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

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Book Description

Title: Turbomachinery Design and Theory

Author: R. S. R. Gorla And A. A. Khan

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 1

Introduction Dimensional Analysis Basic Thermodynamics and Fluid Mechanics

Scilab code Exa 1.1 `Radial Flow Hydraulic`

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

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

Scilab code Exa 1.2 `Centrifugal Pump Head`

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

Scilab code Exa 1.3 `Air Compressor Speed`

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

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

Scilab code Exa 1.4 Pumping Power

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

Scilab code Exa 1.5 Drag Force F

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

```
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 1, Example 5")
disp ("Theoritical Question")
//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
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`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 1, Example 6")
// Geometric and Dynamic similarity equations Q1 / (N1 * D1^2) = Q2 / (N2 * D2^2)
// Head coefficient W2 = W1 * N2^2 * D2^2 / (N1^2 * D1 ^2)
// Also Pressure Delta P = W2 * eta tt * rho
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 : ")
Q2 = 2.5 * 2900 * 0.22^2 / (1450 * 0.32^2)
W2 = 120 * 2900 ^ 2 * 0.22 ^ 2 / ((1450)^2 * 0.32^2)
Pressure = 226.88 * 0.78 * 1000 /100000
```

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

Scilab code Exa 1.7 Axial Gas Turbine

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

Scilab code Exa 1.8 Wind Tunnel

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

Scilab code Exa 1.9 Kinetic Energy

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

Scilab code Exa 1.10 `Radial Inward Flow`

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

Chapter 2

Hyraulic Pumps

Scilab code Exa 2.1 Centrifugal Pump Torque

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

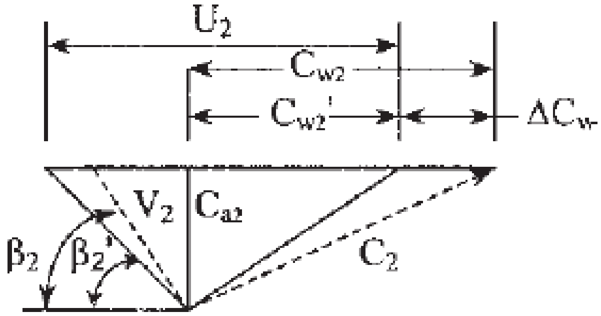

Figure 2.2 Velocity triangle at impeller outlet with slip.

Figure 2.1: Centrifugal Pump Torque

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

Scilab code Exa 2.2 Head Imparted

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 2, Example 2")
//Fluid is entering in radial direction
Cw1 = 0;
alpha1 = 90; //angle is in degrees
beta2 = 22; //angle in degress
Ca1 = 3.5; //velocity of flow in m/s
D= 0.22;
N=1250;
//Ca1 = Ca2
```

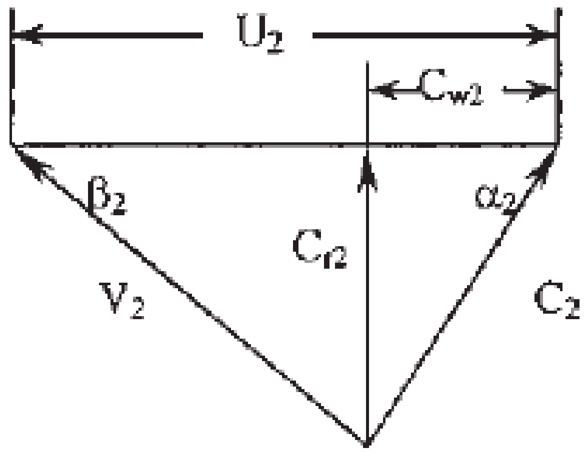

Figure 2.19 Velocity triangle at outlet.

Figure 2.2: Centrifugal Pump Impeller

```
Ca2 = 3.5;
//Head developed H = Cw2*U2/g
//Impeller tip Speed U2 = pi*D*N/60
disp ("Impeller tip speed in m/s is : ")
U2 = %pi * D * N / 60
disp("Whirl velocity at impeller outlet, in m/s is : ")
Cw2 = (U2 - Ca2/tan(22*%pi/180))
disp("Head Imparted is H in meters : ")
H = Cw2 * U2 / 9.81
```

Scilab code Exa 2.3 `Centrifugal Pump Impeller`

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

Scilab code Exa 2.4 Efficiency Lift Discharge

```
// Display mode
```

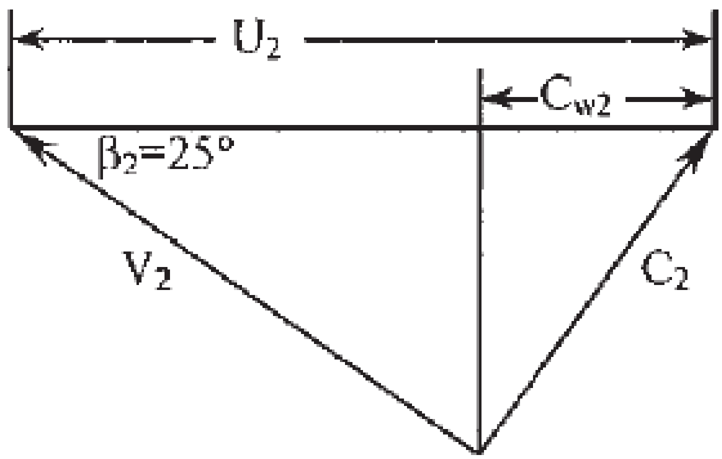

Figure 2.20 Velocity triangle at impeller outlet.

Figure 2.3: Efficiency Lift Discharge

```
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 2, Example 4")
//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
Q = 1550;
beta2 = 25;
H = 6.2;
Diaratio = 2;
D2 = 1.2;
N = 210;
A = 0.65;
disp("Velocity of flow at impeller tip in m/s is :")
Cr2 = Q/(A*1000)
disp("Impeller tip speed in m/s is :")
U2 = %pi * D2 * N / 60
Cw2 = U2 - Cr2 / tan(%pi*25/180)
disp("TheoH is theoritical head in m")
TheoH = Cw2 * U2/9.81
 //Assuming slip factor sigma = 1, efficiency is
 disp("efficiency is ")
 etah = H * 100 / TheoH
 //Power is denoted by P
 disp("Power in kilowatts is : ")
 P = Q * TheoH * 9.81 / 1000
 disp("Centrifugal head is minimum head. Thus we get : ")
 //U2^2-U1^2/2g = 6.2
 //U1 = U2/2
 U2 = (2 * 9.81 * 6.2 /(1-0.25))^(1/2)
 disp("minimum speed in rpm is :")
 minN = U2 * 60 / (%pi * D2)
```

Scilab code Exa 2.5 Horse Power Pump

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

Scilab code Exa 2.6 Impeller Vanes Angled

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

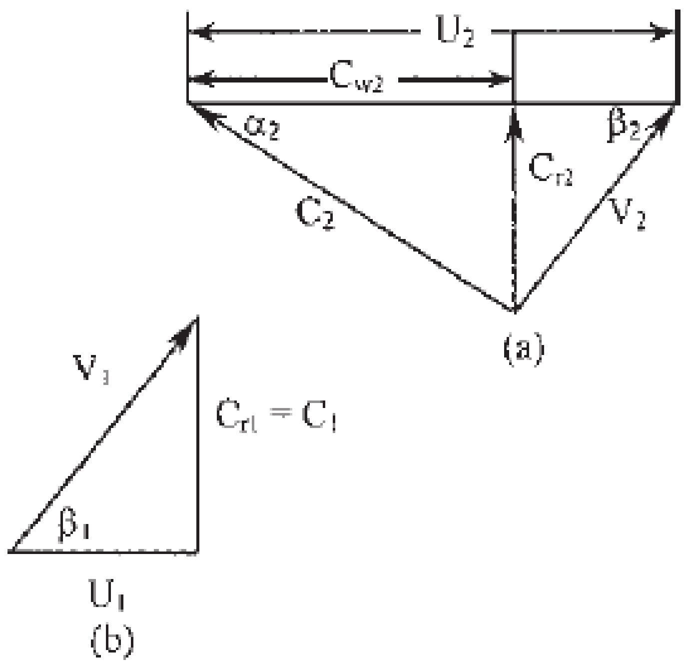

Figure 2.22 Velocity triangle (a) outlet, (b) inlet.

Figure 2.4: Impeller Vanes Angled

```
// Velocity of flow through impeller is constant so Cr1 = Cr2 = 3.5 m/s
disp("Tangential Velocity of impeller at inlet in m/s is :")
//Din and D2 are diameters in meters, N is in rpm, Cr2 in m/s
Din = 0.3;
D2 = 0.6;
N = 950;
Cr2 = 3.5;
U1 = %pi * Din * N / 60
//tanalpha1 = Cr1/U1 3.5/14.93 = 0.234
disp("vane inlet angle of pump alpha1 : ")
alpha1 = atan(0.234) * 180/ %pi
disp("Tangential velocity of impeller at outlet in m/s:")
U2 = %pi * D2 * N / 60
disp("Now For velocity of whirl at impeller outlet, using velocity triangle.in m/s is :")
Cw2 = U2 - Cr2 / tan(46*%pi/180)
//As c2^2 = Cw2^2 + Cw2^2 , Therefore
disp(" Velocity of water at outlet C2 in m/s is :")
C2 = (Cr2^2 + Cw2^2)^(1/2)
disp("alpha2 be the direction of water outlet, Thus we have :")
alpha2 = atan(Cr2/Cw2)*(180/%pi)
disp("Work Done in Newton meters is given by :")
W = Cw2*U2
```

Scilab code Exa 2.7 Vanes At 45 Degrees

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

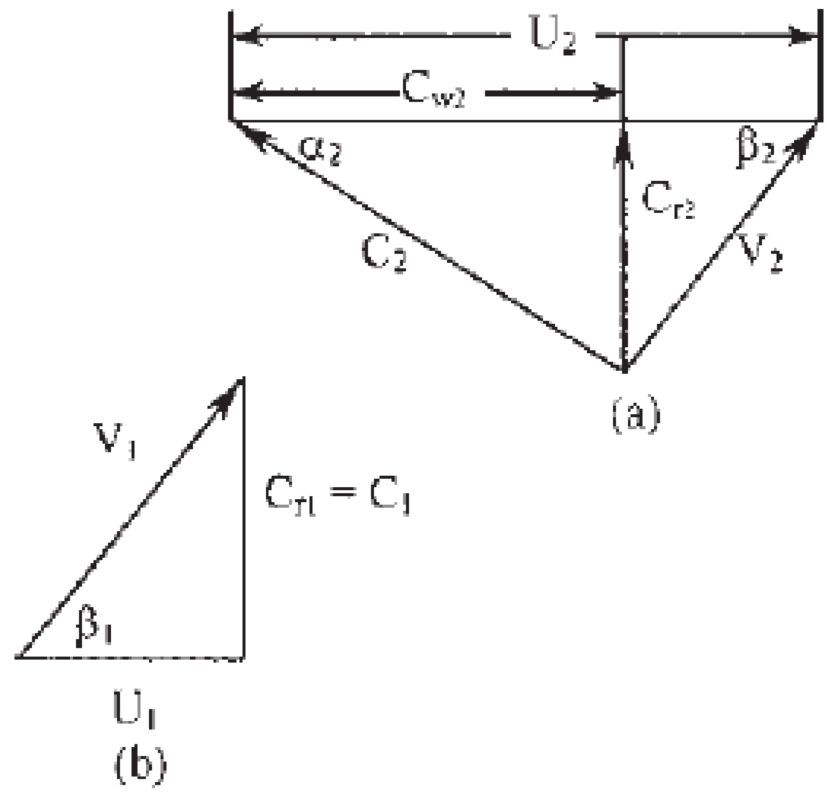

Figure 2.22 Velocity triangle (a) outlet, (b) inlet.

Figure 2.5: Vanes At 45 Degrees

```
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 2, Example 7")
//From Figure Ex26
//Finding Manometric Efficiency
//D2 is dia in meters, N in rpm, Head H in meters ,
    Cr2 and Cw2 in m/s
D2 = 0.5;
D1 = 0.25;
N = 500;
H = 10;
Cr2 = 2;
beta2 = %pi/4;
Cr1 = 2;
//etaman = H/(Cw2*U2/g)
disp("Outlet Velocity be U2 in m/s :")
U2 = %pi * D2 * N / 60
//To Find Cw2
Cw2 = 13-2/(tan(%pi/4))
disp(" Manometric Efficiency be etaman in %: ")
etaman = H*9.81/(Cw2*U2)  *100
disp("Vane Angle at inlet beta 1 in degrees is :")
//U1 = U2/2
beta1 = atan(Cr1/(U2/2))*(180/%pi)
disp("Minimum Starting speed N in rpm is :")
//(U2^2-U1^2/2g = H implies
Nmin = ((2*9.81*10)/((%pi*D2/60)^2 -(%pi*D1/60)^2))
    ^(1/2)
```

Scilab code Exa 2.8 Vanes Radially Exit

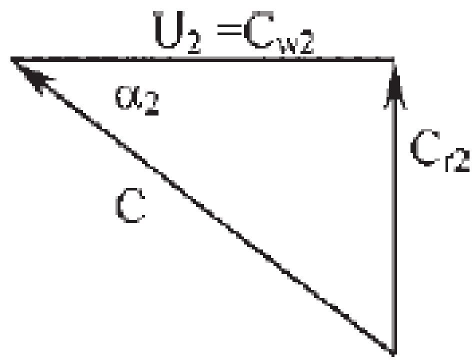

Figure 2.23 Velocity triangle for Example 2.8.

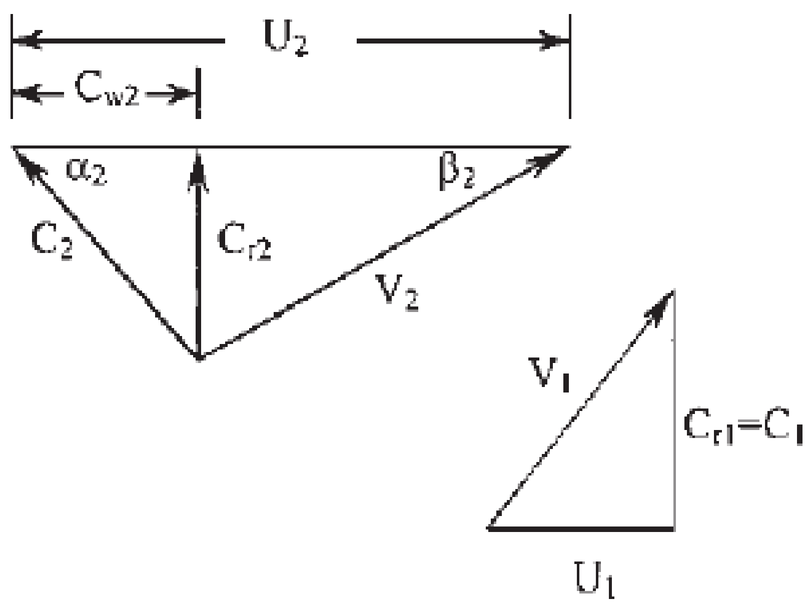

Figure 2.6: Vanes Radially Exit

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 2, Example 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
D2 = 0.6;
N = 550;
Cr2 = 3.5;
U2 = %pi*D2*N/60
Cw2 = U2
g = 9.81;
V=2.5;
disp("Head in meters from where water is being
    lifted is :")
H = Cw2 * U2/ g - (V^2)/(2*g)
//b2 is width
//Qis discharge Q=piD2b2Cr2 in m3/s
b2 = 0.082;
disp("Discharge Q is in m3/s:")
Q = %pi * D2 * b2 * Cr2
disp("Power P in Kilowatts is given as :")
rho = 1000; //density of water 1000kg/m3
P = rho*g*Q*H/1000
```

Scilab code Exa 2.9 Radial Component Water

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

```
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 2, Example 9")
disp("The Given Data")
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")
D2 = 1
U2 = 11
alpha1 = 90
Cr2 = 2.5
beta2 = 32
Q = 5.5
rho = 1000;
disp("Outlet Velocity Cw2 in m/s is :")
Cw2 = U2 - (Cr2/tan(32*%pi/180))
disp("Power in pump in kilowatts is :")
P = rho*Q*Cw2*U2/(1000*60)
//H.P. = 2*pi*N*T/60
disp("Rpm and Torque T in Nm/s are :")
N = 60*U2/(%pi * D2)
T= P*1000*60/(2*%pi*N)
```

Scilab code Exa 2.10 Centrifugal Pump Running

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 2, Example 10")
disp("Given Data N in rpm, H in m, Q - discharge in
```

```
    litres/s:")
N1 = 590
Q1 = 1.83
H1 = 16
N2 = 390
//As H^1/2 / N = constant
H2 = N2^2*H1/(N1^2)
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 :")
x = N1*Q1^(1/2)/H1^(3/4);
Q2 = (x*H2^(3/4)/N2)^2
```

Scilab code Exa 2.11 Ideal Height Hydraulic Efficiency

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 2, Example 11")
D2= 0.37;//in meters
N= 800;//in rpm
Q= 0.03;
Hgiven = 14;
disp("Impeller tip Speed U2 in m/s is :")
U2 = %pi *D2*N/60
disp("Radial velocity at the impeller exit Cr2 = 2.5
    m/s ")
Cr2 = 2.5;
disp("Therefore")
```

```
Cw2 = U2 - Cr2/tan(%pi/4)
disp("When there is no slip , the head H developed
    will be")
g =9.81;
H = Cw2*U2/g
disp("If there are no hydraulic internal losses , the
     power utilized by the pump will be: P")
P = 0.96*8 //given efficiency = 0.96 and Power = 8
    hp
disp("Theoretical flow rate Qtheo in m3/s :")
Qtheo = Q/0.97
disp("Ideal Height Hi :")
Hi = P * 0.746 / (g*Qtheo)
disp("The hydraulic efficiency is etah :")
etah =Hgiven/Hi *100
```

Scilab code Exa 2.12 Actual Work Absolute Velocity

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 2, Example 12")
disp("Exit blade angle beta2 =20 degres")
beta2 = 20;
U2 = 56; //U2 in m/s
Cr2 = 7.5; //in m/s
CW2 = U2 - Cr2/tan(20*%pi/180)
disp("Using slip factor :")
sigma = 0.88
disp("The velocity whirl at exit is :")
Cw2 = sigma*CW2
```

```
disp("Work input per kg of water flow in KJ/kg")
W = Cw2*U2/1000
disp("Absolute velocity at impeller tip C2 in m/s is :")
C2 = (Cr2^2 + Cw2^2)^(1/2)
```

Scilab code Exa 2.13 Theoritical Head

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 2, Example 13")
disp("Assuming the blades are of infinitesimal thickness, the flow area is given by A in m2 = impeller periphery * blade depth")
D2 = 0.26 //in m
d = 0.02//in m
N = 1400//in rpm
g =9.81;
Q= 0.03//m3/s
disp("Area A in m2")
A = D2*%pi*d
disp("Flow velocity Cr2 is given by")
Cr2 = Q/A
disp("Impeller tip speed, U2 in m/s is")
U2 = %pi*D2*N/60
disp("Absolute whirl component, Cw2 in m/s is given by")
Cw2 =  U2 - Cr2/tan(30*%pi/180)
disp("Using Eulers equation, and assuming Cw1 = 0 (i.e., no whirl at inlet) Head H in m")
```

```
H = U2*Cw2/g
disp("Theoretical head with slip is Htheo in m")
Htheo = 0.78*H
disp("To find numbers of impeller blades, using
    Stanitz formula sigma = 1 - 0.63pi/n")
disp("Slip factor, sigma = 0.78")
sigma = 0.78;
disp("Number of blades required")
n = (0.63*%pi)/(1-sigma)
disp("Therefore n = 9")
```

