14  U = 200;
15  Ca = 155;
16  Cp = 1005;
17  N = 8000;
```

```
18  disp ( " tan ( beta1 )−tan ( beta2 ) = Dift −−−−−−(A) " )
19  Dift = Dif*Cp/(tau*U*Ca)
20  disp ( " Using Equation , the degree of reaction (DOF)
       is " )
21  disp ( "DOF = Ca*(tan ( beta1 )+tan ( beta2 ) )/(2U) " )
22  disp ( " tan ( beta1 )+tan ( beta2 ) = Add −−−−−−(B) " )
23  DOF = 0.5;
24  Add = DOF*2*U/Ca
25  disp ( " Solving (A) and (B) equations simultaneously " )
26  beta1 = atan ((Add+Dift)/2)*180/%pi
27  alpha2 = beta1;
28  beta2 = atan (1.29 - tan ( beta1*%pi/180))*180/%pi
29  alpha1 = beta2;
30  disp ( " Let rm be the mean radius " )
31  rm = U/(2*%pi*N)//m
32  disp ( " Using continuity equation in order to find the
        annulus area of flow " )
33  C1 = Ca/cos ( alpha1*%pi/180)//m/s
34  T01 = 290;
35  T1 = T01-C1^2 /(2*Cp)
36  disp ( " Using isentropic relationship at inlet : p1/p01
       = (T1/T01)^(gamma/(gamma−1)) " )
37  disp ( " Static pressure is P1 in bars " )
38  P01 = 1;
39  P1 = P01*(T1/T01)^3.5
40  disp ( " Density in kg/m3 " )
41  R = 287;
42  rho1 = P1/(R*T1) *10^5
43  disp ( " From the continuity equation , " )
44  m = 22;//kg
45  A = m/(rho1*Ca)
46  disp ( " blade height in m is " )
47  h = A/(2*%pi*rm)
48  disp ( " At mean radius , and noting that blades beta ,
      an equivalent to cascade , alpha , nominal air
      deflection is Epsilon " )
49  Epsilon = beta1 - beta2
50  disp ( " Using Fig . Ex515 for cascade nominal
```

```
        deflection vs. air outlet angle, the solidity,")
51  disp("s/c = 0.5")
52  disp("Blade aspect ratio = span/chord")
53  disp("Blade chord = C")
54  C = 0.089/3
55  disp("Blade pitch = s")
56  s = 0.5*C
57  disp("Both the Chord and pitch/span are in meters")
```

Chapter 6

Steam Turbines

Scilab code Exa 6.1 Isentropic expansion

```
1  // Display mode
2  mode (0);
3  // Display warning for floating point exception
4  ieee (1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 6, Example 1")
8  disp("From saturated steam tables, enthalpy of
       saturated vapor at 2 MPa:")
9  disp("Enthalpy in kJ/kg")
10 h1 = 2799.5
11 hg = h1
12 disp("Entropy in kJ/kgK")
13 s1 = 6.3409
14 sg = s1
15 disp("Since the expansion is isentropic, s1 = s2: i.
       e., s1 = s2 = 6.3409 = sf2 +x2sfg2, where x2 is
       the dryness fraction after isentropic expansion,
       sf2 is the entropy of saturated liquid at 0.2MPa,
        sfg2 is the entropy of vaporization at 0.2 MPa.
```

```
        Using tables:")
16  x2 = (sg - 1.5301)/5.5970
17  disp("h2")
18  hf2 = 504.7;
19  hfg2 = 2201.9;
20  disp("h2 in kJ/kg")
21  h2 = hf2+x2*hfg2
22  disp("Using the energy equation:C2 in m/s")
23  C2 = (2*(h1-h2)*1000)^0.5
```

Scilab code Exa 6.2 Mass of steam discharged

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 6, Example 2")
8  disp("Enthalpy of dry saturated steam at 1.3MPa,
       using steam tables ,")
9  h1 = 2787.6
10  s1 = 6.4953
11  disp("Since the expansion process is isentropic , s1
       = s2 = sf2 + x2sfg2 , hence dryness fraction after
        expansion :")
12  x2 = (s1-1.3026)/6.0568
13  disp("Now, the enthalpy at the exit:")
14  hf2=417.46;
15  hfg2 = 2258;
16  h2 = hf2+x2*hfg2
17  disp("Therefore enthalpy drop from 1.3 MPa to 0.1
       MPa in kJ/kg")
18  drop = h1-h2
```

```
19 disp("Actual enthalpy drop due to friction loss in
      the nozzle droping in kJ/kg")
20 Droping = 0.9*drop
21 disp("Hence, the velocity of steam at the nozzle
      exit:")
22 C2 = (2*1000*Droping)^0.5
23 disp("Specific volume of steam at 0.1 MPa: in m3/kg"
      )
24 vg2 = 1.694;
25 Specificv = x2*vg2
26 disp("(since the volume of the liquid is usually
      negligible compared to the volume of dry
      saturated vapor, hence for most practical
      problems, v = xvg)")
27 disp("Mass flow rate of steam at the nozzle exit: in
       kg/h")
28 m = (0.01^2)*%pi*C2/(4*x2*vg2) *3600
```

Scilab code Exa 6.3 Exit area required

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
4 ieee(1);
5 clear;
6 clc;
7 disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 6, Example 3")
8 P1 = 7.5;//MPa
9 h1 = 3404.3;//kJ/kg
10 s1 = 6.7598;//kJ/kg K
11 disp("(h1 and s1 from superheated steam tables)")
12 disp("At the exit state, P2 > Pc = 0.545*7.5 =
      4.0875 MPa; and therefore the nozzle is
      convergent. State 2 is fixed by P2 = 5MPa, s1 =
```