Scilab code Exa 2.14 `Vanes 30 Degrees`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 2, Example 14")
disp("Given data D1 and D2 in meters, N in rpm, Cr2
    in m/s and beta2 in degrees")
D1 = 0.2
D2 = 0.4
N = 1500
Cr2 = 2.8
beta2 = 30
disp("Impeller tip speed, U2 in m/s, is")
U2 = %pi*D2*N/60
disp("Whirl component of absolute velocity Cw2 at
    impeller exit is")
Cw2 = U2 - Cr2/tan(30*%pi/180)
//As tan(alpha2)=2.8/26.58 = 0.1053
alpha2 = atan(0.1053) * 180 /%pi
```

```
disp("Impeller speed at inlet U1 in m/s is ")
U1 = %pi * D1*N/60
//tan(beta1) = 2.8/15.7 = 0.178
beta1 = atan(0.178)*180/%pi
disp("Work done per kg of water W in Nm :")
W = Cw2*U2
```

Scilab code Exa 2.15 Power Hub dia Angles

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 2, Example 15")
rho = 1000;//density in kg/m3
g = 9.81;//force of gravity in m/s2
H = 10;//head in m
Q = 1.3;//Discharge in m3/s
eta = 0.83;//efficiency
U2 = 22;//blade velocity
Ca = 4.5;//Flow velocity
N = 550;//rpm
disp("Power delivered to the water P in kW :")
P = rho*g*H*Q/1000
disp("Power input to the pump Pin in kW :")
Pin = P/eta
disp("Rotor tip diameter is given by D2 in m")
D2 = 60*U2/(%pi*N)
disp("Rotor Hub dia D1 in m :")
D1 = (D2^2 -Q/(%pi*Ca/4))^(1/2)
disp("Rotor velocity at hub is given by U1 in m/s :")
```

```
U1 = D1*U2/D2
disp("Since, the axial velocity is constant, we have
    : rotor inlet angl at tip alpha1t in degrees")
alpha1t = atan(Ca/U1)*180/%pi
disp("Rotor outlet angle alpha2t in degrees :")
alpha2t = atan(Ca/U2)*180/%pi
```

Scilab code Exa 2.16 Mechanical Efficiency

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 2, Example 16")
disp("Given Data:")
Qdel = 72//Discharge in l/s
rho = 1000
Di = 0.09//Inner Dia in m
Do = 0.28//Outer Dia in m
N = 1650//Revolution in min
H = 25//Head
bi = 0.02//Width at inlet in m
bo = 0.018//Width at outlet in m
Qleak = 2//in l/s
etap = 0.56//Efficiency of the pump
cf = 0.85//Contraction factor
g = 9.81//gravity in m/s2
Ploss = 1.41
disp("Total quantity of the water to be handled by
    the pump Qt in l/s")
Qt = Qdel + Qleak
disp("Total quantity of water per side Qw")
```

```
Qw = Qt/2
disp("Impeller speed at inlet U1 in m/s")
U1 = %pi*Di*N/60
disp("Flow area at inlet Af")
Af = %pi*Di*bi*cf
disp("Therefore, the velocity of flow at inlet Crl in m/s")
Crl = Qw/(Af*1000)
disp("From inlet velocity triangle beta1")
beta1 = atan(Crl/U1)*180/%pi//Crl/U1 = 7.708/7.78
disp("Area of flow at outlet Ao")
bo1 = bo / 2
Ao = %pi * Do * bo1* cf
disp("Therefore, the velocity of flow at outlet Cr2")
Cr2 = Qw/(Ao*1000)
disp("The impeller speed at outlet U2")
U2 = %pi*Do*N/60
disp("Now using velocity triangle at outlet Cw2 in m/s")
Cw2 = U2 - Cr2/tan(35*%pi/180)
alpha2 = atan(Cr2/Cw2)*180/%pi
disp("The absolute velocity of water leaving the impeller C2 in m/s")
C2 = Cw2/cos(alpha2*%pi/180)
disp("The manometric efficiency etaman")
etaman =  g*H/(U2*Cw2)
disp("The volumetric efficiency etav")
etav = Qdel/Qt
disp("Water power Pw in kW")
Pw = rho*g*Qdel*H/1000000
disp("Shaft power Ps in kW")
Ps = Pw/etap
disp("Mechanical efficiency is etam")
etam = (Ps - Ploss)/Ps
```

Scilab code Exa 2.17 Single Stage Pump

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

Scilab code Exa 2.18 Diameter of Impeller

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 2, Example 18")
disp("Specific speed N in rpm")
Ns = 38;
He = 70;
H = He/2;
```

```
Q = 55/1000;//in m3/s
rho = 1000;
g = 9.81;
N = Ns * (H)^(3/4)  /  Q^(1/2)
disp("Power Required P in kW")
P = rho*g*Q*He/(0.76*1000)
Hmano = 0.65*H;
beta2 = 28;
//Cr2 = 0.14*U2
disp("From velocity triangle at outlet")
disp("tan(beta2) = Cr2/(U2 - Cw2) or tan(28) = 0.14
   U2/ (U2 - Cw2)")
disp("U2/(U2 - Cw2) = 0.5317/0.14 = 3.798-------(A)")
disp("As the flow at entrance is radial and alpha1 =
    90, the fundamental equation of pump would be")
disp("Hmano/etamano = U2*Cw2/g")
disp("Where etamano manometric efficiency of pump
   which is 65%.")
disp("Therefore, 35/0.65 = U2*Cw2/g")
disp("U2*Cw2 = 35 * 9.81/ 0.65")
disp("Cw2 = 528.23/U2-------(B)")
disp("Substituting for Cw2 in Eq. (A) and solving U2
   ")
U2 = 26.78
D2 = U2 * 60 /(%pi *N)
disp("Where D2 is in meters")
```

Scilab code Exa 2.19 Two Multistage Pumps

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
```

```
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 2, Example 19")
N = 1445//rpm
Q = 0.0352//m3/s
Ns = 14//rpm
g=9.81;
disp("Head developed in each stage is H in m: ")
H = (N * (Q^(1/2))/Ns)^(4/3)
disp("Total head required = 845m")
disp("Number of stages needed = 845/52 = 16")
disp("Number of stages in each pump = 8")
disp("Impeller speed at tip is U2 in m/s")
U2 = 0.96*(2*g*H)^0.5
disp("Impeller Diameter at tip D2")
//D2 = %pi*60*30.6*1445
disp("But U2 = pi*D2*N/60 Therefore D2 real in m")
D2real = U2 *60/(%pi*1445)
```

Scilab code Exa 2.20 Pumps to be Connected

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 2, Example 20")
disp("Specific speed for a single impeller is given by")
disp("Ns = N*Q^0.5/H^0.75")
Ns = 700
H = 105
N = 900
Q = 5500/60//l/s
```

```
H = (N*Q^0.5/Ns)^(4/3)
disp("Hence total number of stages :")
Ht = 105;
Stages = Ht/H
disp("Stages in series are 4")
```

Scilab code Exa 2.21 Specific speed 1150

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 2, Example 21")
disp("Given data")
D2 = 0.9//m
D1 = 0.45//m
Ns = 1150//rpm
Cr = 2.5 //m/s
H = 5.5//m
disp("H,D2 and D1 are in meters, Ns in rpm, Cr in m/
   s")
Q = (%pi*(D2^2-D1^2)/4 )*Cr*1000
disp("Q in l/s")
N = Ns*H^0.75/Q^0.5
disp("Therefore N = 120")
disp("In order to find vane angle at entry, using
   velocity triangle at inlet,U1 in m/s is:")
U1 = %pi*D1*N/60
alpha = atan(Cr/U1)*180/%pi
```

Chapter 3

Hydraulic Turbines

Scilab code Exa 3.1 Generator Pelton Wheel

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

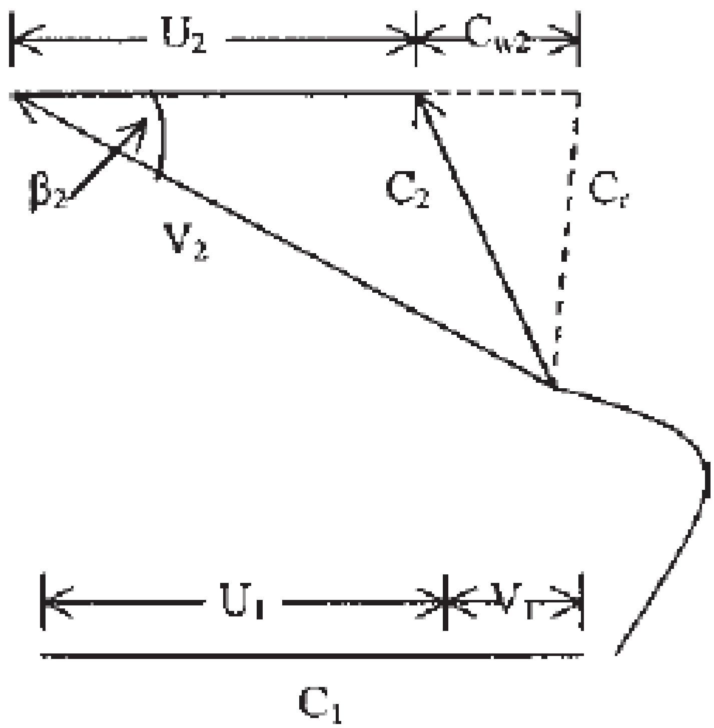

Figure 3.6 Inlet and outlet velocity triangles.

Figure 3.1: Generator Pelton Wheel

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

Scilab code Exa 3.2 Pelton Wheel 725

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

```
N = 725;
disp("Power in kw")
P = rho*g*Q*H*etao/1000
disp("Velocity coefficient Cv = C1/(2gH)^0.5")
C1 = Cv * (2*g*H)^0.5
disp("Speed of the wheel is given by U")
U = 0.45*C1
disp("If D is the wheel diameter, then")
D = 2*U*60/(N*2*%pi)
disp("Jet area A")
A = Q/C1
disp("Jet diameter, d, is given by")
d = (4*A/%pi)^0.5
disp("Diameter ratio D/d =")
R = D/d
disp("Dimensionless specific speed is given by Nsp = NP^0.5/rho^0.5*(gH)^1.25 in radians")
Nsp = (N/60)*(((P/rho)*1000)^0.5) * ((1/(g*H))^1.25) *2*%pi
```

Scilab code Exa 3.3 Pelton Speed 14

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

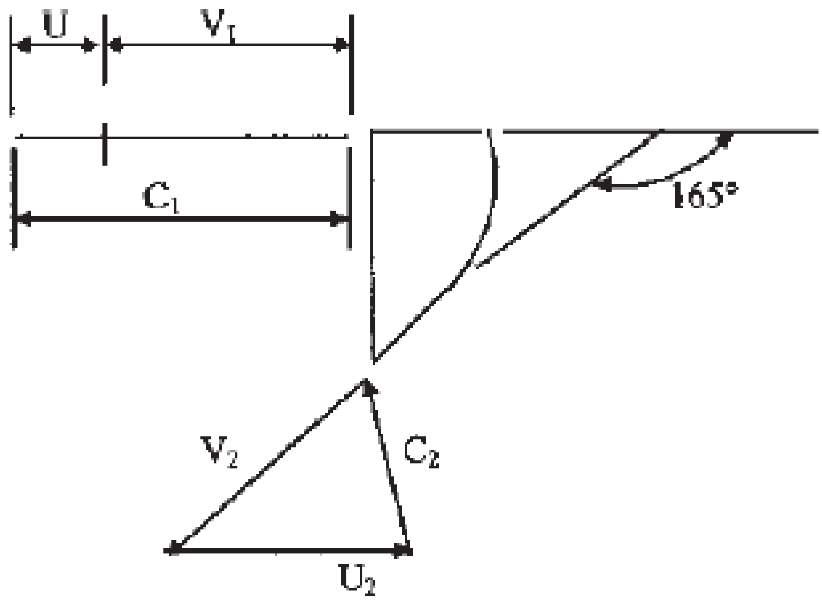

Figure 3.7 Velocity triangle for Example 3.3.

Figure 3.2: Pelton Speed 14

```
U1=U2
Q = 0.82//m3/s
H =45//m
beta2 = 180-160
Cv = 0.98
g = 9.81
disp("Velocity of jet C1")
C1 = Cv*(2*g*H)^0.5
disp("Assuming beta1 = 180")
beta1 = 180;
Cw1 = C1
V1 = C1-U1
disp("From outlet velocity triangle,U1 = U2(
    neglecting losses on buckets)")
V2 = V1
Cw2 = V2*cos(beta2*%pi/180) -U2
disp("Work done per weight mass of water per sec")
W = (Cw1+Cw2)*U1
disp("Power developed P in kw and horse power are
    Pkw,Php")
Pkw = W*Q
Php = Pkw*1000/746//in horse power
disp("Efficiency eta1")
eta1 = 1000*Pkw/(1000*g*Q*H)
```

Scilab code Exa 3.4 Pelton Wheel 12900kW

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

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

Scilab code Exa 3.5 `Double Overhung Pelton`

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

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

Scilab code Exa 3.6 Power Station

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

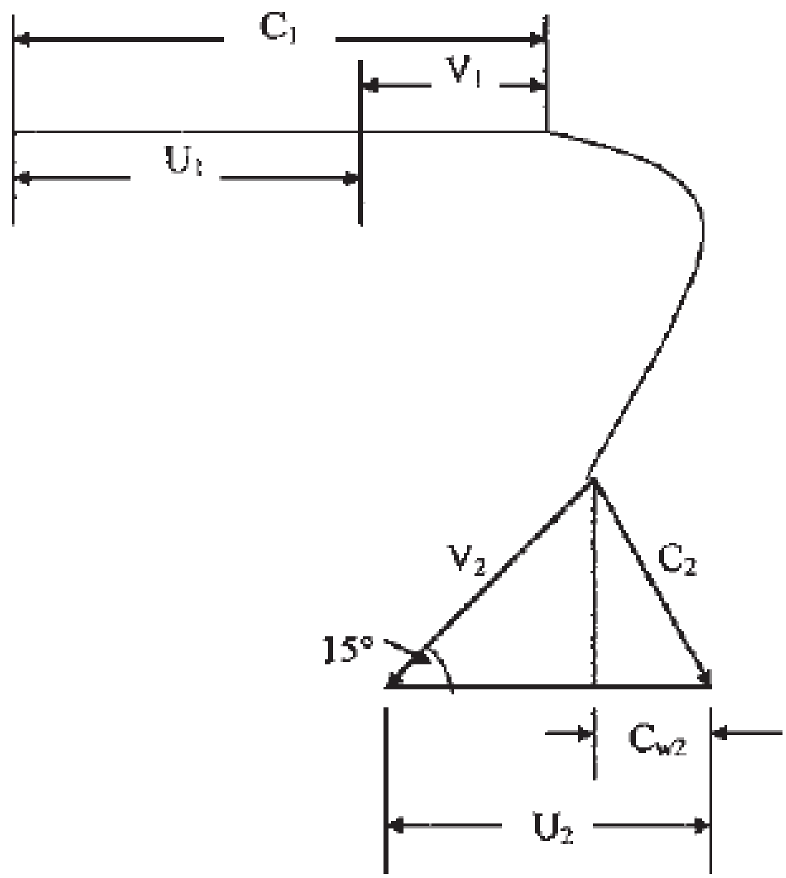

Figure 3.8 Velocity triangle for Example 3.6.

Figure 3.3: Power Station

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

Scilab code Exa 3.7 `Pelton Head 90`

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

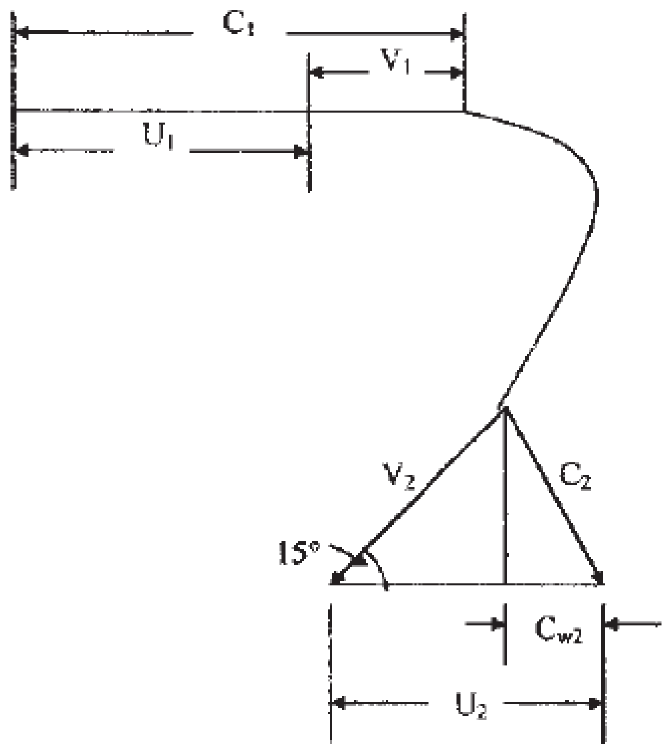

Figure 3.9 Velocity triangle for Example 3.7.

Figure 3.4: Pelton Head 90

```
g = 9.81;
H = 60;
C1 = Cv *(2*g*H)^0.5
U1 =12;
disp("Therefore")
V1 = C1-U1
disp("From outlet velocity triangle")
V2 = V1
alpha = 15;
disp("neglecting losses in m/s")
U2 = U1;
Cw2 = V2*cos(alpha*%pi/180)-U2
Cr2 = V2*sin(alpha*%pi/180)
C2 = (Cw2^2+Cr2^2)^0.5
disp("Work done in kJ/kg")
W = (C1^2-C2^2)/2
disp("Note Work done can also be found by using
    Eulers equation (Cw1U1 + Cw2U2)")
Power = W //kW
disp("Hydraulic Efficiency")
Efficiency = W*2/C1^2
```

Scilab code Exa 3.8 Single Jet Pelton Wheel

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

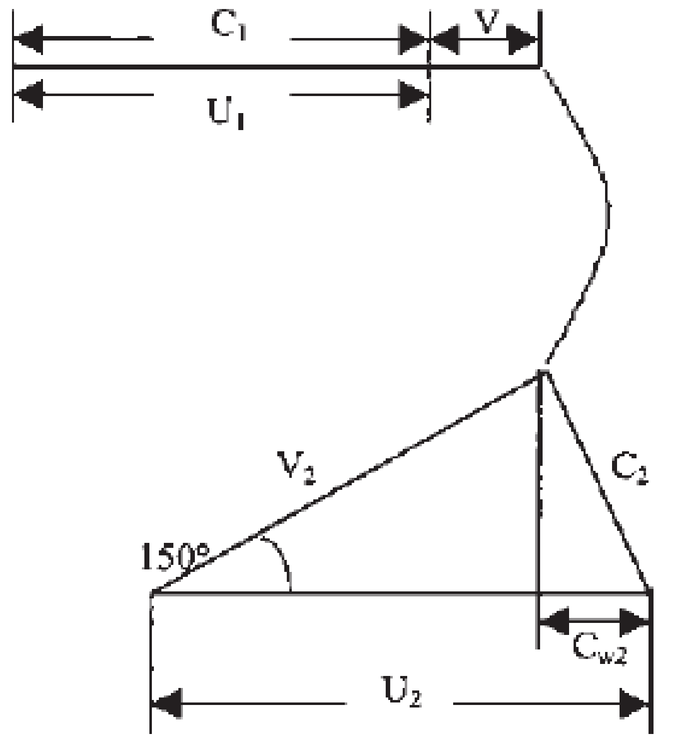

Figure 3.10 Velocity triangles for Example 3.8.

Figure 3.5: Single Jet Pelton Wheel

```
   none of them are rounded, the answers are
   dependent on each other.
disp("Refering Figure and the scientific
   calculations")
disp("Velocity of jet, C1")
Cv = 0.98;
g=9.81;
H = 515;
C1 = Cv*(2*g*H)^0.5
disp("Discharge, Q is given by")
d=0.2;
Q = %pi*C1*d^2 /4
disp("Water power is given by in kW")
rho = 1000;
P = rho*g*Q*H/1000
disp("Bucket velocity, U1, is given by")
Cv1 = 0.46;
U1 = Cv1*(2*g*H)^0.5
disp("Relative velocity, V1, at inlet is given by")
V1 = C1-U1
V2 = 0.88*V1
disp("From the velocity diagram")
U2 = U1
Cw2 = U2 -V2*cos(%pi*15/180)
disp("Therefore force on the bucket F in N")
Cw1 = C1
F = rho*Q*(Cw1-Cw2)
disp("Power produced by the Pelton wheel Pp in kW")
Pp = F*U2/1000
disp("Taking mechanical loss")
loss = 0.04
disp("Therefore, shaft power produced")
Pshaft = Pp*(1-loss)
disp("Overall efficiency etao")
etao = Pshaft/P *100
```

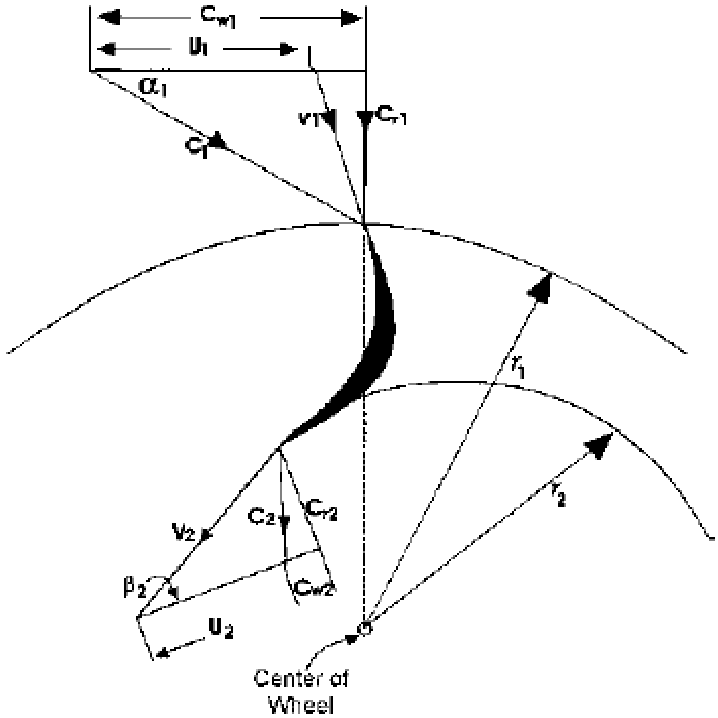

Figure 3.13 velocity triangles for inward flow reaction turbine.

Figure 3.6: Inward Flow Reaction Turbine

Scilab code Exa 3.9 `Inward Flow Reaction Turbine`

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

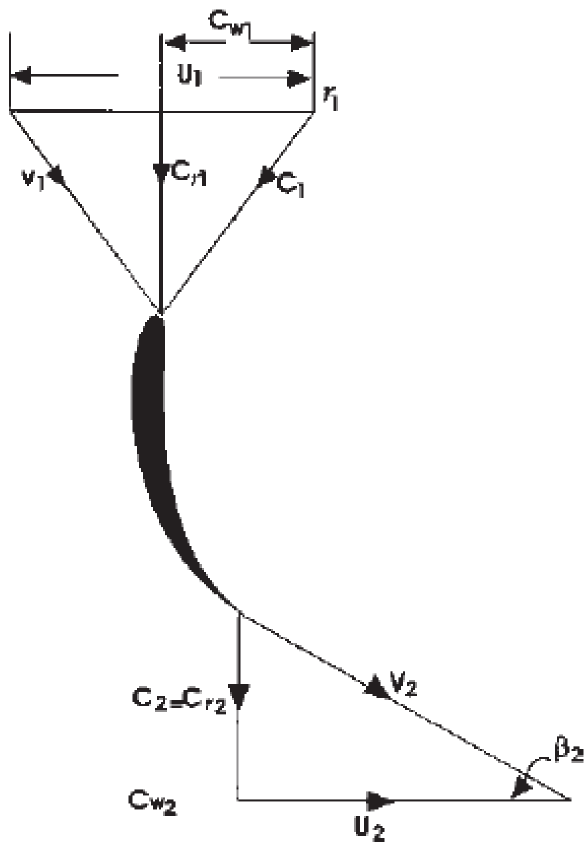

Figure 3.18 Velocity triangles for an axial flow hydraulic turbine.

Figure 3.7: Inward Flow Reaction Turbine

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

Scilab code Exa 3.10 `Runner Axial Flow`

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

```
g = 9.81;
H = 35;
C1 = Cv*(2*g*H)^0.5
disp("The velocity of whirl at inlet")
alpha1 = 30;
Cw1 = C1*cos(alpha1*%pi/180)
disp("Since U1 = U2 = U")
disp("Using outlet velocity triangle")
disp("C2 = U2tan(beta2) = U tan(beta2) = U tan(22)")
disp("Hydraulic efficiency of turbine (neglecting losses)")
//etah = Cw1U1/gH = (H - C2^2/2g)/H
//22.24U + 0.082U^2 - 9.81H = 0
disp("As U is positive,")
U = (-22.24 + ((22.4)^2 + 4*0.082*g*H)^0.5)/(2*0.082) - 0.9
disp("Now using relation")
disp("U = %pi*D*N/60")
D = 1.5;
N = 60*U/(%pi*D)
disp("Hydraulic efficiency")
etah = Cw1*U/(g*H)
```

Scilab code Exa 3.11 Kaplan runner

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

```
H = 5.5;
Cv1 = 0.68;
U1 = Cv*(2*g*H)^0.5
Cr1 = Cv1*(2*g*H)^0.5
N = 65;
disp("Now power is given by")
P = 9000;
eta = 0.85;
Q = P / (g * H * eta)
disp("If D is the runner diameter and, d, the hub
    diameter")
D = (Q*4*9/(%pi*Cr1*8))^0.5
disp("Solving")
Ns = N * P^0.5 / H^1.25
```

Scilab code Exa 3.12 Turbine 12000 HP

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

```
disp("Power = rho*g*Q*H*etao")
etao = 0.85
disp("Discharge, Q")
Q = Power/(g*H*etao)
Cr1 = Q*4/(%pi*(4^2-1.75^2))
beta1 = atan(Cr1/(U1-Cw1))*180/%pi
U2 =U1
Cr2 = Cr1
beta2 = atan(Cr2/U2)*180/%pi
```

Scilab code Exa 3.13 Speed angle reaction turbine

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 3, Example 13")
disp("Outer diameter, D2 = 1.4m")
disp("Inner diameter, D1 = 0.7m")
disp("Angle at which the water enters the vanes,
   alpha1 = 12 degrees")
disp("Velocity of flow at inlet,")
Cr2 = 2.8
Cr1 = Cr2
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.")
disp("Tangential velocity of wheel at inlet,")
alpha1 = 12
U1 = Cr1/tan(alpha1*%pi/180)
D2 = 1.4
N = 60*U1/(%pi*D2)
```

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

Scilab code Exa 3.14 `Discharge 500`

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

Scilab code Exa 3.15 Rotation 290rpm

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 3, Example 15")
disp("Inner diameter of wheel,")
D1 = 1
disp("Outer diameter of wheel,")
D2 = 2
disp("Velocity of flow is constant")
Cr1 = 12//m/s
Cr2 =Cr1
disp("Speed of wheel,")
N = 290//rpm
disp("Vane angle at inlet = beta1")
disp("U1 is the velocity of periphery at inlet.")
U1 = %pi*D1*N/60
disp("From inlet triangle, velocity of whirl is
    given by")
Cw1 = Cr1/tan(20*%pi/180)
beta1 = atan(Cr1/(Cw1-U1))*180/%pi
disp("Let beta2 = vane angle at outlet")
disp("U2 = velocity of periphery at outlet")
U2 = %pi*D2*N/60
disp("From the outlet triangle")
beta2 = atan(Cr2/U2)*180/%pi
```

Scilab code Exa 3.16 Head 30

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

Scilab code Exa 3.17 Power 12400

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

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

Scilab code Exa 3.18 Francis Turbine 1250rpm

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

```
disp("As the flow is radial at outlet, Cw2 = 0 and
    therefore")
Cw2 = 0;
disp("T = -mCw1r1")
disp(" - rQCw1r1")
disp("T = -225Cw1 Nm")
disp("If h1 is the inlet runner height, then inlet
    area, A, is")
h1 = 0.035;
r1 = 0.5;
A = 2*%pi*r1*h1
Q = 0.45;
Cr1 = Q/A
g = 9.81;
H = 125;
rho = 1000;
disp("From velocity triangle, velocity of whirl")
alpha = 70;
disp("Substituting Cw1, torque is given by")
Cw1 = Cr1 * tan(alpha *%pi/180)
T = -1 * 225* Cw1
disp("Negative sign indicates that torque is exerted
     on the fluid. The torque exerted by the fluid is
     +2534Nm")
Ta = -1*T;
disp("Power exerted")
N = 1250;
omega = 2*%pi*N/(60*1000)
P = Ta * omega
disp("Hydraulic efficiency is given by")
disp("etah = Power exerted/Power available")
etah = P * 1000/ (rho * g * H * Q ) * 100
```

Scilab code Exa 3.19 Turbine 130kW

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

Scilab code Exa 3.20 Blade tip hub dia

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

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

Scilab code Exa 3.21 `Overall Efficiency 75`

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

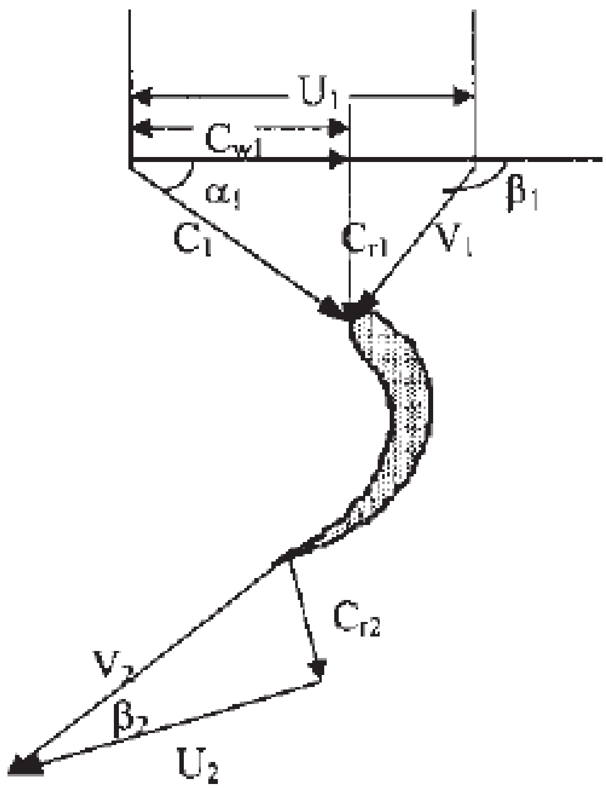

Figure 3.22 Velocity triangles for Example 3.14.

Figure 3.8: Overall Efficiency 75

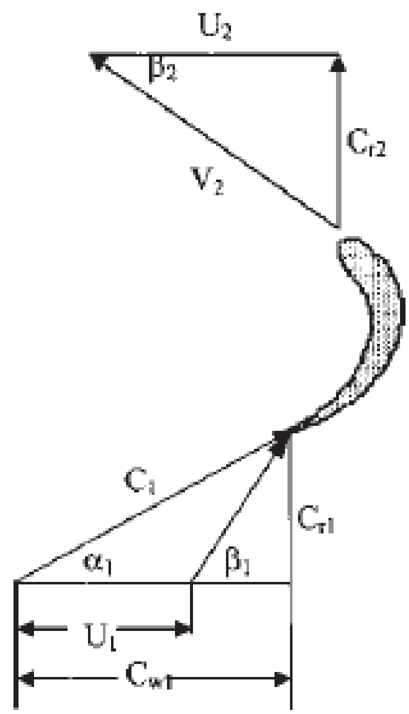

Figure 3.23 Velocity triangles at inlet and outlet for Example 3.15.

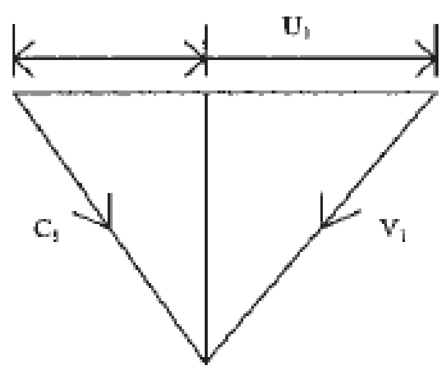

Figure 3.24 Inlet velocity triangle.

Figure 3.9: Overall Efficiency 75

```
Cw2 = 0;
etah = 0.82;
U1 = 10.6;
g = 9.81;
H = 6;
Cw1 = etah*g*H/U1
Cr1 = 4;
alpha1 = atan(Cr1/Cw1)*180/%pi
disp("From Figures")
disp("Blade angle, beta1, is given by")
beta1 = 180 - atan(Cr1/(U1-Cw1)) * 180/%pi
disp("Runner speed at inlet")
N = 235;
D1 = U1*60/(%pi*N)
disp("Overall efficiency")
disp("etao = Power output/Power available")
etao = 0.75
rho = 1000;
P = 128000
disp("From which flow rate")
Q = P/(0.75*rho*g*H)
disp("Also, Q = rho*D1hCr1")
disp("where h1 is the height of runner. Therefore,")
h1 = Q/(%pi*D1*Cr1)
```

Scilab code Exa 3.22 Kaplan 10000kW

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

```
disp("Head, H = 8 m, Power, P = 10,000kW")
disp("Overall efficiency, etao = 0.86")
P = 10000;
g = 9.81;
H = 8;
rho = 1000;
U1 = 2*(2*g*H)^0.5
disp("Flow ratio Cr1/(2gH)^0.5")
Cr1 = 0.6*(2*g*H)^0.5
disp("Hub diameter, D1 = 0.35 D2")
disp("Overall efficiency,etao = P/rho*gQH")
etao = 0.86;
Q = P/(rho*g*H*etao) * 1000
disp("Now using the relation")
disp("Q = Cr1 * pi*(D1^2- D2^2)/4")
D1 = (Q*4/(Cr1*%pi*(1-0.35^2)))^0.5
disp("The peripheral velocity of the turbine at
    inlet")
N = U1*60/(%pi*D1)
```

Scilab code Exa 3.23 Vanes 12 degrees

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

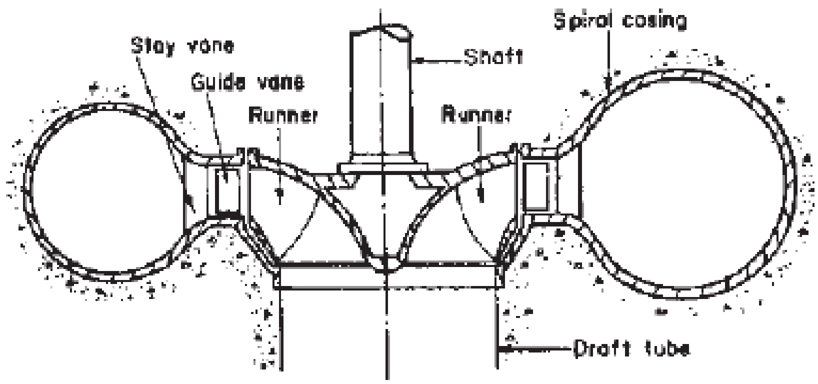

Figure 3.11 Outlines of a Francis turbine.

Figure 3.10: Vanes 12 degrees

```
D1 = 0.9
disp("Radial Discharge")
alpha2 = 90
Cr2 = 2.8
Cr1 = Cr2
disp("From velocity triangle at inlet , The
   peripheral velocity of the wheel at inlet")
alpha1 = 12
U1 = Cr1/tan(alpha1*%pi/180)
N = 60*U1/(%pi*D1)
disp("Considering velocity triangle at outlet
   peripheral velocity at outlet")
U2 = %pi*D2*N/60
beta2 = atan(Cr2/U2)*180/%pi
```

Scilab code Exa 3.24 `Inward Flow 70kW`

```
// Display mode
```

```
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 3, Example 24")
Q = 0.545//m3/s
D1 = 0.8//m
D2 = 0.4//m
H =14//m
alpha2 = 90//degrees
N = 370
//beta1 = beta2
disp("Peripheral velocity of the wheel at inlet")
U1 = %pi*D1*N/60
disp("Velocity of flow at the exit,")
Cr2 = 2.8//m/s
alpha2 = 90
C2 = Cr2
g = 9.81;
disp("Work done/s by the turbine per kg of water = Cw*U1/g")
disp("But this is equal to the head utilized by the turbine, i.e.")
disp("Cw1U1/g = H - C2/2g")
disp("(Assuming there is no loss of pressure at outlet)")
Cw1 = (H - C2/(2*g) )*g/U1
disp("Work done per second by turbine")
rho = 1000;
W = rho*Q*Cw1*U1/(1000)//kW
disp("Available power or water power")
Pav = rho*g*Q*H /1000//kW
disp("Actual available power")
Pac = 70//kW
disp("Overall turbine efficiency is")
etat = Pac/Pav  * 100
```

```
disp("This is the actual hydraulic efficiency as required in the problem. Hydraulic Efficiency is")
etah = W/Pav  * 100
disp("This is the theoretical efficiency")
disp("Q = pi*D1b1Cr1 = pi*D2b2Cr2")
disp("(Neglecting blade thickness)")
Cr1 = Cr2 * D2/D1
disp("Drawing inlet velocity triangle")
//Cr1/(U1-Cw1) = 0.203
beta1 = atan(0.203)* 180/%pi
C1 = (Cw1^2+Cr1^2)^0.5
//Cw1/C1 = 0.995
aplha1 = acos(0.995)*180 /%pi
```

Scilab code Exa 3.25 Francis Turbine 500kW

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 3, Example 25")
P = 5000//kW
alpha1 = 30//degrees
H= 30//m
g = 9.81;
Ns = 270
etah = 0.9
etao = 0.86
disp("Specific speed of the turbine is")
N = Ns* H^1.25 / (P^0.5)
disp("Velocity of Flow:")
```

```
Cr1 = 0.28* (2*g*H)^0.5
disp("From inlet velocity triangle Cr1 = C1sin(
    alpha1)")
C1 = Cr1 / sin(alpha1*%pi/180)
Cw1 = C1 * cos(alpha1*%pi/180)
disp("Work done per (sec) (kg) of water")
//W = Cw1*U1/g
W = etah*H
disp("Peripheral Velocity,")
U1 = W*g/Cw1
disp("But U1 = pi*D1N/60")
D1 = 60*U1/(%pi*N)
disp("Power, P = rho*gQH*etao")
rho = 1000;
Q = P/(rho*g*H*etao) * 1000
disp("Also Q = k*pi*D1b1Cr1 (where k is the blade
    thickness coefficient and b1 is the breath of the
     wheel at inlet) or")
k = 0.95
b1 = Q/(k*%pi*D1*Cr1)
disp("From inlet velocity triangle")
beta1 = atan(Cr1/(U1-Cw1)) * 180/%pi
```