```
              s2 = 6.7598 kJ/kgK")
13  disp("T2 = 4358K, v2 = 0.06152m3/kg, h2 = 3277.9 kJ/
       kg (from the superheated steam tables or the
       Mollier Chart).")
14  disp("The exit velocity:")
15  h2 = 3277.9; //kJ/kg
16  C2 = (2*1000*(h1-h2))^0.5
17  disp("Using the continuity equation, the exit area
       is")
18  m = 2.8;
19  v2 = 0.06152;
20  A2 = m*v2/C2
```

Scilab code Exa 6.4 Ratio of cross sectional area

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 6, Example 4")
8  disp("Critical pressure for maximum mass flow is
       given by Fig. Ex64")
9  disp("Pc is critical pressure in MPa")
10  P1 = 0.8; //MPa
11  n = 1.135; //index
12  Pc = P1*(2/(n+1))^(n/(n-1))
13  P2 = Pc;
14  disp("From the Mollier chart:")
15  disp("h1 = 2769 kJ/kg")
16  disp("h2 = 2659 kJ/kg")
```

```
17  disp("h3 = 2452 kJ/kg")
18  h1 = 2769;
19  h2 = 2659;
20  h3 = 2452;
21  disp("Enthalpy drop from 0.8 MPa to 0.15 MPa:")
22  Deltah13 = h1-h3
23  disp("Enthalpy drop from 0.8 MPa to 0.462 MPa:")
24  Deltah12 = h1-h2
25  disp("Dryness fraction:")
26  x2 = 0.954
27  x3 = 0.902
28  disp("The velocity at the exit in m/s")
29  C3 = (2*1000*Deltah13)^0.5
30  disp("The velocity at the throat in m/s")
31  C2 = (2*1000*Deltah12)^0.5
32  disp("Mass discharged at the throat")
33  disp("m2 = A2C2/x2vg2")
34  disp("Mass discharged at the exit")
35  disp("m3 = A3C3/x3vg3")
36  disp("A3C3/x3vg3 = A2C2/x2vg2")
37  disp("A3/A2 = (C2/C3) * (x3vg3/x2vg2)")
38  disp("Area Ratio A3/A2 = Ar")
39  vg3 = 1.1593;
40  vg2 = 0.4038;
41  Ar = C2*x3*vg3/(C3*x2*vg2)
```

Scilab code Exa 6.5 Convergent Divergent Nozzle

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
```

```
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 6, Example 5")
8  disp("At the state point 2, the dryness fraction is
       0.85 and the pressure is 0.1 MPa.")
9  disp("This problem can be solved easily by the
       Mollier chart or by calculations.")
10 disp("Enthalpy and entropy may be determined using
       the following equations:")
11 disp("h2 = hf2 + x2hfg2 and s2 = sf2 + x2sfg2;")
12 hf2 = 417.46
13 x2 = 0.85
14 hfg2 = 2258
15 h1 = hf2+x2*hfg2
16 sf2 = 1.3026
17 sfg2 = 6.0568
18 s2 = sf2+x2*sfg2
19 disp("Since s1 = s2, the state 1 is fixed by s1 =
       6.451 kJ/kg K, and point 1 is at the dry
       saturated line.")
20 disp("Therefore pressure P1 may be determined by the
        Mollier chart or by calculations: i.e.: P1 =
       1.474 MPa.")
21 disp("Elthalpies are in kJ/kg, entropy in kJ/kgK and
        Pressure in MPa")
```

Scilab code Exa 6.6 Steam leaving nozzle at 925

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
```

```
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 6, Example 6")
8  disp("From the data given, the velocity diagram can
       be constructed as shown in Fig. Ex66. The problem
        can be solved either graphically or by
       calculation.")
9  disp("Applying the cosine rule to the triangle ABC,
       V1 and V2 in m/s implies")
10 U = 250;
11 C1 = 925;
12 alpha1 = 20;
13 V1 = (U^2 + C1^2 -2*U*C1*cos(alpha1*%pi/180))^0.5
14 k = 0.7;
15 V2 = k*V1
16 disp("Velocity of whirl at inlet:")
17 Cw1 = C1*cos(alpha1*%pi/180)
18 disp("Axial component at inlet:")
19 Ca1 = C1*sin(alpha1*%pi/180)
20 disp("Blade angle at inlet")
21 beta1 = atan(Ca1/(Cw1-U))*180/%pi
22 disp("beta2 = beta1 = outlet blade angle")
23 beta2 = beta1
24 Cw2 = cos(beta2*%pi/180)*V2 - U
25 disp("Ca2 = FE")
26 Ca2 = (U+Cw2)*tan(beta2*%pi/180)
27 disp("Velocity of whirl at inlet, Cw1 = 869.22 m/s;"
       )
28 disp("Velocity of whirl at outlet, Cw2 = 183.69 m/s"
       )
29 disp("Tangential force on blades in N")
30 m = 0.182;//kg/s
31 Ft = (Cw1+Cw2)*m
32 disp("Axial force on blades in N")
33 Fa = m*(Ca1-Ca2)
34 disp("Work done on blades in kW")
35 disp("= tangential force on blades * blade velocity"
       )
```

```
36  W = Ft*250/1000
37  disp("Efficiency of blading = Work done on blades/
        Kinetic energy supplied")
38  etab = W/(m*C1^2) * 1000 *2 * 100
39  disp("Inlet angle of blades beta1 = 27.068 = beta2."
        )
```

Scilab code Exa 6.7 Steam leaving nozzle at 590

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 6, Example 7")
8  disp("Blade speed U is given by: in m/s")
9  D = 1050;
10  N = 2800;
11  U1 = %pi*D*N/(60*1000)
12  disp("The velocity diagram is shown in Fig. Ex67.
        Applying the cosine rule to the triangle ABC,")
13  C1 = 590;
14  alpha1 = 20;
15  V1 =(U1^2+C1^2-2*U1*C1*cos(alpha1*%pi/180))^0.5
16  disp("Applying the sine rule to the triangle ABC,
        C1sin (ACB) = V1/sin (alpha1)")
17  disp("but sin(ACB) = sin(180-beta1) = sin(beta1)")
18  beta1 = asin(C1*sin(alpha1*%pi/180)/V1)*180/%pi
19  beta2 = beta1;
20  disp("From Triangle ABD")
21  Cw1 = C1*cos(alpha1*%pi/180)
```

```
22  disp ("From triangle CEF")
23  disp ("Ca2/(U + Cw2) = tan(beta2) = tan(beta1) = tan
        (26.75) = 0.504")
24  Ca2 =155;
25  Cw2 = Ca2/tan(beta1*%pi/180) -U1
26  DeltaCw = Cw1+Cw2
27  disp ("Relative velocity at the rotor outlet is :")
28  V2 = Ca2/sin(beta2*%pi/180)
29  disp ("Blade velocity coefficient is :")
30  k = V2/V1
31  disp ("Work done on the blades per kg/s: in kW")
32  W = DeltaCw *U1/1000
33  disp ("Diagram efficiency")
34  etad = 2*W/(C1^2) *100000
```

Scilab code Exa 6.8 1 stage impulse turbine

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp ("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 6, Example 8")
8  disp ("From triangle ABC Figure Ex68")
9  C1 = 460;
10 a = 22;//degrees
11 Cw1 = C1 *cos(a*%pi/180)
12 Ca1 = C1*sin(a*%pi/180)
13 disp ("Now from triangle BCD")
14 BD = Ca1/tan(33*%pi/180)
15 disp ("Hence, blade speed is given by: in m/s")
```

```
16  U = Cw1-BD
17  disp("From Triangle BCD, relative velocity at blade
        inlet is given by: in m/s")
18  V1 = Ca1/sin(33*%pi/180)
19  disp("Velocity coefiicient")
20  k = 0.75
21  V2 = V1*k
22  disp("From triangle BEF")
23  BF = V2*cos(33*%pi/180)
24  Cw2 = BF-U
25  AF = Cw2;
26  Ca2 = V2*sin(33*%pi/180)
27  disp("The change in velocity of whirl:")
28  DeltaCw = Cw1+Cw2
29  disp("Diagram efficiency")
30  etad = 2*DeltaCw*U/C1^2 * 100
31  disp("End thrust on the shaft per unit mass flow: in
        N")
32  F = Ca1-Ca2
```

Scilab code Exa 6.9 Parson Turbine

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 6, Example 9")
8  disp("The blade speed, in m/s")
9  D = 1.3;
10 N = 3000;
```

```
11  U = %pi*D*N/60
12  disp(" Velocity  of  flow , in  m/s")
13  Ca = 0.5*U
14  C2 = 102;
15  disp("Draw  lines  AB  and  CD  parallel  to  each  other
         Fig .  Ex69  at  the  distance  of  102  m/s ,  i . e . ,
         velocity  of  flow ,  Ca1 =  102  m/s .")
16  disp("At  any  point  B,  construct  an  angle  alpha2 = 20
          degrees  to  intersect  line  CD  at  point  C.  Thus ,
         the  velocity  triangle  at  the  outlet  is  completed .
          For  Parson  s  turbine ,")
17  disp(" alpha1 =  beta2  ,  beta1 =  alpha2  ,  C1 =  V2  and
         V1 =  C2")
18  disp("By  measurement")
19  Cw1 = 280.26;
20  Cw2 = 76.23;
21  DeltaCw = Cw1+Cw2
22  disp("The  inlet  angles  are  53.22  degrees . Specific
         volume  of  vapor  at  0.5  MPa,  from  the  steam  tables
         ,  is  in  m3/kg")
23  vg = 0.3749
24  disp(" Therefore  the  mass  flow  is  given  by :")
25  x2 = 1;
26  A= %pi *1.3*6;
27  m = A*C2/(x2*vg)/100
28  disp("Power  developed  in  kW")
29  P = m*C2*DeltaCw/1000
```

Scilab code Exa 6.10 Steam leaving nozzle at 950

```
1  // Display  mode
2  mode (0);
3  // Display  warning  for  floating  point  exception
```

```scilab
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 6, Example 10")
 8  disp("With the help of alpha1, U and C1, the
        velocity triangle at the blade inlet can be
        constructed easily as shown in Fig. Ex610")
 9  disp("Applying the cosine rule to the triangle ABC,"
        )
10  C1 = 950;
11  U = 380;
12  alpha1 = 20;
13  V1 = (U^2+C1^2-2*U*C1*cos(alpha1*%pi/180))^0.5
14  disp("Now, applying the sine rule to the triangle
        ABC,")
15  disp("V1/sin(alpha1) = C1/sin(180-beta1) = C1/sin(
        beta1)")
16  beta1 = asin(C1*sin(alpha1*%pi/180)/V1)*180/%pi
17  disp("From triangle ACD")
18  Cw1 = C1*cos(alpha1*%pi/180)
19  disp("As beta1 = beta2, using triangle BEF and
        neglecting friction loss, i.e. V1 = V2")
20  beta2 = beta1;
21  V2 = V1;
22  BF = V2 *cos(beta2*%pi/180)
23  Cw2 = BF-U
24  disp("Change in velocity of whirl:")
25  DeltaCw = Cw1+Cw2
26  disp("Tangential force on blades: in N")
27  m = 12;
28  F = m*DeltaCw/60
29  disp("Horse Power")
30  P = m*U*DeltaCw/(60*1000*0.746)
```

Scilab code Exa 6.11 Steam leaving nozzle at 700

```scilab
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 6, Example 11")
8  disp("Velocity triangles for this problem are shown
       in Fig.Ex611")
9  disp("From the triangle ACD,")
10 C1 = 700;
11 alpha1 = 22;
12 Ca1 = C1*sin(alpha1*%pi/180)//in m/s
13 beta1 = 34;
14 V1 = Ca1/sin(beta1*%pi/180)//in m/s
15 disp("Whirl component of C1 is given by in m/s")
16 Cw1 = C1*cos(alpha1*%pi/180)
17 disp("BD = Cw1 - U = V1cosbeta1")
18 BD = V1*cos(beta1*%pi/180)
19 disp("Hence, blade speed in m/s")
20 U = Cw1-BD
21 disp("Using the velocity coefficient to find V2:")
22 k = .9;
23 V2 = k*V1
24 disp("From velocity triangle BEF,")
25 beta2 = beta1;
26 Ca2 = V2*sin(beta2*%pi/180)
27 Cw2 = V2*cos(beta2*%pi/180) - U
28 DeltaCw = Cw1+Cw2
```