Scilab code Exa 3.26 35MW Generator

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 3, Example 26")
disp("In this case, the generator is fed by two
    Pelton turbines.")
```

```
disp("Power developed by each turbine,")
PT = 35000/2
disp("Using Pelton wheel efficiency in order to find
    available power of each turbine")
P = PT / 0.84
disp("But, P = rho*gQH")
rho = 1000;
g = 9.81;
H = 350
Q = P/(rho*g*H) * 1000
disp("Velocity of jet,Cj")
Cv = 0.96;
Cj = Cv*(2*g*H)^0.5
disp("Area of jet, A")
A = Q/Cj
disp("Diameter of jet , d")
d = (4*A/%pi)^0.5
disp("Diameter of wheel D = d * jet ratio")
r = 12;
D= d*12
disp("Peripheral velocity of the wheel")
U = 0.45*(2*g*H)^0.5
disp("But U = pi*DN/60 or")
N = 60*U/(%pi*D)
disp("Specific speed,")
Ns = N*PT^0.5 / H^1.25
```

Chapter 4

Centrifugal Compressors and Fans

Scilab code Exa 4.1 `Air leaving impeller`

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

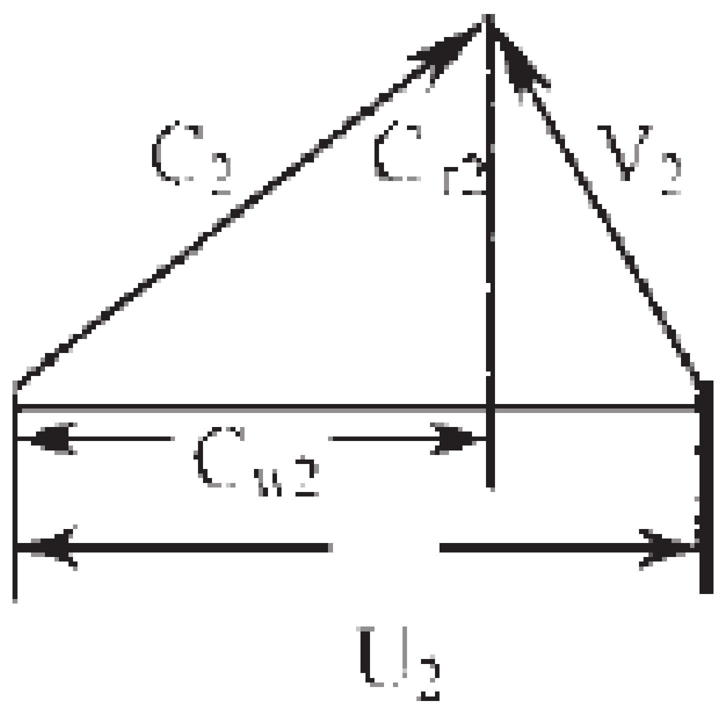

Figure 4.1: Air leaving impeller

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

Scilab code Exa 4.2 Speed Centrifugal Compressor270

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

```
A2 = 0.18;//m2
m = rho2*A2*Cr2
disp("The temperature equivalent of work done (
    neglecting c):")
disp("Therefore, T02 - T01 =sigma*U2^2/Cp")
T01 = 290;
Cp = 1005;
T02 = T01 + sigma*U2^2/Cp
disp("The static temperature at the impeller exit, "
    )
T2 = T02 - C2^2/(2*Cp)
disp("The Mach number at the impeller tip:")
gamma = 1.4;
R = 287;//
M2 = C2 / (gamma *R*T2)^0.5
disp("The overall pressure ratio of the compressor (
    neglecting psi): P03/P01")
etac = 0.88;//efficiency
psi = 1;//neglected
ratio = (1+etac*sigma*psi*U2^2  /(Cp*T01))^3.5
```

Scilab code Exa 4.3 Centrifugal Compressor 16000rpm

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

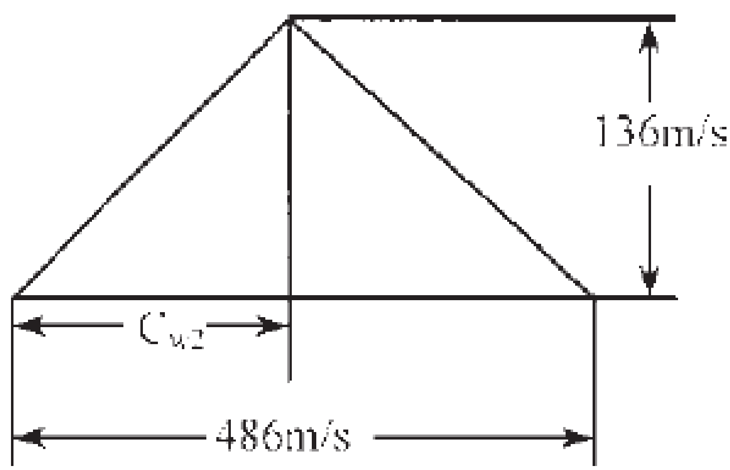

Figure 4.13 Velocity triangle at exit.

Figure 4.2: Centrifugal Compressor 16000rpm

```
N = 16000//rpm
U2 = %pi* D* N/60
disp("Assuming isentropic flow between impeller inlet and outlet , then T02a")
T01 = 293;//K
stagratio = 4.2
T02a = T01*(stagratio)^0.286
disp("Using compressor efficiency , the actual temperature rise T02a-T01")
etac = 0.82
rise = (T02a-T01)/etac
disp("Since the flow at the inlet is axial , Cw1 = 0")
disp("W = U2Cw2 = Cp (T02 - T01)")
Cp = 1005
W = Cp*(rise)
Cw2 = W/U2
Slip = U2-Cw2
disp("Slip factor:")
sigma = Cw2/U2
```

Scilab code Exa 4.4 Adiabatic Efficiency

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

```
//Atmospheric pressure = 1 bar
//Atmospheric temperature = 25 degree Celcius
//Slip factor = 0.90
disp("Neglect the power input factor.")
disp("The impeller tip speed is given by:")
D = 1;
N = 5945;
U2 = %pi*D*N/60
disp("The work input:")
sigma = 0.9;
W = sigma * U2^2 / 1000
disp("Using the isentropic  P T  relation and denoting isentropic temperature by T3a, we get:")
T1 = 298;
r = 2.2;
T3a = T1 * (r)^ 0.286
disp("Hence the isentropic temperature rise: T3a - T1")
rise = T3a -T1
disp("The temperature equivalent of work done: T3 - T1")
Cp = 1.005
Weq = W/Cp
disp("The compressor adiabatic efficiency is given by:")
etac = rise/Weq  * 100
disp("The air temperature at the impeller exit is:")
T3 = T1 + Weq
disp("Power input:")
m = 28;
P = m * W
```

Scilab code Exa 4.5 `Centrifugal Compressor 9000rpm`

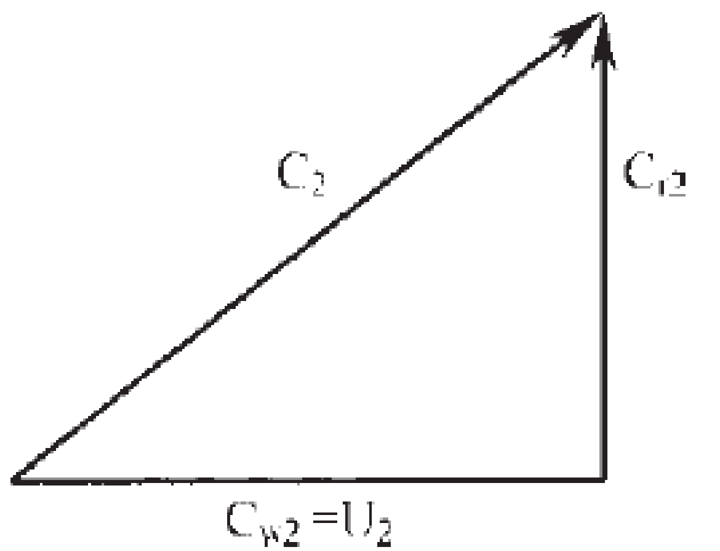

Figure 4.14 Velocity triangle at impeller exit.

Figure 4.3: Centrifugal Compressor 9000rpm

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

Scilab code Exa 4.6 `Centrifugal Compressor No prewhirl`

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

```
etac = 0.88;
sigma = 0.95;
U2 = 457;
Cp = 1005;
T01 = 288;
r = (1+etac*sigma*U2^2/(Cp*T01) )^3.5
disp("The work per kg of air")
Cw2 = 0.95*U2;
W = U2*Cw2 / 1000//kJ/kg
disp("The power for 29kg/s of air")
m = 29;
P = W * m  //kW
```

Scilab code Exa 4.7 Centrifugal Compressor 10000rpm

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

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

Scilab code Exa 4.8 `Centrifugal Compressor 19 vanes`

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

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

Scilab code Exa 4.9 Problem 8 repeat

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

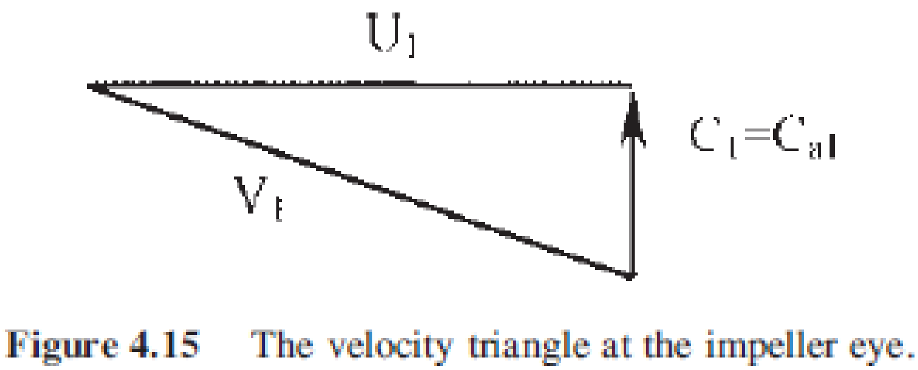

Figure 4.4: Compressor 15000rpm

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

Scilab code Exa 4.10 `Compressor 15000rpm`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 4, Example 10")
disp("Inlet stagnation temperature:")
R = 287;
Ta = 298;
C1 = 145;
```

```
Cp = 1005;
T01 = Ta + C1^2 /(2*Cp)
disp("Using the isentropic  P T  relation for the compression process,")
disp("x = P03/P01")
x = 4;
T03a = T01 * (4)^0.286
disp("Using the compressor efficiency,")
disp("T02-T01 = y")
T02a = T03a;
etac = 0.89;
y = (T02a-T01)/etac
disp("Hence, work done on the air is given by: in kJ/kg")
W = Cp * y / 1000
U2 = (W*1000/0.89)^0.5 //m/s
disp("Hence, the impeller tip diameter")
N = 15000; //rpm
D = 60*U2/(%pi*N) //m
disp("The air density at the impeller eye is given by:")
P1 = 1*100;
rho1 = P1/(R*Ta)* 1000
disp("Using the continuity equation in order to find the area at the impeller eye,")
m = 8; //kg/m
A1 = m/(rho1*C1) //m2
disp("The power input is: in kW")
P = m*W
```

Scilab code Exa 4.11 Double sided compressor

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

```
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 4, Example 11")
disp("Let Uer be the impeller speed at the eye root. Then the vane angle at the eye root is:")
disp("alphaer = atan(Ca/Uer)")
Der = 0.14; //m
N = 15000; //rpm
Uer = %pi*Der*N/60
disp("Hence, the vane angle at the impeller eye root :")
Ca = 145; //m/s
alphaer = atan(Ca/Uer)*180/%pi
disp("Impeller velocity at the eye tip")
Det = 0.28;
Uet = %pi*Det*N/60
disp("Therefore vane angle at the eye tip:")
alphaet = atan(Ca/Uet)*180/%pi
disp("Work input:")
m = 10;
psi = 0.89;
sigma = 1.03;
D2 = 0.48;
U2 = %pi*D2*N/60
W = m*psi*sigma*U2^2  /1000
disp("The relative velocity at the eye tip:")
V1 = (Uet^2+Ca^2)^0.5
disp("Hence, the maximum relative Mach number at the eye tip:")
disp("M1 = V1/(gamma*R*T1)")
disp("where T1 is the static temperature at the inlet")
T01 = 290;
C1 = 145;
Cp = 1005;
T1 = T01 - C1^2 / (2*Cp)
```

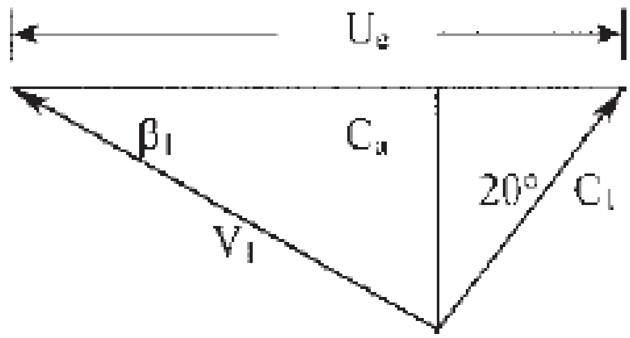

Figure 4.16 The velocity triangle at the impeller eye.

Figure 4.5: Recalculating 412

```
disp("The Mach number at the inlet then is:")
gamma = 1.4;
R = 287;
M1 = (V1)/(gamma*R*T1)^0.5
```

Scilab code Exa 4.12 `Recalculating 412`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 4, Example 12")
disp("Figure shows the velocity triangle with the
    prewhirl angle. From the velocity triangle:")
```

```
Ca = 145;//m/s
C1 = Ca/cos(20*%pi/180)//m/s
disp("Equivalent dynamic temperature: Eq = C1^2/2Cp")
Cp = 1005;
Eq = C1^2 / (2*Cp)
Cw1 = Ca*tan(20*%pi/180)
disp("Relative velocity at the inlet:")
Ue = 220;//m/s
V1 = (Ca^2 +(Ue - Cw1)^2)^0.5
disp("Therefore the static temperature at the inlet:")
T01 = 290;//K
T1 = T01-Eq
gamma = 1.4;
R = 287;
M1 = V1/(gamma*R*T1)^0.5
disp("Note the reduction in Mach number due to prewhirl.")
```

Scilab code Exa 4.13 `Centrifugal Compressor 16500rpm`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 4, Example 13")
disp("Let: rh = hub radius")
disp("     rt = tip radius")
disp("The flow area of the impeller inlet annulus is:")
rh = 0.0625;
```

```
rt = 0.125;
A = %pi*(rt^2-rh^2);
A1 = A + 0.0012
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.")
disp("Assuming a density based on the inlet
    stagnation condition,")
P01 = 1; //in bars
R = 287;
T01 = 288;//K
rho1 = P01*10^5  /(R*T01)
disp("Using the continuity equation,")
m = 5.5;
Ca = m/(rho1*A1)
disp("Since the whirl component at the inlet is zero
    , the absolute velocity at the inlet is C1 = Ca."
    )
C1 = Ca;
disp("The temperature equivalent of the velocity is:
     Eq")
Cp = 1005;
Eq = C1^2 /(2*Cp)
T1 = T01 - Eq
disp("Using isentropic  P T  relationship,")
P1 = P01*10^5 * (T1/T01)^3.5 /1000//kPa
rho1a = P1*1000/(R*T1) * 1.004
Caa = m/(rho1a * A1)
Eqa = Caa^2 /(2*Cp) * 1.003
T1a = T01 - Eqa
P1a = P01*10^5 *(T1a/T01)^3.5 /1000 //kPa
rho1b = P1a*1000/(R*T1a)
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:")
N = 16500;//rpm
```

```
Uet = 2*%pi*rt*N/60//m/s
disp("The blade angle at the eye tip:")
betat = atan(Uet/Caa)*180/%pi
disp("At the hub,")
Ueh = 2*%pi*rh*N/60//m/s
disp("The blade angle at the hub:")
betah = atan(Ueh/Caa)*180/%pi
disp("The Mach number based on the relative velocity
    at the eye tip using the inlet velocity triangle
    is:")
U1 = 216;
V1 = (Caa^2+U1^2)^0.5
disp("The relative Mach number")
gamma = 1.4;
M1 = V1/(gamma*R*T1a)^0.5
disp("A very small factor is multiplied to make
   approximity")
```

Scilab code Exa 4.14 ToT Efficiency 88

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 4, Example 14")
disp("The absolute Mach number of the air at the
   impeller tip is:")
disp("M2 = C2/(gamma*R*T2)^0.5")
disp("where T2 is the static temperature at the
   impeller tip. Let us first calculate C2 and T2.")
U2 = 364;
sigma = 0.89;
```

```
Cw2 = sigma*U2
disp("From the velocity triangle,")
Cr2 = 28;
C2 = (Cr2^2+Cw2^2)^0.5
disp("With zero whirl at the inlet")
disp("W/m = sigam*U2^2 = Cp (T02 - T01)")
T01 = 288;
Cp = 1005;
T02 = T01 + sigma*U2^2 / Cp
disp("Static Temperature")
T2 = T02 - C2^2 /(2*Cp)
gamma = 1.4;
R = 287;
M2 = (C2^2/(gamma*R*T2))^0.5
disp("Using the isentropic  P T  relation:")
disp("Ratioa = P02/P01 ")
etac = 0.88;
Ratioa = (1+etac * (T02/T01  - 1))^3.5
disp("Ratiob = P2/P02")
Ratiob = (T2/T02)^3.5
P01 = 1*100;
disp("Static Pressure in kPa")
P2 = Ratiob*Ratioa*P01
rho2 = P2*1000/(R*T2)
disp("Mass flow: in kg/s")
A = 0.085;//m2
m = rho2*Cr2*A
```

Scilab code Exa 4.15 Centrifugal Compressor 15500rpm

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

```
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 4, Example 15")
disp("Impeller tip speed")
D2 = 0.56;//m
N = 15500;//rpm
U2 = %pi*D2*N/60 + 0.188
R = 287;
disp("Overall stagnation temperature rise Stagr =
    T03-T01")
psi = 1.04;
sigma = 0.9;
Cp =1005;
Stagr = psi*sigma*U2^2 /Cp
disp("Since T03 = T02")
T01 = 290;
T02 = Stagr + T01
disp("Now pressure ratio for impeller rat = P02/P01"
    )
rat = (T02/T01)^3.5
P01 = 101 //kPa
P02 = rat * P01
Cw2 = sigma*U2
disp("Let Cr2 = 105 m/s")
Cr2 = 105;
disp("Outlet area normal to periphery")
disp("A2 = pi*D2 * impeller depth")
A2 = %pi*D2*0.038
disp("From outlet velocity triangle")
C2 = (Cr2^2 +Cw2^2)^0.5
T2 = T02 - C2^2 /(2*Cp)
disp("Using isentropic  P T  relations")
P2 = P02*(T2/T02)^3.5
disp("From equation of state")
rho2 = P2/(R*T2) * 1000
disp("The equation of continuity gives")
m = 16;
Cr2a = m/(A2*P2) * 100
```