```
29  disp("mass flow rate is given by m. in kg/s")
30  P = 1600;
31  m = P*1000/(DeltaCw*U)
32  disp("Thrust on the shaft in N")
33  Ft = m*(Ca1-Ca2)
34  disp("Diagram efficiency")
35  etad = 2*U*DeltaCw/C1^2 * 100
```

Scilab code Exa 6.12 Axial velocity constant

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 6, Example 12")
8  disp("For 50% reaction turbine Fig. Ex612, alpha1 =
       beta2, and alpha2 = beta1. From the velocity
       triangle ACD, angles in degrees")
9  disp("All velocities in m/s")
10 C1 = 105;//m/s
11 alpha1 = 20;
12 Cw1 = C1*cos(alpha1*%pi/180)
13 disp("Applying cosine rule to the Triangle ABC:")
14 U = 40;//m/s
15 V1 = (C1^2+U^2-C1*2*U*cos(alpha1*%pi/180))^0.5
16 BD = Cw1-U//ms/
17 beta1 = acos(BD/V1)*180/%pi//degrees
18 disp("Change in the velocity of whirl is:")
19 Cw2 = BD;
20 DeltaCw = Cw1+Cw2
```

```
21  disp("Horse Power generated")
22  m = 2;
23  P = m*U*DeltaCw/(0.746*1000)
```

Scilab code Exa 6.13 Blade height and power developed

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory ,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 6, Example 13")
8  disp("Figure Ex613 shows the velocity triangles.")
9  alpha1 = 18;
10  beta2 = alpha1;
11  alpha2 = 25;
12  beta1 = alpha2;
13  disp("From the velocity triangle , velocities in m/s"
        )
14  C1 = 90;//m/s
15  Cw1 = C1*cos(alpha1*%pi/180)//m/s
16  Ca1 = C1*sin(alpha1*%pi/180)
17  CD = Ca1;
18  disp("From triangle BDC")
19  BD = Ca1/sin(beta1*%pi/180)
20  disp("Hence blade velocity is given by:")
21  U = Cw1-BD
22  disp("Applying the cosine rule ,")
23  V1 = (C1^2+U^2-2*U*C1*cos(alpha1*%pi/180))^0.5
24  disp("From triangle AEF")
25  C2 = V1;
```

```
26  Cw2 = C2*cos(alpha2*%pi/180)
27  disp("Change in the velocity of whirl: m/s")
28  DeltaCw = Cw1+Cw2
29  disp("Power developed by the rotor: in kW")
30  m = 10;
31  P = m*U*DeltaCw/1000
32  disp("From superheated steam tables at 5 bar, 250
        degree Celcius, the specific volume of steam is:
        in m3/kg")
33  v = 0.4744
34  disp("Blade height is given by the volume of flow
        equation: in m")
35  disp("v = pi*D*h*Ca")
36  disp("where Ca is the velocity of flow and h is the
        blade height.Therefore,")
37  D=0.72;
38  Ca = Ca1;
39  h = v/(%pi*Ca*D)
```

Scilab code Exa 6.14 RPM 440

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 6, Example 14")
8  disp("Figure Ex613 shows the velocity triangles.")
9  disp("From the velocity diagram,")
10 disp("V2 = 1.2U")
11 disp("Ca2 = V2 cos(beta2)")
```

```
12  disp (" = 1.2 Ucos70")
13  disp (" = 0.41U m/s")
14  disp ("At mean diameter ,")
15  disp ("U = piDN/60 = 2piN(Dh + h)/(60∗2)")
16  disp ("where Dh is the rotor diameter at the hub and
        h is the blade height .")
17  disp ("Substituting the value of U in the above
        equation ,")
18  N = 440; //rpm
19  disp ("Ca2 = 0.41∗2∗%pi∗N∗(14.5h+h)/(2∗60) = 146.45h
        m/s")
20  disp ("Annular area of flow is given by:")
21  disp ("A = pih(Dh + h) = pih(14.5h + h)")
22  disp ("A = 15.5 pih^2")
23  disp ("Specific volume of saturated steam at 0.90 bar
        , vg = 1.869m3/kg.")
24  disp ("Then the specific volume of steam v = (1.869)
        ∗ (0.95) = 1.776m3/kg.")
25  v = 1.776;
26  disp ("The mass flow rate is given by:kg/s")
27  mrate = 6.8; //kg/kW h
28  P = 5.5; //MW
29  m = P∗1000∗mrate/3600 //kg/s
30  h = (m∗v/(146.45∗15.5∗%pi))^(1/3)
```

Scilab code Exa 6.15 Two row velocity compounded impulse turbine

```
1  // Display mode
2  mode (0) ;
3  // Display warning for floating point exception
4  ieee (1) ;
```

```
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 6, Example 15")
 8  disp("Figure Ex615 shows velocity triangles")
 9  disp("Graphical solutions")
10  U = 115;//m/s
11  C1 = 590;//m/s
12  alpha1 = 18;//degrees;
13  beta2 = 20;//degrees
14  disp("The velocity diagrams are drawn to scale, as
        shown in Fig. Ex615a, and the relative velocity:"
        )
15  V1 = 482//m/s
16  k = 0.9;
17  V2 = k*V1
18  disp("The absolute velocity at the inlet to the
        second row of moving blades, C3, is equal to the
        velocity of steam leaving the fixed row of blades
        .")
19  C2 = 316.4;
20  C3 = k*C2
21  disp("Driving Force in N")
22  m = 1;
23  DeltaCw1 = 854;
24  DeltaCw2 = 281.46;
25  disp("For the first row of moving blades,in N")
26  F1 = m*DeltaCw1
27  disp("For the second row of moving blades, in N")
28  F2 = m*DeltaCw2
29  disp("where DeltaCw1 and DeltaCw2 are scaled from
        the velocity diagram.")
30  disp("Total driving force")
31  F = F1+F2
32  disp("Power = driving force *blade velocity in kW
        per kg/s")
33  s = 115;
34  P = F*s/1000
```

```
35  disp("Energy supplied to the wheel")
36  E = m*C1^2 /(2*1000)
37  disp("Therefore, the diagram efficiency is:")
38  etad = P*1000*2/C1^2 *100
39  disp("Maximum diagram efficiency:")
40  etadm = (cos(alpha1*%pi/180))^2 *100
41  Ca1 = 182.32;
42  Ca2 = 148.4;
43  Ca3 = 111.3;
44  Ca4 = 97.57;
45  disp("Axial thrust on the first row of moving blades
        (per kg/s): in N")
46  F1 = m*(Ca1-Ca2)
47  disp("Axial thrust on the second row of moving
       blades (per kg/s): in N")
48  F2 = m*(Ca3-Ca4)
49  disp("Total axial thrust:in N")
50  F = F1+F2
```

Scilab code Exa 6.16 Reaction stage turbine

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 6, Example 16")
8  disp("Figure Ex616 shows velocity triangles")
9  disp("The velocity triangles can easily be
       constructed as the blade velocity and blade
       angles are given.From velocity triangles , work
```

```
      output per kg is given by:")
10 U = 300; //m/s
11 alpha1 = 25;
12 beta1 = 60;
13 alpha2 = 71.1;
14 beta2 = 32;
15 disp("Wt = U*(Cw1+Cw2)")
16 Wt = U*(450*cos(alpha1*%pi/180)+247*cos(alpha2*%pi
      /180))
17 disp("Power output i kW")
18 m = 5;
19 P = m*Wt/1000
20 disp("Degree of reaction is given by: DOR")
21 V1 = 220; //m/s
22 V2 = 443; //m/s
23 DOR = (V2^2 -V1^2)/ (2*Wt) * 100
24 disp("Axial thrust: in N")
25 Ca1 = 190.5; //m/s
26 Ca2 = 234; //m/s
27 F = m*(Ca1-Ca2)
28 disp("The thrust is negative because its direction
      is the opposite to the fluid flow.")
```

Scilab code Exa 6.17 Series of stages

```
1 // Display mode
2 mode(0);
3 // Display warning for floating point exception
4 ieee(1);
5 clear;
6 clc;
7 disp("Turbomachinery Design and Theory,Rama S. R.
      Gorla and Aijaz A. Khan, Chapter 6, Example 17")
```

```scilab
8  disp("Using the given data, the velocity triangles
      for the inlet and outlet are shown in Fig Ex617")
9  C2 = 225; //m/s
10 V2 = 375; //m/s
11 C1 = 400; //m/s
12 V1 = 200; //m/s
13 disp("Work done per unit mass flow: in J/kg")
14 U = 250;
15 Wt = U*(C1*cos(25*%pi/180)+C2*cos(70.2*%pi/180))
16 disp("Degree of reaction DOR")
17 DOR = (V2^2 - V1^2)/(2*Wt) *100
18 disp("Power output: in kW")
19 m = 5.2;
20 P = m*Wt/1000
21 disp("Isentropic static enthalpy drop in the stator:
      in kJ/kg")
22 etas = 0.93;
23 Deltahs = (C1^2 - 0.89*C2^2)/etas /1000
24 disp("Isentropic static enthalpy drops in the rotor:
      in kJ/kg")
25 etaf = 0.94;
26 Deltahr = Wt/(etas*etaf) /1000
27 disp("Since the state of the steam at the stage
      entry is given as 10 bar, 300 degree Celsicus,")
28 disp("Enthalpy at nozzle exit: in kJ/kg")
29 Hn = 3051.5 - Deltahs
30 disp("Enthalpy at rotor exit: in kJ/kg")
31 Hr = 3051.5 - Deltahr
32 disp("The rotor inlet and outlet conditions can be
      found by using the Mollier Chart.")
33 disp("Rotor inlet conditions: P1 = 7 bar, T1 = 235
      Degree Celsius")
34 disp("Rotor outlet conditions: P2 = 5 bar, T2 = 2208
      Degree Celsius")
```

Chapter 7

Axial Flow and Radial Flow Gas Turbines

Scilab code Exa 7.1 Impulse gas turbine

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 7, Example 1")
8  disp("From isentropic p T relation for expansion
       process")
9  disp("T02a/T01 = (P02/P01)^((gam-1)/gam)")
10 P02 = 1.03;
11 P01 = 5.2;
12 T01 = 1000;
13 gam = 1.33;
14 T02a = T01*(P02/P01)^((gam-1)/gam)
15 disp("Using isentropic efficiency of turbine")
```

```
16  etat = 0.88;
17  T02 = T01 - etat*(T01-T02a)//K
18  disp("Using steady-flow energy equation")
19  disp("1/2 * (C2^2 - C1^2) = Cp(T01 - T02)")
20  Cpg = 1147;
21  C1 = 140;
22  C2 = (2*Cpg*(T01-T02) + C1^2)^0.5//m/s
23  disp("From velocity triangle, velocity of whirl at
        rotor inlet in m/s")
24  Cw2 = C2*sin(57*%pi/180)
25  disp("Turbine work output is given by in kW")
26  m = 28;
27  Wt = m*Cpg*(T01-T02)/1000
```