```
disp("Thus, impeller outlet radial velocity = 81.63 m/s")
disp("Impeller outlet Mach number")
gamma = 1.4;
M2 = C2/(gamma*R*T2)^0.5
disp("From outlet velocity triangle")
alpha2 = acos(Cr2/C2)*180/%pi
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)")
r = 0.323;
r2 = 0.28;
Cw = Cw2*r2/r
disp("The radial component of velocity can be found by trial and error. Choose as a first try, Cr = 105 m/s")
Cr = 105;
C = (Cw^2+Cr^2)^0.5
x = C^2 /(2*Cp)
disp("T = 482.53 - 68 (since T = T02 in vaneless space)")
T = T02-x
P = P02*(T/T02)^3.5
rho = rho2/(R*T2) * 10^5 * 1.132
disp("The equation of continuity gives")
A = 2*%pi*r*0.038
Cra = m/(rho*A)
disp("Next try Cra = 79.41 m/s")
Cra = 79.41;
x1 = (Cra^2 + Cw^2)/(2*Cp)
Ta = T02 -x1
Px = P02*(Ta/T02)^3.5//Pa
rhox = P/(Ta*R) * 1000  + 0.1
Crb = m/(rhox*A)
disp("Try Crb = 68.1m/s")
x2 = (Crb^2+Cw^2)/(2*Cp)
Tb = T02-x2
```

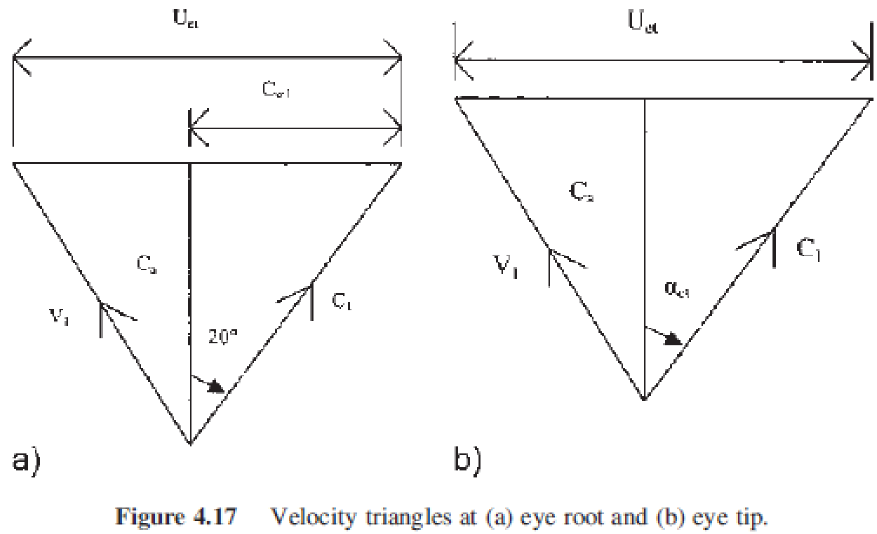

Figure 4.6: Double sided compressor 15500

```
Py = P02*(Tb/T02)^3.5
rhoy = Py/(Tb*R)* 1000
Crc = m/(rhoy*A)
disp("Taking Crc as 68.63 m/s, the vane angle")
alpha = atan(Cw/Crc)*180/%pi
disp("Mach number at vane")
M = (2*Cp*x1/(gamma*R*Tb))^0.5
//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`

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

```
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 4, Example 16")
disp("At eye root, Ca = 150 m/s")
Ca = 150;
C1 = Ca / cos(20*%pi/180)
Cw1 = Ca*tan(20*%pi/180)
disp("Impeller speed at eye root")
Der = 0.18;
N = 15500;//rpm
Uer = %pi*Der*N/60//m/s
disp("From velocity triangle")
betaer = atan(Ca/(Uer-Cw1))*180/%pi
disp("At eye tip from Figure")
Det = 0.3175;
Uet = %pi*Det*N/60
alphaet = atan(Ca/(Uet-Cw1))*180/%pi
disp("Mach number will be maximum at the point where relative velocity is maximum.")
disp("Relative velocity at eye root is:")
Ver = Ca/sin(betaer*%pi/180)
disp("Relative velocity at eye tip is:")
Vet = Ca/sin(alphaet*%pi/180)
disp("Relative velocity at the tip is maximum.")
disp("Static temperature at inlet:")
T01 =288;
Cp = 1005;
T1 = T01-Vet^2 /(2*Cp)
gamma = 1.4;
R = 287;
Mmax = Vet/(gamma*R*T1)^0.5
```

Scilab code Exa 4.17 Vanes 17 stagnation T and P

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 4, Example 17")
disp("Pressure is in bar and temperature in Kelvin")
disp("Mechanical efficiency is")
disp("etam = Work transferred to air/Work supplied to shaft")
disp("or shaft power = W/etam")
disp("for vaned impeller, slip factor, by Stanitz formula is")
disp("sigma = 1 - 0.63*pi/n")
n = 17;
R = 287;
sigma = 1-0.63*%pi/n;
disp("Work input per unit mass flow")
disp("W = psi*sigma*U2Cw2")
psi = 1.04;
U2 = 475;//m/s
W = psi*sigma*U2^2 /1000
disp("Work input for 2.5 kg/s")
Wi = W*2.5
disp("Shaft Power")
etam = 0.96;
Pshaft = Wi/etam
disp("The overall pressure ratio is pRatio = P03/P01")
P01 = 1.01;
etac = 0.84;
Cp = 1005;
T01 = 288;
pRatio = (1+etac*psi*sigma*U2^2 /(Cp*T01))^3.5
disp("Stagnation pressure at diffuser exit")
P03 = P01*pRatio
```

```
m = 2.5;
T03 = Wi*1000/(m*Cp) +T01
T02 = T03;
disp("Static temperature at diffuser exit")
C3 = 90;
T3 = T03 - C3^2 /(2*Cp)
disp("Static pressure at diffuser exit")
P3 = P03*(T3/T03)^3.5
disp("The reaction is 0.5 = (T2 - T1)/(T3 - T1)")
disp("x = T3 - T1")
C1 = 150;
x = Wi*1000/(m*Cp) + (C1^2 - C3^2)/(2*Cp)
disp("y = T2-T1")
y = 0.5*x
disp("Substituting T2 - T1")
T2 = T01 - C1^2 /(2*Cp) + y
disp("At the impeller exit")
disp("T02 = T2 + C2^2/2Cp")
disp("T03 = T2 + C2^2/2Cp (Since T02 = T03)")
C2 = (2*Cp*((T03-T01)+(T01-T2)))^0.5
disp("Mach number at impeller outlet")
M2 = C2/(1.4*R*T2)^0.5
disp("Radial velocity at impeller outlet")
Cw2 = sigma*U2;
Cr2 = (C2^2 - Cw2^2)^0.5
disp("Diffuser efficiency is given by")
disp("etaD = (h3a - h2)/(h3 - h2)")
disp(" = isentropic enthalpy increase/actual
    enthalpy increase")
disp(" = (T3a - T2)/(T3 - T2)")
disp(" z = P3/P2 implies")
etaD = 0.821;
z = (1+etaD *(T3-T2)/T2)^3.5
P2 = P3/z
disp("From isentropic  P T  relations in bars")
P02 = P2*(T02/T2)^3.5
disp("Impeller efficiency is")
etai = T01*((P02/P01)^0.286 -1)/(T03-T01) * 100
```

```
rho2 = P2/(R*T2) * 10^5//in kg/m3
disp("m = rho2A2Cr2")
disp(" = 2pi*r2*rho2*b2")
m = 2.5;
b2 = 0.0065;
N = U2*2.27*246.58*b2*60/m
```

Chapter 5

Axial Flow Compressors and Fans

Scilab code Exa 5.1 Work of compression

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

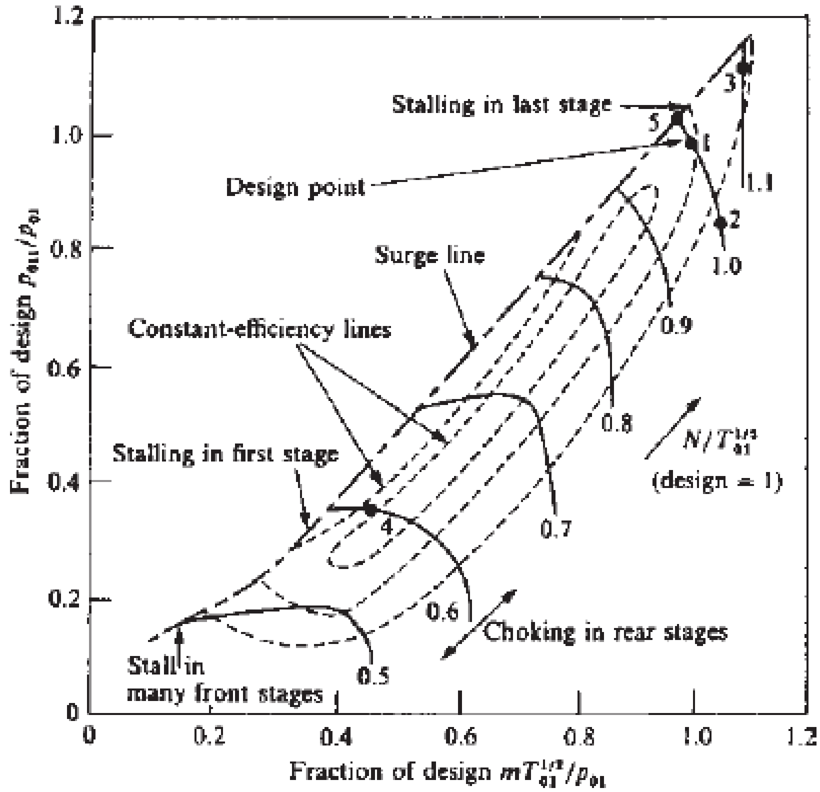

Figure 5.12 Axial flow compressor characteristics.

Figure 5.1: Work of compression

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

Scilab code Exa 5.2 One stage compressor

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

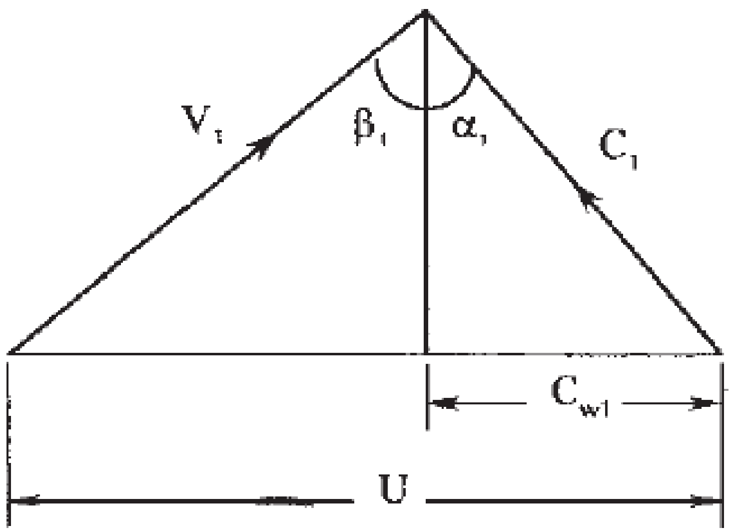

Figure 5.13 Inlet velocity triangle.

Figure 5.2: Compressor 5000rpm

Scilab code Exa 5.3 `Compressor 5000rpm`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 5, Example 3")
disp("Rotor speed is given by:")
D = 0.95; //m
N = 5000; //rpm
U = %pi*D*N/60
disp("Blade speed at the hub:")
Dh = 0.85;
Uh = %pi*Dh*N/60
disp("From the inlet velocity triangle (Figure)")
```

```
disp("tanalpha1 = Cw1/Ca and tanbeta1 = (U - Cw1)/Ca")
disp("Adding the above two equations:")
disp("U/Ca = tanalpha1 + tanbeta1")
alpha1 = 28;
beta1 = 56;
Ca = U/(tan(alpha1*%pi/180) + tan(beta1*%pi/180))
disp("Therefore, Ca = 123.47 m/s (constant at all radii)")
disp("The mass flow rate: in kg/s")
disp("m = pi*(rt^2 - rh^2)rho*Ca")
rt = 0.475;
rh = 0.425;
rho = 1.2;
m = %pi*rho*Ca*(rt^2 -rh^2)
disp("The power required per unit kg for compression is:")
disp("Wc = lambda*U*Ca*(tan(beta1) - tan(beta2)) in kJ/kg")
lambda = 1;
beta2 = alpha1;
Wc = lambda*U*Ca*(tan(beta1*%pi/180) - tan(beta2*%pi/180)) /1000
disp("The total power required to drive the compressor is: in kW")
P = m*Wc
disp("At the inlet to the rotor tip:")
Cw1t = Ca*tan(alpha1*%pi/180)//m/s
disp("Using free vortex condition, i.e., Cwr = constant, and using h as the subscript for the hub,")
Cw1h = Cw1t*rt/rh//m/s
disp("At the outlet to the rotor tip,")
alpha2 = beta1;
Cw2t = Ca *tan(alpha2*%pi/180)
Cw2h = Cw2t*rt/rh
disp("Hence the flow angles at the hub:")
alpha1a = atan(Cw1h/Ca)*180/%pi
```

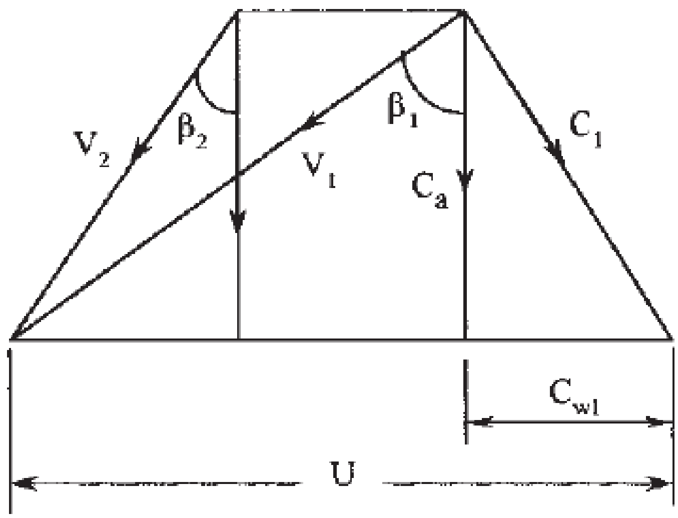

Figure 5.14 Velocity triangle at the mean radius.

Figure 5.3: Stage air angles for vortex

```
beta1a = atan((Uh/Ca) - tan(alpha1a*%pi/180))*180/%pi
alpha2a = atan(Cw2h/Ca)*180/%pi
beta2a = atan((Uh/Ca)  - tan(alpha2a*%pi/180)) *180/%pi
disp("The degree of reaction at the hub is given by:")
A = Ca*(tan(beta1a*%pi/180)+tan(beta2a*%pi/180))/(2*Uh) * 100
```

Scilab code Exa 5.4 `Stage air angles for vortex`

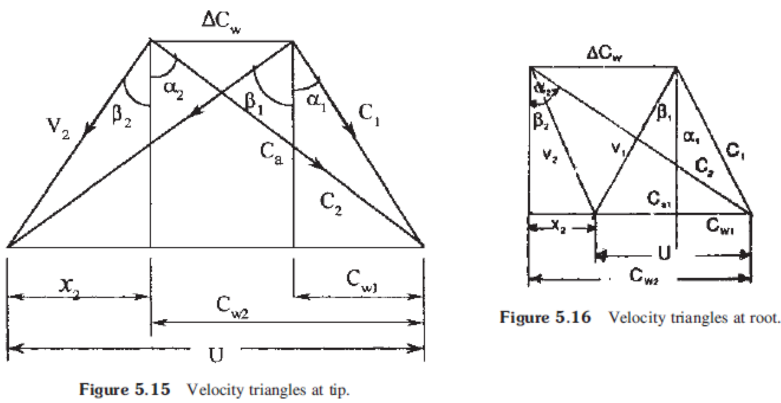

Figure 5.4: Stage air angles for vortex

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 5, Example 4")
disp("Calculation at mean radius:")
disp("Wc = U(Cw2 - Cw1) = U*DeltaCw")
disp("or")
disp(" Cp(T02 - T01) = CpDeltaT0s = lambda*U*DeltaCw")
Cp = 1005;
DeltaT0s = 15;
lambda = 0.85;
Um = 185;
DeltaCw = Cp*DeltaT0s/(lambda*Um)
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,")
disp("Um = DeltaCw + 2Cw1")
```

```
disp("Cw1 in m/s alpha1 in degrees")
Cw1 = (Um - DeltaCw)/2//m/s
Ca = 140;
alpha1 = atan(Cw1/Ca)*180/%pi
beta2 = alpha1
beta1 = atan((DeltaCw + Cw1)/Ca)*180/%pi
alpha2 = beta1
disp("Calculation at the blade tip: Using the free
    vortex diagram (Fig. 5.15), Velocity in m/s")
disp("(DeltaCw * U)t = (DeltaCw * U)m")
Ut = 240;
DeltaCwt =DeltaCw*Um/Ut
Cwt = Cw1*Um/Ut
alpha1t = atan(Cwt/Ca)*180/%pi
disp("From the velocity triangle at the tip, x2 +
    DeltaCwt + Cwt = Ut")
x2 = Ut-DeltaCwt - Cwt
beta1t = atan((DeltaCwt+x2)/Ca)*180/%pi
alpha2t = atan((Cwt+DeltaCwt)/Ca)*180/%pi
beta2t = atan(x2/Ca)*180/%pi
disp("Calculation at the blade root: (DeltaCwr * U)r
     = (DetaCw * U)m")
Ur = Ca;
DeltaCwr = DeltaCw*Um/Ur
Cwr = Cw1*Um/Ur
Cw2tip = Ca*tan(alpha2t*%pi/180)
Cw2root = Cw2tip*Ut/Ur
alpha1r = atan(Cwr/Ca)*180/%pi
x3 = Cw2root-Ur
beta1r = atan((Ur-Cwr)/Ca)*180/%pi
alpha2r = atan(Cw2root/Ca)*180/%pi
beta2r = -atan(x3/Ca)*180/%pi
```

Scilab code Exa 5.5 Degree of reaction for Ex54

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

Scilab code Exa 5.6 Temperature rise in first stage

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

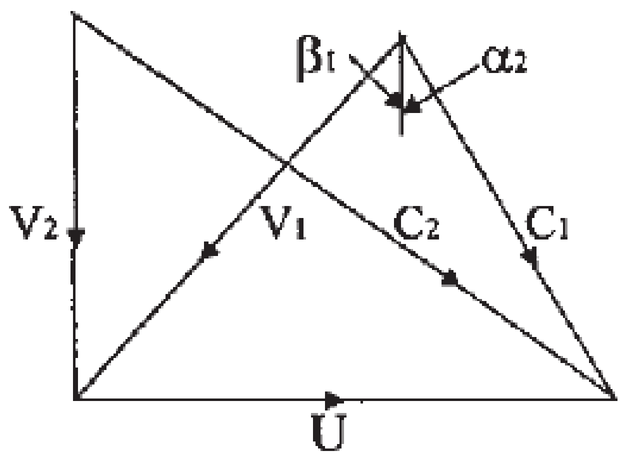

Figure 5.17 Combined velocity triangles for Example 5.6.

Figure 5.5: Temperature rise in first stage