Scilab code Exa 7.2 Nozzle efflux angle 68

```
 1  // Display mode
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 7, Example 2")
 8  disp("The specific work output in kJ/kg")
 9  etats = 0.85;
10  Cpg = 1.147;
11  T01 = 800 + 273;
12  gam = 1.33;
13  W = etats*Cpg*T01*(1-(1/4)^((gam-1)/gam))
14  disp("Since alpha1 = 0, alpha3 = 0, Cw1 = 0 and
        specific work output is given by")
15  U = 480;
16  Cw2 = W*1000/U//m/s
17  disp("From velocity triangle")
```

```
18  alpha2 = 68;
19  C2 = Cw2/sin(alpha2*%pi/180)//m/s
20  disp("Axial velocity is given by in m/s")
21  Ca2 = C2*cos(alpha2*%pi/180)//m/s
22  disp("Total−to−total efficiency, etatt, is")
23  disp("etatt = (T01−T03)/(T01−T03a)")
24  disp("        = W/(T01−(T3+C3^2 /(2Cpg)))")
25  disp("        = W/((W/etats) − (C3^2 /(2Cpg)))")
26  C3 = Ca2;//m/s
27  etatt = W/((W/etats) - (C3^2 / (2*Cpg*1000))) *100//
        in %
28  disp("The degree of reaction DOR")
29  disp("DOR = Ca*(tan(beta3) − tan(beta2))/(2U)")
30  DOR = (1- Ca2*tan(alpha2*%pi/180) / (2*U))*100//%
```

Scilab code Exa 7.3 Stagnation temperature of 1100K

```
 1  // Display mode
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 7, Example 3")
 8  disp("From Figure Ex73")
 9  Ca = 250 //m/s
10  Ca3 = Ca;//m/s
11  Ca2 = Ca3;//m/s
12  Ca1 = Ca2;//m/s
13  U = 350;//m/s
14  disp("From velocity triangle (b)")
15  alpha2 = 63;
```

```
16  C2 = Ca2/cos(alpha2*%pi/180)//m/s
17  disp("From Figure (c)")
18  alpha3 = 9;
19  C3 = Ca3/cos(alpha3*%pi/180)//m/s
20  Cw3 = Ca3*tan(alpha3*%pi/180)//m/s
21  beta3 = atan((U+Cw3)/Ca3)*180/%pi
22  disp("From Figure(b)")
23  Cw2 = Ca2*tan(alpha2*%pi/180)//m/s
24  beta2 = atan((Cw2-U)/Ca2)*180/%pi
25  disp("Power output in kW")
26  m = 15;
27  W = m*U*Ca*(tan(beta2*%pi/180) + tan(beta3*%pi/180))
       /1000
28  disp("The degree of reaction is given by")
29  DOR = Ca*(tan(beta3*%pi/180) - tan(beta2*%pi/180))
       /(2*U) *100
```

Scilab code Exa 7.4 Throat area for 73

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 7, Example 4")
8  disp("Nozzle Throat area in m2, A = m/(rho2*Ca2)")
9  disp("rho2 = P2/(RT2)")
10 disp("T2 = T02 − C2^2  /(2Cp)")
11 T02 = 1100;//Kelvin
12 C2 = 550.67;//m/s
13 Cp = 1.147;
14 T2 = T02 - C2^2 /(2*Cp*1000)
15 disp("From nozzle loss coefficient")
```

```
16  lambdaN = 0.05;
17  T2a = T2 - lambdaN *C2^2 /(2*Cp*1000)
18  disp("Using isentropic p T relation for nozzle
        expansion")
19  P01 = 5;//bars
20  gam = 1.33;
21  T01 = T02;
22  P2 = P01/((T01/T2a)^(gam/(gam-1)))
23  disp("Critical Pressure ratio = r = P01/Pc")
24  r = ((gam+1)/2)^(gam/(gam-1))
25  disp("P01/P2 = r1")
26  r1 = P01/P2
27  disp("Since r1<r, and therefore nozzle is unchoked."
        )
28  C2 = (2*Cp*1000*(T01-T2))^0.5//m/s
29  disp("Therefore, nozzle throat area in m2")
30  R = 0.287;
31  rho2 = P2*100/(R*T2)//kg/m3
32  m = 15;//ks
33  A = m/(rho2*C2)//m2
```

Scilab code Exa 7.5 Inlet stagnation temperature is 1000 K

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 7, Example 5")
8  disp("Velocities are in m/s, temperature in Kelvin,
        Angles in degrees.")
9  disp("Degree of reaction DOR = 0")
10 disp("DOR = (T2-T3)/(T1-T3)")
```

```
11  disp("Therefore T2 = T3")
12  disp("From isentropic p  T relation for expansion")
13  T01 = 1000;
14  disp("P01/P03 = r")
15  r = 1.8
16  T03a = T01/(r^0.249)
17  disp("Using turbine efficiency")
18  disp("T03 = T01-etat*(T01-T03a)")
19  etat = 0.85;
20  T03 = T01 - etat*(T01-T03a)
21  disp("In order to find static temperature at turbine
        outlet, using static and stagnation temperature
        relation")
22  C3 = 270;
23  Cpg = 1.147;
24  T3 = T03- C3^2 / (2*Cpg*1000)
25  T2 = T3;
26  disp("Dynamic Temperature in K is C^2 /2Cpg = Td")
27  Td = 1000-T2
28  C2 = (2*Cpg*1000*Td)^0.5//m/s
29  disp("Since Cpg*DeltaTos = U*(Cw3+Cw2) = U*Cw2 (Cw3
        =0)")
30  U = 290;
31  Cw2 = Cpg*1000*(1000-884)/U//m/s
32  disp("From velocity triangle")
33  alpha2 = asin(Cw2/C2)*180/%pi
34  Ca2 = C2;
35  beta2 = atan((Cw2-U)/(Ca2*cos(alpha2*%pi/180)))*180/
        %pi
```

Scilab code Exa 7.6 Inlet stagnation temperature is 1150 K

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
```

```
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
       Gorla and Aijaz A. Khan, Chapter 7, Example 6")
8  disp("Annulus area A is given by")
9  disp("A = 2 pi*rm*h")
10 disp("where h = blade height")
11 disp("rm = mean radius")
12 disp("As we have to find the blade height from the
       outlet conditions, in this case annulus area is
       A3.")
13 disp("h = A3/2 pi*rm")
14 disp("Um = pi*Dm*N")
15 Um = 300;//m/s
16 N = 240;//rps
17 Dm = Um/(%pi*N)
18 rm = Dm/2
19 disp("Temperature drop in the stage is given by Drop
       = T01-T03")
20 Drop = 145//Kelvins
21 T01 = 1150;
22 T03 = T01-Drop
23 C3 = 390;
24 Cpg = 1.147;
25 T3 = T03-C3^2 / (2*Cpg*1000)
26 disp("Using turbine efficiency to find isentropic
       temperature drop")
27 eta = 0.88;
28 T03a = T01-Drop/eta
29 disp("Using isentropic p T relation for expansion
       process")
30 P01 = 8;
31 P03 = P01/(T01/T03a)^(4)
32 disp("Also from isentropic relation")
33 P3 = P03/(T03a/T3)^4
34 disp("where P01,P3;P03 are in bars")
35 R = 0.287;
```

```
36  rho3 = P3/(R*T3) *100//kg/m3
37  m = 34;//kg/s
38  Ca3 = C3;
39  A3 = m/(rho3*Ca3)
40  h = A3/(2*%pi*rm)
41  disp("where h is in m")
```

Scilab code Exa 7.7 Rotation 14500rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 7, Example 7")
8  Cpg = 1147;
9  disp("Temperature Drop = T01 -T03")
10 Drop = 145;
11 U = 345;
12 psi = Cpg*(Drop)/U^2
13 disp("Using velocity diagram")
14 disp("U/Ca = tan(beta3) - tan(alpha3)")
15 disp("tan(beta3) = 1/phi + tan(alpha3)")
16 alpha3 = 12;
17 phi = 0.75;
18 beta3 = atan(1/phi + tan(alpha3*%pi/180))*180/%pi
19 disp("Psi = phi*(tan(beta2) +tan(beta3))")
20 disp("DOR = phi/2 *(tan(beta3) - tan(beta2))")
21 disp("tan(beta3) = (psi + 2*DOR)/(2*phi)")
22 DOR = (tan(beta3*%pi/180) *2*phi - psi)/2 *100
23 disp("tan(beta2) = (psi-2*DOR)/(2*phi)")
24 beta2 = atan((psi-2*DOR/100)/(2*phi))*180/%pi
25 alpha2 = atan(tan(beta2*%pi/180)+(1/phi))*180/%pi
```

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```
26  Ca1 = U*phi//m/s
27  C2 = Ca1/cos(alpha2*%pi/180)//m/s
28  disp("R2 = T02-T2 = C2^2 /2Cp")
29  R2 = C2^2 /(2*Cpg)
30  disp("R3 = T2-T2s = Tn*C2^2/(2 Cpg)")
31  Tn = 0.05;
32  R3 = Tn*C2^2 /(2*Cpg)
33  T2 = 1100-R2//K
34  T2s = T2 - R3//K
35  P01 = 4;//bars
36  T01 = 1100;
37  P2 = P01*(T2s/T01)^4
38  R = 0.287;
39  rho2 = P2*100/(R*T2)//kg/m3
40  disp("Nozzle Throat area in A in m2")
41  C1 = C2;//m/s
42  rho1 = 0.907;//kg/m3
43  m = 24;
44  A = m/(rho1*C1)
45  A1 = m/(rho1*Ca1)
```

Scilab code Exa 7.8 Equal stage inlet and outlet velocities

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 7, Example 8")
8  disp("From Velocity tiangles")
9  disp("C is velocity in m/s, angles are in degrees")
10 Ca = 255;//m/s
11 alpha2 = 60;
```

```
12  Cw2 = Ca * tan(alpha2*%pi/180)
13  alpha3 = 12;
14  Cw3 = Ca * tan(alpha3*%pi/180)
15  U = 345; //m/s
16  Vw2 = Cw2-U //m/s
17  beta2 = atan(Vw2/Ca)*180/%pi
18  Vw3 = Cw3+U //m/s
19  beta3 = atan(Vw3/Ca)*180/%pi
20  disp("Degree of Reaction DOR")
21  phi = Ca/U;
22  DOR = phi*(tan(beta3*%pi/180) - tan(beta2*%pi/180))
        /2 *100
23  psi = Ca*(tan(beta2*%pi/180) + tan(beta3*%pi/180))/U
24  m = 20;
25  disp("W in kW")
26  W = m*U*(Cw2+Cw3)
27  disp("lambdaN = 2Cp(T2-T2a)/C2^2")
28  lambdaN = Ca*sec(alpha2*%pi/180)
29  C2 = lambdaN;
30  disp("T2-T2a = R")
31  Cp = 1147;
32  Ra = 0.05*0.5*lambdaN^2 /Cp
33  T02 = 1150; //K
34  T01 = T02; //K
35  T2 = T02 - C2^2 /(2*Cp) //K
36  T2a = T02-C2^2 /(2*Cp) - Ra
37  P01 = 4 //bars
38  P2 = P01/(T01/T2)^4
39  R = 0.287;
40  disp("rho2 is density in kg/m3")
41  rho2 = P2/(R*T2) *100
42  disp("Area in m2")
43  m = 20;
44  A2 = m/(rho2*C2)
```