```
disp("Since the degree of reaction is 50%, the
   velocity triangle is symmetric as shown in Figure
   Ex56")
disp("Using the degree of reaction equation")
disp("DOF = Ca(tanbeta1 + tanbeta2)/2U")
disp("phi = Ca/U")
disp("Now, for the relative Mach number at the inlet
   :")
DOF = 0.5;
phi = 0.56;
beta1 = atan(2*DOF/phi - tan(32*%pi/180))*180/%pi
disp("Mr1 = V1/(gamma*RT1)^0.5")
disp("V1^2 = gamma*R*Mr1^2*(T01 - C1^2/2Cp)")
disp("From the velocity triangle,")
disp("V1 = Ca/cosbeta1; and C1 = Ca/cosalpha1")
disp("alpha1 = beta2(since DOF = 0.5)")
disp("C1 = Ca/cos32 = Ca/0.848")
disp("V1 = Ca/cos 49.24 = Ca/0.653")
disp("Hence: C1^2/ = Ca^2/0.719; and V1^2 = Ca
```

```
^2/0.426")
disp("Substituting for V1 and C1,")
Ca = ((104.41*295*1445)/(1445+104.41))^0.5
disp("The stagnation temperature rise may be
   calculated as: Rise in Kelvin = T02-T01")
Cp = 1005;
Rise = Ca^2*(tan(beta1*%pi/180)- tan(32*%pi/180))/(
   Cp*phi)
```

Scilab code Exa 5.7 `Rpm 152 rps`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 5, Example 7")
disp("The following equation provides the
   relationship between the temperature rise and the
    desired angles:")
disp("T02 - T01 = lambda*U*Ca*(tan(beta1) - tan(
   beta2))/Cp")
disp("T02-T01 = Rise")
Rise = 24;
lambda = 0.93;
U = 205;
Ca = 155.5;
Cp = 1005;
disp("Dif = tan(beta1) - tan(beta2)")
Dif = Rise*Cp/(U*lambda*Ca)
disp("Using the degree of reaction equation:")
disp("DOF = Ca*(tan(beta1) + tan(beta2))/(2*U)")
disp("tan(beta1) + tan(beta2) = Add")
```

```
DOF = 0.5;
Add = DOF*2*U/Ca
beta1 = atan((Add+Dif)/2)*180/%pi
alpha2 = beta1
beta2 = atan(Add - tan(beta1*%pi/180))*180/%pi
alpha1 = beta2
disp("The mean radius, rm, is given by: in m")
N = 152; //rpm
rm = U/(2*%pi*N)
disp("The blade height, h in m, is given by: m = rho*ACa, where A is the annular area of the flow.")
C1 = Ca/cos(alpha1*%pi/180)
T01 = 290;
disp("Static temperature in kelvin")
T1 = T01- C1^2 /(2*Cp)
disp("Using the isentropic  P T  relation:")
disp("Static pressure: P1 in bars")
P01 = 1;
P1 = P01*(T1/T01)^3.5
R = 287/1000;
disp("Density rho1 in kg/m3")
rho1 = P1/(R*T1) * 100
disp("From the continuity equation:")
m = 22;
A = m/(rho1*Ca)
disp("and the blade height:")
rm = 0.215;
h =A/(2*%pi*rm)
```

Scilab code Exa 5.8 polytropic efficiency 87

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

```
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 5, Example 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:")
Ca = 158;
beta2 = 30;
Vx2 = Ca*tan(beta2*%pi/180)
disp("V1 = C2 = (U - Vx2)^2 + Ca^2)^1/2")
U = 245;
Vx2 = 91.22;
Ca = 158;
C2 = ((U - Vx2)^2 + Ca^2)^0.5
V1 = C2
beta1 = acos(Ca/V1)*180/%pi
disp("Stagnation temperature rise in the stage , in Kelvin")
disp("DeltaT0s = UCa(tanbeta1 - tanbeta2)/Cp")
Cp = 1005;
DeltaT0s = U*Ca*(tan(beta1*%pi/180) - tan(beta2*%pi/180))/Cp
disp("n /(n-1) = inf * gamma/(gamm-1 = 3.05)")
disp("Number of stages")
N = (4.5^(1/3.05) -1)*290/DeltaT0s
disp("implies N = 12 stages")
```

Scilab code Exa 5.9 `Rotor speed 200`

```
// Display mode
```

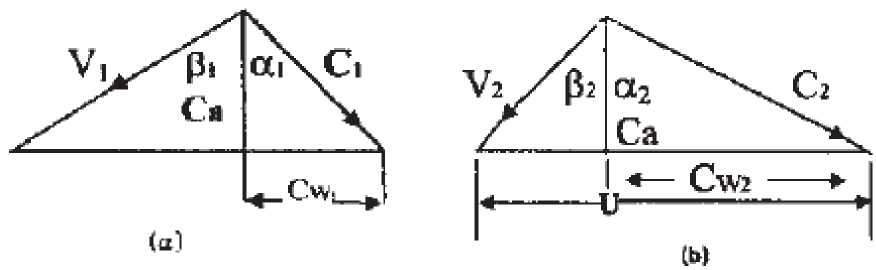

Figure 5.18 Velocity triangles (a) inlet, (b) outlet.

Figure 5.6: Rotor speed 200

```
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 5, Example 9")
disp("For 50% degree of reaction at the mean radius
   (Fig. Ex59), alpha1 = beta2 and alpha2 = beta1.")
disp("From the inlet velocity triangle,")
Ca = 180;
C1 = 185;
Cp = 1005;
alpha1 = acos(Ca/C1)*180/%pi
beta2 = alpha1
disp("From the same velocity triangle,")
Cw1 = (C1^2 - Ca^2)^0.5
U = 200;
beta1 = atan((U-Cw1)/Ca)*180/%pi
alpha2 = beta1
disp("Static temperature at stage inlet may be
   determined by using stagnation and static
   temperature relationship as given below: in
   Kelvin")
T01 = 290;
```

```
T1 = T01 - C1^2/(2*Cp)
disp("Stagnation temperature rise of the stage is
    given by")
lambda = 0.86;
DeltaT0s = lambda*U*Ca*(tan(beta1*%pi/180)-tan(beta2
    *%pi/180))/Cp
disp("Stage pressure ratio is given by")
etas = 0.86;
Rs = (1+ etas*DeltaT0s/T01)^3.5
```

Scilab code Exa 5.10 Isentropic Efficiency

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 5, Example 10")
disp("Using the isentropic P T relation for the
    compression process,")
disp("P02/P01 = r, T02a in Kelvin is")
r = 6
T01 = 285;
gam = 1.4;
x = (gam-1)/gam;
T02a = T01*r^x
disp("Using the polytropic P T relation for the
    compression process:")
etainf = 0.85;
disp("(n-1)/n = R")
R = (gam-1)/(gam*etainf)
disp("Actual temperature rise:")
T02 = T01*r^R
```

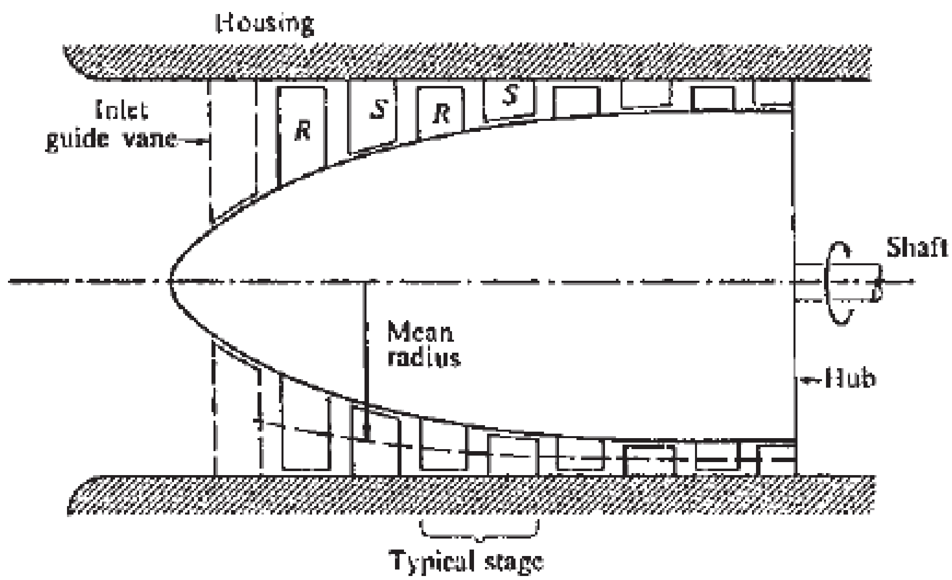

Figure 5.3 Schematic of an axial compressor section.

Figure 5.7: Rotation 5500rpm

```
disp("The compressor isentropic efficiency is given
    by:")
etac = (T02a-T01)/(T02-T01) *100
```

Scilab code Exa 5.11 Rotation 5500rpm

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
```

```
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 5, Example 11")
disp("As no inlet guide vanes alpha1 = 0; Cw1 = 0")
disp("Stagnation temperature, T01 in Kelvins, is given by")
T01 = 290;
C1 = 145;
Cp = 1005;
Ca = C1;
T1 = T01 - (C1/(2*Cp)) - 1
disp("The Mach number relative to tip is")
M = 0.96;
gam = 1.4;
R = 287;
V1 = M*(gam*R*T1)^0.5 *1.04
disp("i.e., relative velocity at tip = 340.7 m/s. From velocity triangle at inlet Fig 511")
Ut = (V1^2 - C1^2)^0.5
disp("Radius in m")
N = 5500;
rt = Ut*60/(2*%pi*N)
beta1 = atan(Ut/Ca)*180/%pi
DeltaT0s = 22;
Tau = 0.92;
disp("tan(beta1) - tan(beta2) = Dif")
Dif = DeltaT0s*Cp/(Tau*Ut*Ca)
beta2 = atan(1.588)*180/%pi
h = 0.268;
rm = 0.402;
A = 2*%pi*rm*h//m2
P01 = 1;//bar
P1 = P01*(T1/T01)^3.5
R = 287;
rho1 = P1/(R*T1) * 10^5
m = rho1*A*Ca
disp("Stage pressure ratio is")
etas = 0.9;
Rs = (1+etas*DeltaT0s/T01)^3.5
```

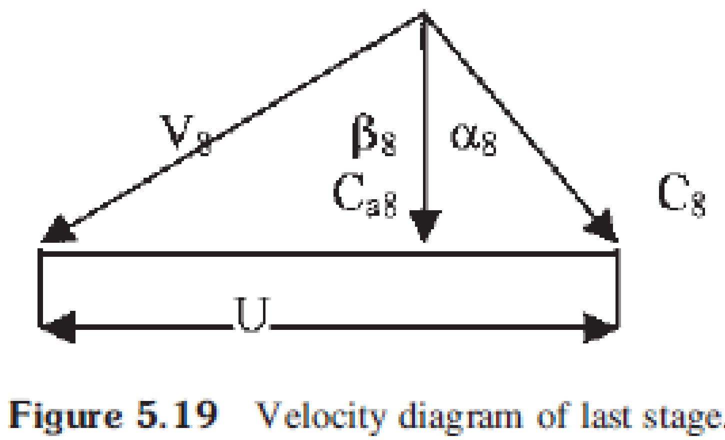

Figure 5.8: Number of stages

```
W = Cp*DeltaT0s//kJ/kg
disp("Power required by the compressor in kW")
P = m*W/1000
disp("In order to find out rotor air angles at the
   root section , radius at the root can be found as
   given below.")
rr = rm - h/2
disp("Impeller speed at root is")
Ur = 2*%pi*rr*N/60
disp("Therefore , from velocity triangle at root
   section")
beta1 = atan(Ur/Ca)*180/%pi
disp("tanbeta1 − tanbeta2 = R")
R = DeltaT0s*Cp/(Tau*Ur*Ca)
beta2 = atan(tan(46.695*%pi/180)-1.078)*180/%pi
```

Scilab code Exa 5.12 Number of stages

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 5, Example 12")
disp("If N is the number of stages, then overall pressure rise is:")
disp("R = (1+(N*DeltaT0s)/T01)^((n-1)/n)")
disp("Exp=(n-1)/n = etaac *gam/(gam-1)")
disp("(where hac is the polytropic efficiency) substituting values")
etaac = 0.87;
gam = 1.4;
Exp = etaac *gam/(gam-1)
R=4.5;
Cp = 1005;
DeltaTs = 22;
T01 = 290;
N = ((R^(1/3.05)) -1)*T01/DeltaTs
disp("Hence number of stages = 8")
disp("Stagnation temperature rise, DeltaTs, per stage = 22K, as we took 8 stages, therefore")
DeltaT0s = DeltaTs*N/8
disp("From velocity triangle cos(a8) = Ca8/C8")
alpha8 = 20;
C8 = 160;
Ca8 = C8*cos(alpha8*%pi/180)
disp("Using degree of reaction, DOF = 0.5")
disp("0.5 = Ca8(tanbeta8 + tanbeta9)/(2U)")
disp("0.5 = 150.35(tanbeta8 + tanbeta9)/2U --------(A)")
disp("DelTaT0s = TauUCa8*(tanbeta8 - tanbeta9)/Cp")
disp("23.1 = 0.85*U*150.35(tanbeta8 - tan20)/1005 -------(B)")
Tau = 0.85;
```

```
beta9 = alpha8;
disp("From Eq. (A) U = 150.35(tanbeta8 - 0.364) ------(C)")
disp("From Eq. (B) U = 181.66/(tanbeta8 - 0.364) ------(D)")
disp("Comparing Eqs. (C) and (D), we have")
disp("150.35(tanbeta8 + 0.364)= 181.66/(tanbeta8 - 0.364)")
disp("(tan(beta8))^2 = p")
p = 181.66/150.35 + 0.364^2
beta8 = atan(p^0.5)*180/%pi
disp("Substituting in Eq. (C)")
U = Ca8*(tan(beta8*%pi/180) + tan(beta9*%pi/180))
disp("The rotational speed is given by N in rps")
N = U/(2*%pi*0.0925)
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.")
disp("Stagnation temperature of last stage: Fig. Ex512")
T08 = T01 + 7*DeltaT0s
disp("Pressure ratio of the first stage is: Rat = P09/P08")
Rat = 1.1643
disp("Rat1 = P09/P01")
Rat1 = 4
P01 = 1;//in bars
P09 = Rat1*P01//bars
P08 = P09/Rat
T8 = T08 - C8^2 /(2*Cp)
disp("Using stagnation and static isentropic temperature relationship for the last stage, we have pressure in bars")
P8 = P08*(T8/T08)^(3.5)
R = 287;
rho8 = P8/(R*T8)*100000//in kg/m3
disp("Using mass flow rate m = rho8*A8*Ca8")
```

```
m = 3.5;
A8 = m/(rho8*Ca8)
r = 0.0925;
h = A8/(2*%pi*r)
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`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 5, Example 13")
disp("No. of stages = 10")
disp("The overall stagnation temperature rise is:")
T01 = 290;
R = 4.5;
etac = 0.88;
T1 = (290*(4.5^0.286 - 1))
disp("The stagnation temperature rise of a stage")
T0s = T1/10
disp("The stagnation temperature rise in terms of air angles is:")
disp("T0s = TauUCa(tanalpha2 - tanalpha1)/Cp")
disp("(tanalpha2 - tanalpha1) = T0s * Cp/(TauUCa)")
disp("(tanalpha2 - tanalpha1)= Dif -------(A)")
Tau = 0.87;
Cp = 1005;
U = 218;
Ca = 165;
Dif = T0s*Cp/(Tau*U*Ca)
```

```
disp("From degree of reaction DOF")
disp("DOF = (1 - Ca*(tanalpha2 + tanalpha1)/2U)")
disp("0.76 = (1 - 165(tanalpha2 + tanalpha1)/(2*218))")
disp("(tanalpha2 + tanalpha1) = Add -------(B)")
Add = (1-0.76)*(2*U)/Ca
disp("Adding (A) and (B), we get")
alpha2 = atan((Add+Dif)/2)*180/%pi
alpha1 = atan((Add-Dif)/2)*180/%pi
disp("Similarly, for beta1 and beta2, degree of reaction")
disp("Add1 = tanbeta1 + tanbeta2 = 2.01")
Add1 = 2.01;
disp("and Dif1 = tanbeta1 - tanbeta2 = 0.501")
Dif1 = 0.501;
beta1 = atan((Add1+Dif1)/2)*180/%pi
beta2 = atan((Add1-Dif1)/2)*180/%pi
```

Scilab code Exa 5.14 `Rotation 5400rpm`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 5, Example 14")
disp("Impeller speed is U in m/s")
rt = 0.45;//m
N = 5400;//rpm
U = 2*%pi*rt*N/60
disp("From velocity triangle")
disp("U = Ca*(tanalpha1 + tanbeta1)")
alpha1 = 28;
```

```
beta1 = 58;
Ca = U/(tan(alpha1*%pi/180)+tan(beta1*%pi/180))
disp("Flow area is A in m2")
rtip=rt;//m
rroot=0.42;//m
A = %pi*(0.45^2 - 0.42^2)
disp("Mass flow rate is m in kg/s")
rho = 1.5;//kg/m3
m = rho*A*Ca
disp("Power absorbed by the compressor P in kW")
disp(" = Tau*U(Cw2 - Cw1)")
disp(" = Tau*U*Ca*(tanalpha2-tanalpha1)")
alpha2 = beta1;
Tau = 0.93;
P = Tau*U*Ca*(tan(alpha2*%pi/180)-tan(alpha1*%pi/180))*1.001
disp("Total Power in kW")
Pt = m*P/1000*1.017
disp("and whirl velocity at impeller tip Cwt in m/s")
Cwt = Ca*tan(alpha1*%pi/180)
disp("Now using free vortex condition")
disp("r Cw = constant")
disp("[ rhCw1h = rtCw1t (where subscripts h for hub and t for tip)")
rh = 0.4;
Cw1h = rt*Cwt/rh
Cw2t = Ca*tan(alpha2*%pi/180)
Cw2h = Cw2t*rt/rh
disp("Therefore, the flow angles at the hub are")
alpha1h = atan(Cw1h/Ca)*180/%pi
Uh = 2*%pi*rh*N/60
beta1h = atan((Uh-Ca*tan(alpha1h*%pi/180))/Ca)*180/%pi
alpha2h = atan(Cw2h/Ca)*180/%pi
beta2h = atan((Uh-Ca*tan(alpha2h*%pi/180))/Ca)*180/%pi
disp("Finally, the degree of reaction at the hub is
```

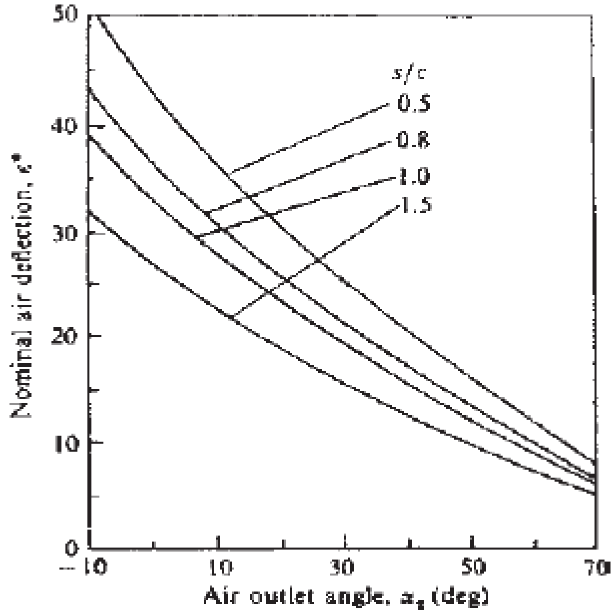

Figure 5.20 Cascade nominal deflection versus air outlet angle.