Scilab code Exa 7.9 Turbine inlet temperature 900C

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 7, Example 9")
8  disp("At 50%.   alpha2 = beta3; alpha3 = beta2")
9  U = 340;
10 disp("C2 in m/s")
11 C2 = U/cos(15*%pi/180)
12 disp("Heat drop in blade moving row in Hdrop K")
13 C3 = 105; //m/s
14 Cp = 1147;
15 Hdrop = (C2^2 - C3^2)/(2*Cp)
16 disp("Therefore heat drop in a stage")
17 Hdropstage = Hdrop *2
18 disp("Number of stages n = ")
19 n = (1173-943)/Hdropstage
20 disp("Therefore No. of stages = 2")
```

Scilab code Exa 7.10 Gas leaving stage in axial direction

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 7, Example 10")
8  disp("For no loss up to throat Ps in bars")
```

```
9  P01 = 4;//bar
10  gam = 1.33;
11  Ps = P01*(2/(gam+1))^(gam/(gam-1))
12  T01 = 1100;//K
13  Ts = 944;//K
14  Cpg = 1147;
15  U = 300;//m/s
16  C = (2*Cpg*(T01-Ts))^0.5//m/s
17  R = 0.287;
18  rhos = Ps*100/(R*Ts)//kg/m3
19  disp("Throat area in m2")
20  m=20;//kg/s
21  A = m/(rhos*C)
22  disp("Angle alpha1 , at any radius r and alpha1m at
        the design radius rm are related by the equation"
        )
23  disp("tan(alpha1) = rm*tan(alpha1m)/r")
24  disp("Given")
25  disp("Tip radius/Root radius = rt/rr = 1.4")
26  disp("Therefore mean radius/root radius = 1.2")
27  alpha1m = 25
28  alpha1r = atan(1.2*tan(alpha1m*%pi/180))*180/%pi
29  alpha1t = atan(tan(alpha1r*%pi/180)/1.4)*180/%pi
30  disp("Velocity in m/s")
31  disp("Cw2 = rm*x*Cw2m/rr = rm*Ca2/(rr*tan(alpha2m))"
        )
32  Cw2 = 1.2*250/tan(alpha1m*%pi/180)
33  disp("Power developed in kW")
34  W = m*U*Cw2/1000
```

Scilab code Exa 7.11 Inward radial flow gas turbine

```
1  // Display mode
```

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```scilab
 2  mode(0);
 3  // Display warning for floating point exception
 4  ieee(1);
 5  clear;
 6  clc;
 7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 7, Example 11")
 8  disp("The overall efficiency of turbine from nozzle
        inlet to diffuser outlet is given by")
 9  disp("etatt = (T01 - T03)/(T01 - T03ss)")
10  disp("Turbine work per unit mass flow")
11  disp("W = U2^2 = Cp(T01 - T03); (Cw3 = 0)")
12  disp("Now using isentropic p  T  relation")
13  disp("T01 (1 - T03ss/T01) = T01(1 - (P03/P01)((gamma
        -1)/gamma)")
14  disp("Therefore")
15  disp("U2^2 = etatt*Cp*T01(1 - (P03/P01)^((gamma-1)/
        gamma)")
16  etatt = 0.9;
17  Cp = 1147;
18  T01 = 1145;
19  P03 = 100;
20  P01 = 310;
21  U2 = (etatt*Cp*T01*(1 - (P03/P01)^0.2498))^0.5
22  disp("Impeller tip speed, U2 = 539.45 m/s")
23  disp("The Mach number of the absolute flow velocity
        at nozzle exit is given by")
24  disp("M = C1/a1 = U1/alpha1*sin(alpha1)")
25  disp("Since the flow is adiabatic across the nozzle,
         we have")
26  disp("T01 = T02 = T2 + C2^2/2Cp = T2 + U2^2/2Cp(sin(
        alpha2))^2")
27  disp("or T2/T01 = 1 - U2^2/2CpT01(sin(alpha2))^2;
        but Cp = gamma*R/(gamma - 1)")
28  disp("Therefore; T2/T01 = 1 - U2^2*(gamma - 1)/(2
        gammaRT01(sin(alpha2))^2")
29  disp("   =  1- U2^2*(gammaa-1)/(2*a01^2 * (sin(alpha2
        ))^2)")
```

```
30  disp("But (T2/T01)^2 = a2/a01 = a2/a02; since T01 =
        T02")
31  disp("and a2/a02 = U2/M2*a02*sin(alpha2)")
32  disp(" Therefore (U2/M2*a02*sin(alpha2))^2 = 1 - U2
        ^2*(gammaa-1)/(2*a01^2 * (sin(alpha2))^2)")
33  disp("and 1 = (U2/a02*sin(alpha2))^2 *((gamma - 1)/2
        + 1/M2^2)")
34  disp("or (sin(alpha2))^2 = (U2/a02)^2 * ((gamma - 1)
        /2 + 1/M2^2)")
35  disp("Therefore nozzle angle alpha2 = 75 degrees")
```

Scilab code Exa 7.12 Rotation 30500rpm

```
1  // Display mode
2  mode(0);
3  // Display warning for floating point exception
4  ieee(1);
5  clear;
6  clc;
7  disp("Turbomachinery Design and Theory,Rama S. R.
        Gorla and Aijaz A. Khan, Chapter 7, Example 12")
8  disp("Dimensionless specific speed is")
9  disp("Ns = 0.336*(C3/C0)^0.5*(A3/Ad)^0.5    in rev")
10 disp("A3 and Ad are in m2")
11 D3t = 0.064;//m
12 D3h = 0.026;//m
13 A3 = %pi*(D3t^2 - D3h^2)/4
14 D2 = 0.092;//m
15 Ad = %pi*D2^2/4
16 disp("Dimensionless specific speed Ns in rev and Nsa
         in rad")
17 Ns = 0.336*(0.447*A3/Ad)^0.5//rev
18 Nsa = 0.904
19 disp("The flow rate at outlet for the ideal turbine
        is given by Q3 in m3/s")
```

```scilab
20  disp("Ns = 0.18*(Q3/(N*D2^3))^0.5")
21  N = 30500;
22  Q = (Ns/0.18)^2*N*D2^3/60
23  disp("The power developed by the turbine is given by
        in kW")
24  disp("W = m*U3^2")
25  disp("  = rho3*Q3*U3^2")
26  rho3 = 1.75; //kg/m3
27  Wt = rho3*Q*(%pi*N*D2/60)^2 /1000
```

Chapter 8

Cavitation in Hydraulic Machinery

Scilab code Exa 8.0 Theory

```
1  // Display  mode
2  mode (0) ;
3  // Display  warning  for  floating  point  exception
4  ieee (1) ;
5  clear ;
6  clc ;
7  disp (" Turbomachinery  Design  and  Theory ,Rama S. R.
       Gorla  and  Aijaz  A. Khan ,  Chapter  8")
8  disp (" Cavitation  in  Hydraulic  Machinery ")
9  disp (" Just  Theory  No  Solved / Unsolved  Examples ")
```