Figure 5.9: Rotation 8000rpm

```
    DOF in %")
DOF = Ca*(tan(beta1h*%pi/180)+tan(beta2h*%pi/180))
    /(2*Uh) *100
```

Scilab code Exa 5.15 `Rotation 8000rpm`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
```

```
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 5, Example 15")
disp("Angles are in degrees, lengths in meters,
    velocities in m/s, temperatures are in Kelvins")
disp("Using Equation at the mean radius")
disp("Wc = Cp(DeltaTA + DeltaTB) =DeltaTS")
disp("Dif = T02-T01")
Dif = 20;
tau = 0.94;
U = 200;
Ca = 155;
Cp = 1005;
N = 8000;
disp("tan(beta1)-tan(beta2) = Dift -------(A)")
Dift = Dif*Cp/(tau*U*Ca)
disp("Using Equation, the degree of reaction (DOF)
    is")
disp("DOF = Ca*(tan(beta1)+tan(beta2))/(2U)")
disp("tan(beta1)+tan(beta2) = Add -------(B)")
DOF = 0.5;
Add = DOF*2*U/Ca
disp("Solving (A) and (B) equations simultaneously")
beta1 = atan((Add+Dift)/2)*180/%pi
alpha2 = beta1;
beta2 = atan(1.29-tan(beta1*%pi/180))*180/%pi
alpha1 = beta2;
disp("Let rm be the mean radius")
rm = U/(2*%pi*N)//m
disp("Using continuity equation in order to find the
     annulus area of flow")
C1 = Ca/cos(alpha1*%pi/180)//m/s
T01 = 290;
T1 = T01-C1^2 /(2*Cp)
disp("Using isentropic relationship at inlet: p1/p01
     = (T1/T01)^(gamma/(gamma-1))")
disp("Static pressure is P1 in bars")
P01 = 1;
P1 = P01*(T1/T01)^3.5
```

```
disp("Density in kg/m3")
R = 287;
rho1 = P1/(R*T1) *10^5
disp("From the continuity equation,")
m = 22;//kg
A = m/(rho1*Ca)
disp("blade height in m is")
h = A/(2*%pi*rm)
disp("At mean radius, and noting that blades beta,
    an equivalent to cascade, alpha, nominal air
    deflection is Epsilon")
Epsilon = beta1-beta2
disp("Using Fig. Ex515 for cascade nominal
    deflection vs. air outlet angle, the solidity,")
disp("s/c = 0.5")
disp("Blade aspect ratio = span/chord")
disp("Blade chord = C")
C = 0.089/3
disp("Blade pitch = s")
s = 0.5*C
disp("Both the Chord and pitch/span are in meters")
```

Chapter 6

Steam Turbines

Scilab code Exa 6.1 `Isentropic expansion`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 6, Example 1")
disp("From saturated steam tables, enthalpy of saturated vapor at 2 MPa:")
disp("Enthalpy in kJ/kg")
h1 = 2799.5
hg = h1
disp("Entropy in kJ/kgK")
s1 = 6.3409
sg = s1
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:")
x2 = (sg - 1.5301)/5.5970
disp("h2")
hf2 = 504.7;
hfg2 = 2201.9;
disp("h2 in kJ/kg")
h2 = hf2+x2*hfg2
disp("Using the energy equation:C2 in m/s")
C2 = (2*(h1-h2)*1000)^0.5
```

Scilab code Exa 6.2 Mass of steam discharged

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

```
disp("Actual enthalpy drop due to friction loss in the nozzle droping in kJ/kg")
Droping = 0.9*drop
disp("Hence, the velocity of steam at the nozzle exit:")
C2 = (2*1000*Droping)^0.5
disp("Specific volume of steam at 0.1 MPa: in m3/kg")
vg2 = 1.694;
Specificv = x2*vg2
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)")
disp("Mass flow rate of steam at the nozzle exit: in kg/h")
m = (0.01^2)*%pi*C2/(4*x2*vg2) *3600
```

Scilab code Exa 6.3 Exit area required

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 6, Example 3")
P1 = 7.5;//MPa
h1 = 3404.3;//kJ/kg
s1 = 6.7598;//kJ/kg K
disp("(h1 and s1 from superheated steam tables)")
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 =
```

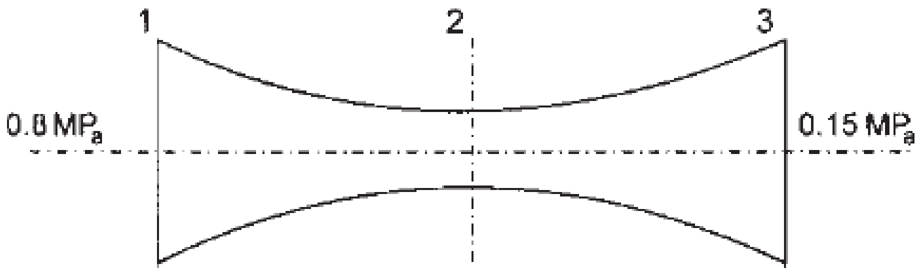

Figure 6.6 Convergent–divergent nozzle.

Figure 6.1: Ratio of cross sectional area

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

Scilab code Exa 6.4 Ratio of cross sectional area

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

```
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 6, Example 4")
disp("Critical pressure for maximum mass flow is
   given by Fig. Ex64")
disp("Pc is critical pressure in MPa")
P1 = 0.8;//MPa
n = 1.135;//index
Pc = P1*(2/(n+1))^(n/(n-1))
P2 = Pc;
disp("From the Mollier chart:")
disp("h1 = 2769 kJ/kg")
disp("h2 = 2659 kJ/kg")
disp("h3 = 2452 kJ/kg")
h1 = 2769;
h2 = 2659;
h3 = 2452;
disp("Enthalpy drop from 0.8 MPa to 0.15 MPa:")
Deltah13 = h1-h3
disp("Enthalpy drop from 0.8 MPa to 0.462 MPa:")
Deltah12 = h1-h2
disp("Dryness fraction:")
x2 = 0.954
x3 = 0.902
disp("The velocity at the exit in m/s")
C3 = (2*1000*Deltah13)^0.5
disp("The velocity at the throat in m/s")
C2 = (2*1000*Deltah12)^0.5
disp("Mass discharged at the throat")
disp("m2 = A2C2/x2vg2")
disp("Mass discharged at the exit")
disp("m3 = A3C3/x3vg3")
disp("A3C3/x3vg3 = A2C2/x2vg2")
disp("A3/A2 = (C2/C3) * (x3vg3/x2vg2)")
disp("Area Ratio A3/A2 = Ar")
vg3 = 1.1593;
vg2 = 0.4038;
Ar = C2*x3*vg3/(C3*x2*vg2)
```

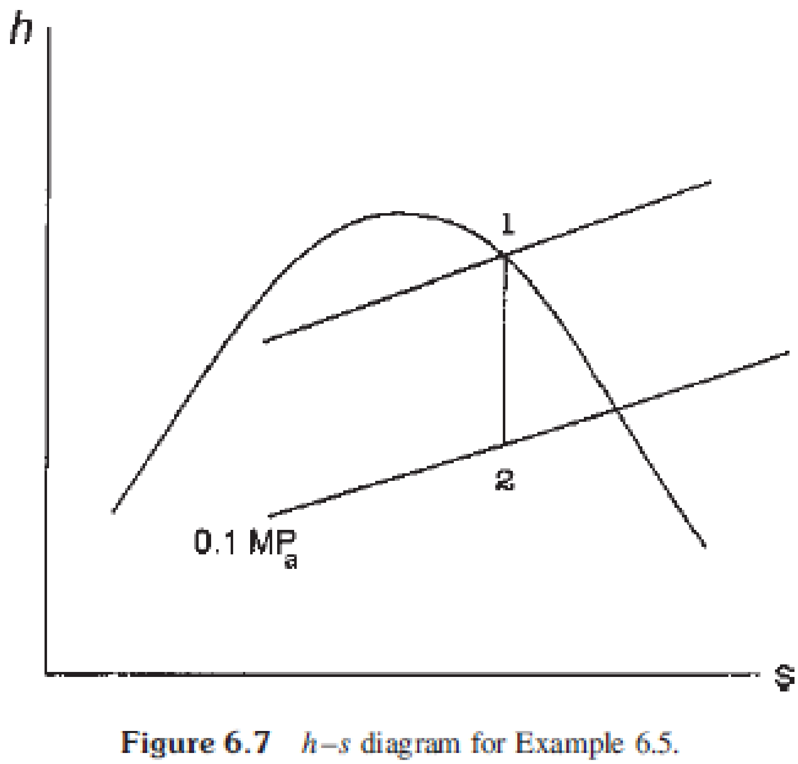

Figure 6.2: Convergent Divergent Nozzle

Scilab code Exa 6.5 `Convergent Divergent Nozzle`

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

```
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 6, Example 5")
disp("At the state point 2, the dryness fraction is
   0.85 and the pressure is 0.1 MPa.")
disp("This problem can be solved easily by the
   Mollier chart or by calculations.")
disp("Enthalpy and entropy may be determined using
   the following equations:")
disp("h2 = hf2 + x2hfg2 and s2 = sf2 + x2sfg2;")
hf2 = 417.46
x2 = 0.85
hfg2 = 2258
h1 = hf2+x2*hfg2
sf2 = 1.3026
sfg2 = 6.0568
s2 = sf2+x2*sfg2
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.")
disp("Therefore pressure P1 may be determined by the
    Mollier chart or by calculations: i.e.: P1 =
   1.474 MPa.")
disp("Elthalpies are in kJ/kg, entropy in kJ/kgK and
    Pressure in MPa")
```

Scilab code Exa 6.6 Steam leaving nozzle at 925

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

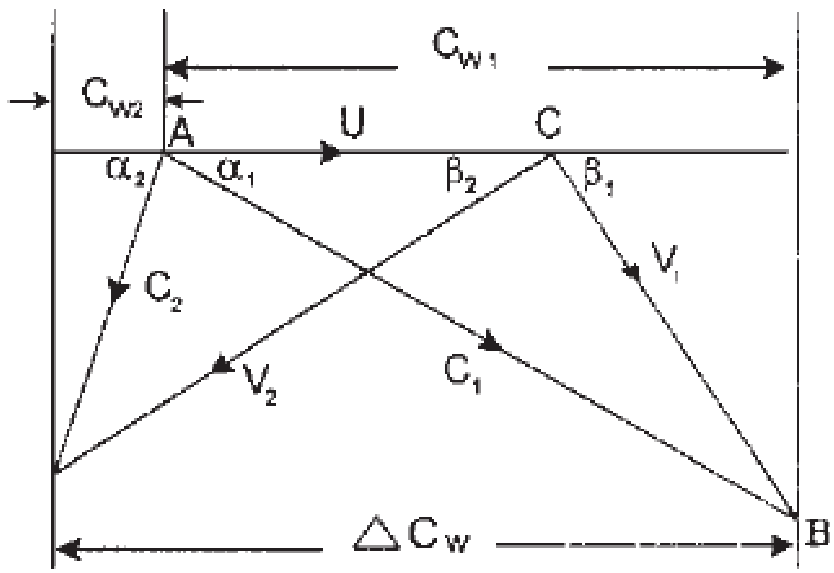

Figure 6.23 Velocity triangles for Example 6.6.

Figure 6.3: Steam leaving nozzle at 925

```
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 6, Example 6")
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.")
disp("Applying the cosine rule to the triangle ABC, V1 and V2 in m/s implies")
U = 250;
C1 = 925;
alpha1 = 20;
V1 = (U^2 + C1^2 -2*U*C1*cos(alpha1*%pi/180))^0.5
k = 0.7;
V2 = k*V1
disp("Velocity of whirl at inlet:")
Cw1 = C1*cos(alpha1*%pi/180)
disp("Axial component at inlet:")
Ca1 = C1*sin(alpha1*%pi/180)
disp("Blade angle at inlet")
beta1 = atan(Ca1/(Cw1-U))*180/%pi
disp("beta2 = beta1 = outlet blade angle")
beta2 = beta1
Cw2 = cos(beta2*%pi/180)*V2 - U
disp("Ca2 = FE")
Ca2 = (U+Cw2)*tan(beta2*%pi/180)
disp("Velocity of whirl at inlet, Cw1 = 869.22 m/s;")
disp("Velocity of whirl at outlet, Cw2 = 183.69 m/s")
disp("Tangential force on blades in N")
m = 0.182;//kg/s
Ft = (Cw1+Cw2)*m
disp("Axial force on blades in N")
Fa = m*(Ca1-Ca2)
disp("Work done on blades in kW")
disp("= tangential force on blades * blade velocity")
```

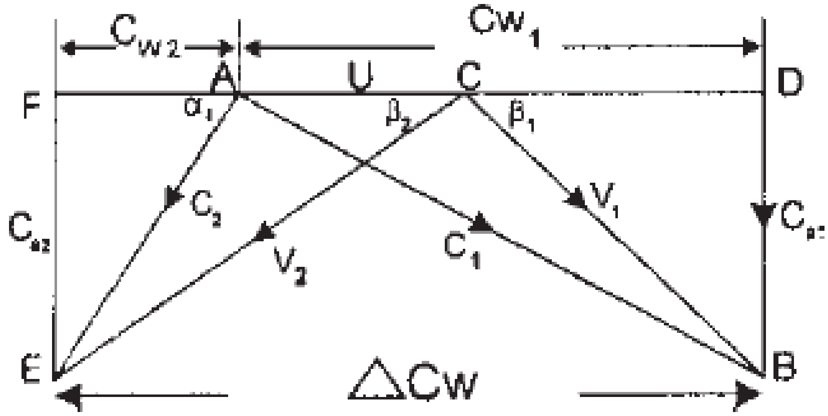

Figure 6.24 Velocity diagram for Example 6.7.

Figure 6.4: Steam leaving nozzle at 590

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

Scilab code Exa 6.7 `Steam leaving nozzle at 590`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
```

```
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 6, Example 7")
disp("Blade speed U is given by: in m/s")
D = 1050;
N = 2800;
U1 = %pi*D*N/(60*1000)
disp("The velocity diagram is shown in Fig. Ex67. Applying the cosine rule to the triangle ABC,")
C1 = 590;
alpha1 = 20;
V1 =(U1^2+C1^2-2*U1*C1*cos(alpha1*%pi/180))^0.5
disp("Applying the sine rule to the triangle ABC, C1sin (ACB) = V1/sin (alpha1)")
disp("but sin(ACB) = sin(180-beta1) = sin(beta1)")
beta1 = asin(C1*sin(alpha1*%pi/180)/V1)*180/%pi
beta2 = beta1;
disp("From Triangle ABD")
Cw1 = C1*cos(alpha1*%pi/180)
disp("From triangle CEF")
disp("Ca2/(U + Cw2) = tan(beta2) = tan(beta1) = tan(26.75) = 0.504")
Ca2 =155;
Cw2 = Ca2/tan(beta1*%pi/180) -U1
DeltaCw = Cw1+Cw2
disp("Relative velocity at the rotor outlet is:")
V2 = Ca2/sin(beta2*%pi/180)
disp("Blade velocity coefficient is:")
k = V2/V1
disp("Work done on the blades per kg/s: in kW")
W = DeltaCw *U1/1000
disp("Diagram efficiency")
etad = 2*W/(C1^2) *100000
```

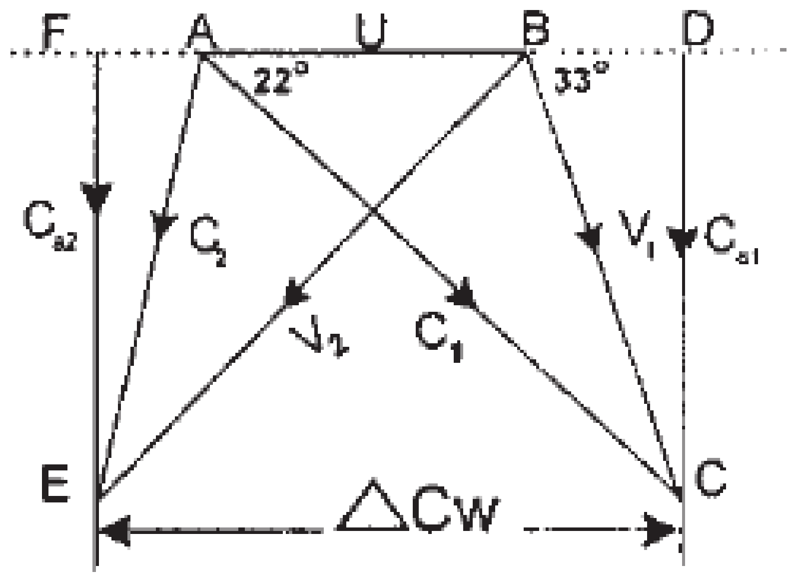

Figure 6.25 Velocity triangles for Example 6.8.

Figure 6.5: 1 stage impulse turbine

Scilab code Exa 6.8 1 stage impulse turbine

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 6, Example 8")
disp("From triangle ABC Figure Ex68")
C1 = 460;
a = 22;//degrees
Cw1 = C1 *cos(a*%pi/180)
Ca1 = C1*sin(a*%pi/180)
disp("Now from triangle BCD")
BD = Ca1/tan(33*%pi/180)
disp("Hence, blade speed is given by: in m/s")
U = Cw1-BD
disp("From Triangle BCD, relative velocity at blade inlet is given by: in m/s")
V1 = Ca1/sin(33*%pi/180)
disp("Velocity coefiicient")
k = 0.75
V2 = V1*k
disp("From triangle BEF")
BF = V2*cos(33*%pi/180)
Cw2 = BF-U
AF = Cw2;
Ca2 = V2*sin(33*%pi/180)
disp("The change in velocity of whirl:")
DeltaCw = Cw1+Cw2
disp("Diagram efficiency")
etad = 2*DeltaCw*U/C1^2 * 100
disp("End thrust on the shaft per unit mass flow: in N")
F = Ca1-Ca2
```

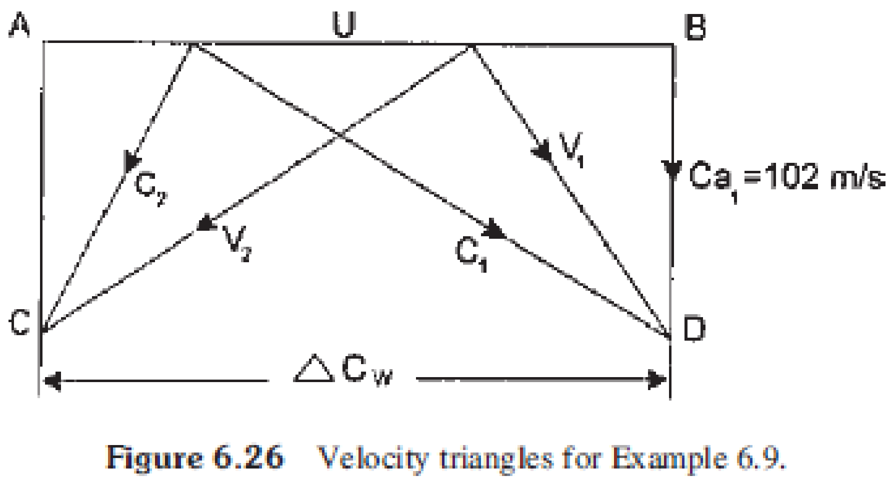

Figure 6.6: Parson Turbine

Scilab code Exa 6.9 `Parson Turbine`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 6, Example 9")
disp("The blade speed, in m/s")
D = 1.3;
N = 3000;
U = %pi*D*N/60
disp("Velocity of flow,in m/s")
```

```
Ca = 0.5*U
C2 = 102;
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.")
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 Parsons turbine,")
disp("alpha1 = beta2 , beta1 = alpha2 , C1 = V2 and V1 = C2")
disp("By measurement")
Cw1 = 280.26;
Cw2 = 76.23;
DeltaCw = Cw1+Cw2
disp("The inlet angles are 53.22 degrees.Specific volume of vapor at 0.5 MPa, from the steam tables, is in m3/kg")
vg = 0.3749
disp("Therefore the mass flow is given by:")
x2 = 1;
A= %pi*1.3*6;
m = A*C2/(x2*vg)/100
disp("Power developed in kW")
P = m*C2*DeltaCw/1000
```

Scilab code Exa 6.10 Steam leaving nozzle at 950

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

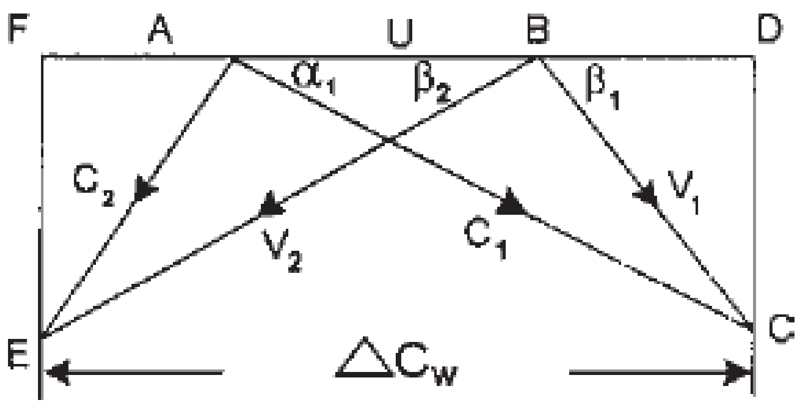

Figure 6.27 Velocity triangles for Example 6.10.

Figure 6.7: Steam leaving nozzle at 950

```
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 6, Example 10")
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")
disp("Applying the cosine rule to the triangle ABC,"
    )
C1 = 950;
U = 380;
alpha1 = 20;
V1 = (U^2+C1^2-2*U*C1*cos(alpha1*%pi/180))^0.5
disp("Now, applying the sine rule to the triangle
    ABC,")
disp("V1/sin(alpha1) = C1/sin(180-beta1) = C1/sin(
    beta1)")
beta1 = asin(C1*sin(alpha1*%pi/180)/V1)*180/%pi
disp("From triangle ACD")
Cw1 = C1*cos(alpha1*%pi/180)
disp("As beta1 = beta2, using triangle BEF and
```

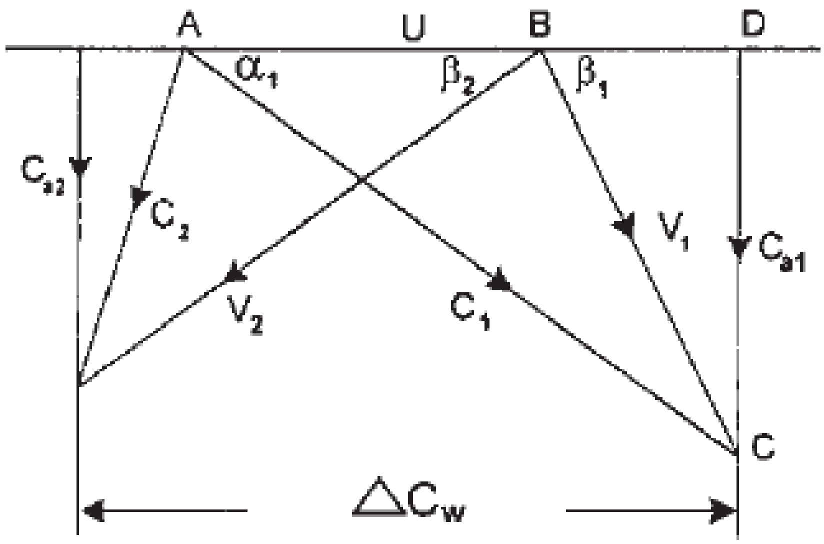

Figure 6.28 Velocity triangles for Example 6.11.

Figure 6.8: Steam leaving nozzle at 700

```
    neglecting friction loss, i.e. V1 = V2")
beta2 = beta1;
V2 = V1;
BF = V2 *cos(beta2*%pi/180)
Cw2 = BF-U
disp("Change in velocity of whirl:")
DeltaCw = Cw1+Cw2
disp("Tangential force on blades: in N")
m = 12;
F = m*DeltaCw/60
disp("Horse Power")
P = m*U*DeltaCw/(60*1000*0.746)
```

Scilab code Exa 6.11 `Steam leaving nozzle at 700`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 6, Example 11")
disp("Velocity triangles for this problem are shown in Fig.Ex611")
disp("From the triangle ACD,")
C1 = 700;
alpha1 = 22;
Ca1 = C1*sin(alpha1*%pi/180)//in m/s
beta1 = 34;
V1 = Ca1/sin(beta1*%pi/180)//in m/s
disp("Whirl component of C1 is given by in m/s")
Cw1 = C1*cos(alpha1*%pi/180)
disp("BD = Cw1 - U = V1cosbeta1")
BD = V1*cos(beta1*%pi/180)
disp("Hence, blade speed in m/s")
U = Cw1-BD
disp("Using the velocity coefficient to find V2:")
k = .9;
V2 = k*V1
disp("From velocity triangle BEF,")
beta2 = beta1;
Ca2 = V2*sin(beta2*%pi/180)
Cw2 = V2*cos(beta2*%pi/180) - U
DeltaCw = Cw1+Cw2
disp("mass flow rate is given by m. in kg/s")
P = 1600;
```

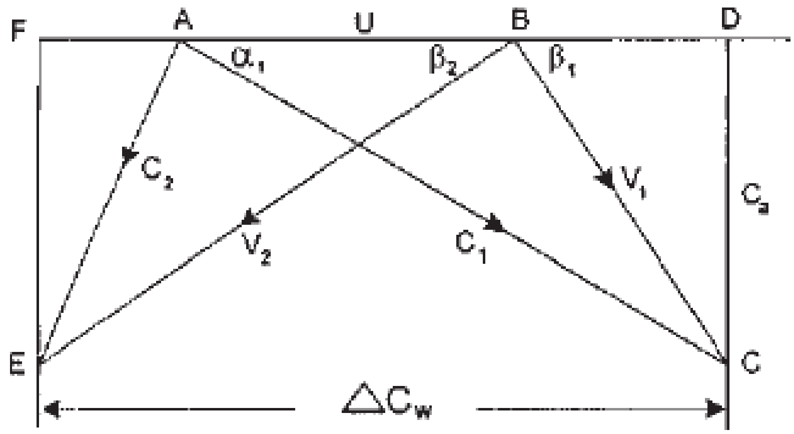

Figure 6.29 Velocity triangles for Example 6.12.

Figure 6.9: Axial velocity constant

```
m = P*1000/(DeltaCw*U)
disp("Thrust on the shaft in N")
Ft = m*(Ca1-Ca2)
disp("Diagram efficiency")
etad = 2*U*DeltaCw/C1^2 * 100
```

Scilab code Exa 6.12 `Axial velocity constant`

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

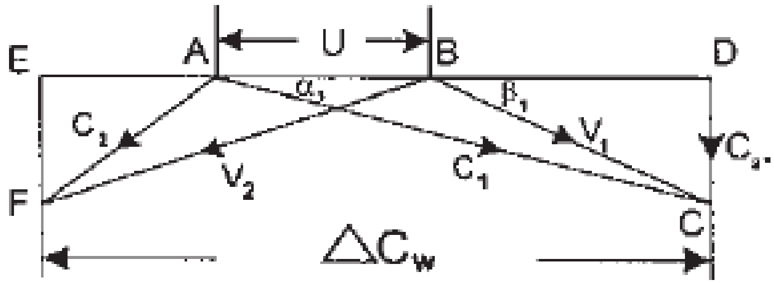

Figure 6.30 Velocity triangles for Example 6.13.

Figure 6.10: Blade height and power developed

```
disp("For 50% reaction turbine Fig. Ex612, alpha1 = beta2, and alpha2 = beta1. From the velocity triangle ACD, angles in degrees")
disp("All velocities in m/s")
C1 = 105; //m/s
alpha1 = 20;
Cw1 = C1*cos(alpha1*%pi/180)
disp("Applying cosine rule to the Triangle ABC:")
U = 40; //m/s
V1 = (C1^2+U^2-C1*2*U*cos(alpha1*%pi/180))^0.5
BD = Cw1-U//ms/
beta1 = acos(BD/V1)*180/%pi//degrees
disp("Change in the velocity of whirl is:")
Cw2 = BD;
DeltaCw = Cw1+Cw2
disp("Horse Power generated")
m = 2;
P = m*U*DeltaCw/(0.746*1000)
```

Scilab code Exa 6.13 Blade height and power developed

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 6, Example 13")
disp("Figure Ex613 shows the velocity triangles.")
alpha1 = 18;
beta2 = alpha1;
alpha2 = 25;
beta1 = alpha2;
disp("From the velocity triangle, velocities in m/s")
C1 = 90;//m/s
Cw1 = C1*cos(alpha1*%pi/180)//m/s
Ca1 = C1*sin(alpha1*%pi/180)
CD = Ca1;
disp("From triangle BDC")
BD = Ca1/sin(beta1*%pi/180)
disp("Hence blade velocity is given by:")
U = Cw1-BD
disp("Applying the cosine rule,")
V1 = (C1^2+U^2-2*U*C1*cos(alpha1*%pi/180))^0.5
disp("From triangle AEF")
C2 = V1;
Cw2 = C2*cos(alpha2*%pi/180)
disp("Change in the velocity of whirl: m/s")
DeltaCw = Cw1+Cw2
disp("Power developed by the rotor: in kW")
m = 10;
P = m*U*DeltaCw/1000
disp("From superheated steam tables at 5 bar, 250 degree Celcius, the specific volume of steam is: in m3/kg")
v = 0.4744
disp("Blade height is given by the volume of flow
```

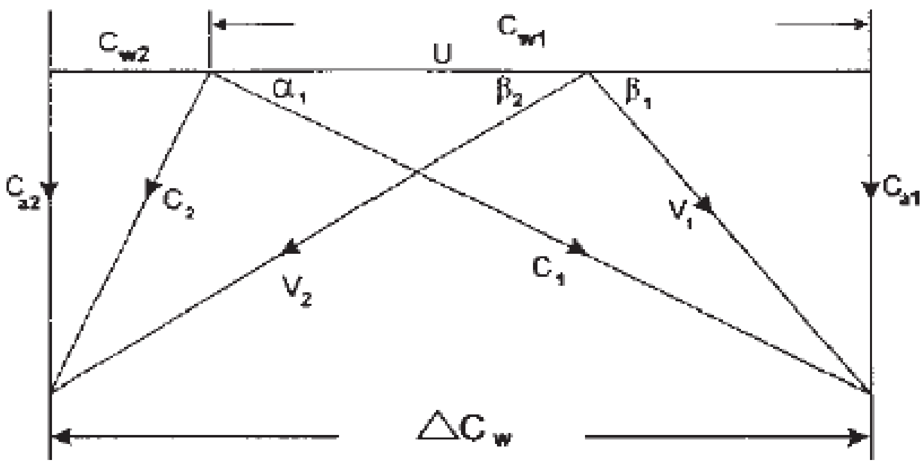

Figure 6.31 Velocity triangles for Example 6.14.

Figure 6.11: RPM 440

```
    equation: in m")
disp("v = pi*D*h*Ca")
disp("where Ca is the velocity of flow and h is the
    blade height.Therefore,")
D=0.72;
Ca = Ca1;
h = v/(%pi*Ca*D)
```

Scilab code Exa 6.14 RPM 440

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

```
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 6, Example 14")
disp("Figure Ex613 shows the velocity triangles.")
disp("From the velocity diagram,")
disp("V2 = 1.2U")
disp("Ca2 = V2 cos(beta2)")
disp("    = 1.2Ucos70")
disp("    = 0.41U m/s")
disp("At mean diameter,")
disp("U = piDN/60 = 2piN(Dh + h)/(60*2)")
disp("where Dh is the rotor diameter at the hub and h is the blade height.")
disp("Substituting the value of U in the above equation,")
N = 440; //rpm
disp("Ca2 = 0.41*2*%pi*N*(14.5h+h)/(2*60) = 146.45h m/s")
disp("Annular area of flow is given by:")
disp("A = pih(Dh + h) = pih(14.5h + h)")
disp("A = 15.5pih^2")
disp("Specific volume of saturated steam at 0.90 bar, vg = 1.869m3/kg.")
disp("Then the specific volume of steam v = (1.869) * (0.95) = 1.776m3/kg.")
v = 1.776;
disp("The mass flow rate is given by:kg/s")
mrate = 6.8; //kg/kW h
P = 5.5; //MW
m = P*1000*mrate/3600 //kg/s
h = (m*v/(146.45*15.5*%pi))^(1/3)
```

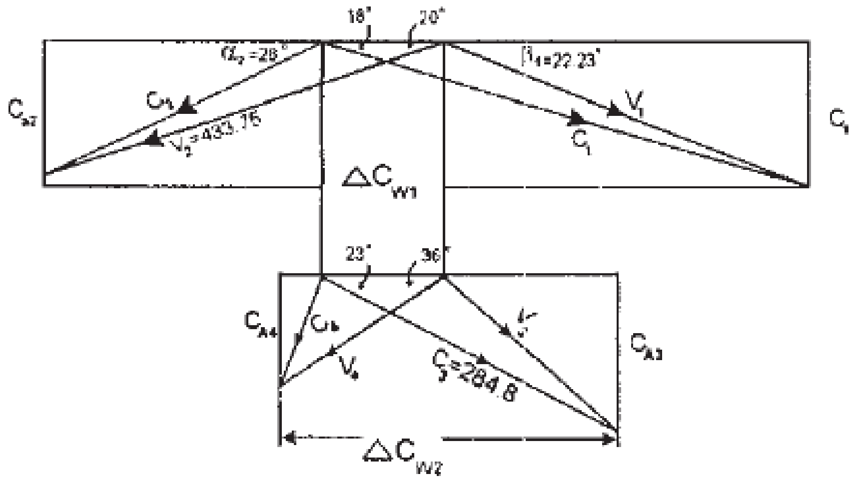

Figure 6.32 Velocity triangle for Example 6.15.

Figure 6.12: Two row velocity compounded impulse turbine

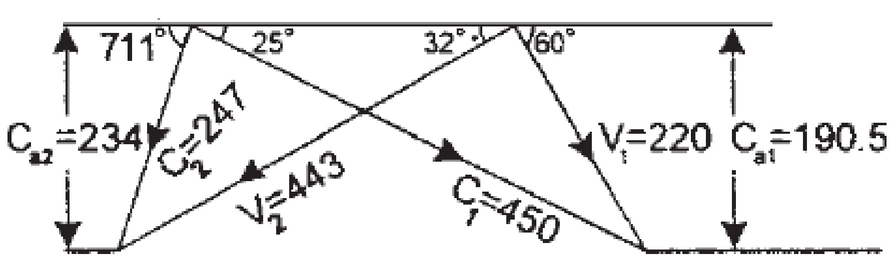

Figure 6.33 Velocity diagram for Example 6.16.

Figure 6.13: Two row velocity compounded impulse turbine

Scilab code Exa 6.15 Two row velocity compounded impulse turbine

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 6, Example 15")
disp("Figure Ex615 shows velocity triangles")
disp("Graphical solutions")
U = 115;//m/s
C1 = 590;//m/s
alpha1 = 18;//degrees;
beta2 = 20;//degrees
disp("The velocity diagrams are drawn to scale, as shown in Fig. Ex615a, and the relative velocity:")
V1 = 482//m/s
k = 0.9;
V2 = k*V1
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.")
C2 = 316.4;
C3 = k*C2
disp("Driving Force in N")
m = 1;
DeltaCw1 = 854;
DeltaCw2 = 281.46;
disp("For the first row of moving blades,in N")
F1 = m*DeltaCw1
disp("For the second row of moving blades, in N")
F2 = m*DeltaCw2
disp("where DeltaCw1 and DeltaCw2 are scaled from the velocity diagram.")
```

```
disp("Total driving force")
F = F1+F2
disp("Power = driving force *blade velocity in kW per kg/s")
s = 115;
P = F*s/1000
disp("Energy supplied to the wheel")
E = m*C1^2 /(2*1000)
disp("Therefore, the diagram efficiency is:")
etad = P*1000*2/C1^2 *100
disp("Maximum diagram efficiency:")
etadm = (cos(alpha1*%pi/180))^2 *100
Ca1 = 182.32;
Ca2 = 148.4;
Ca3 = 111.3;
Ca4 = 97.57;
disp("Axial thrust on the first row of moving blades (per kg/s): in N")
F1 = m*(Ca1-Ca2)
disp("Axial thrust on the second row of moving blades (per kg/s): in N")
F2 = m*(Ca3-Ca4)
disp("Total axial thrust:in N")
F = F1+F2
```

Scilab code Exa 6.16 Reaction stage turbine

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
```

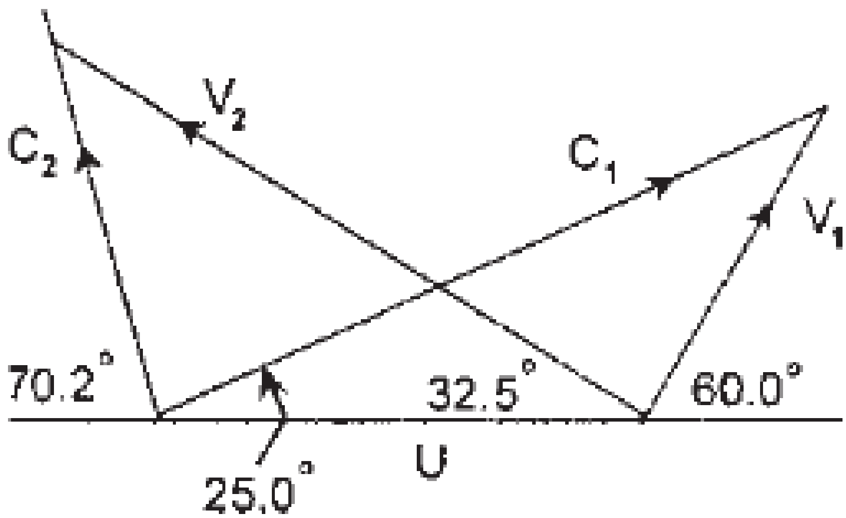

Figure 6.34 Velocity diagram for Example 6.17.

Figure 6.14: Reaction stage turbine

```
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 6, Example 16")
disp("Figure Ex616 shows velocity triangles")
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:")
U = 300; //m/s
alpha1 = 25;
beta1 = 60;
alpha2 = 71.1;
beta2 = 32;
disp("Wt = U*(Cw1+Cw2)")
Wt = U*(450*cos(alpha1*%pi/180)+247*cos(alpha2*%pi
   /180))
disp("Power output i kW")
m = 5;
P = m*Wt/1000
disp("Degree of reaction is given by: DOR")
V1 = 220; //m/s
V2 = 443; //m/s
DOR = (V2^2 -V1^2)/ (2*Wt) * 100
disp("Axial thrust: in N")
Ca1 = 190.5; //m/s
Ca2 = 234; //m/s
F = m*(Ca1-Ca2)
disp("The thrust is negative because its direction
   is the opposite to the fluid flow.")
```

Scilab code Exa 6.17 Series of stages

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

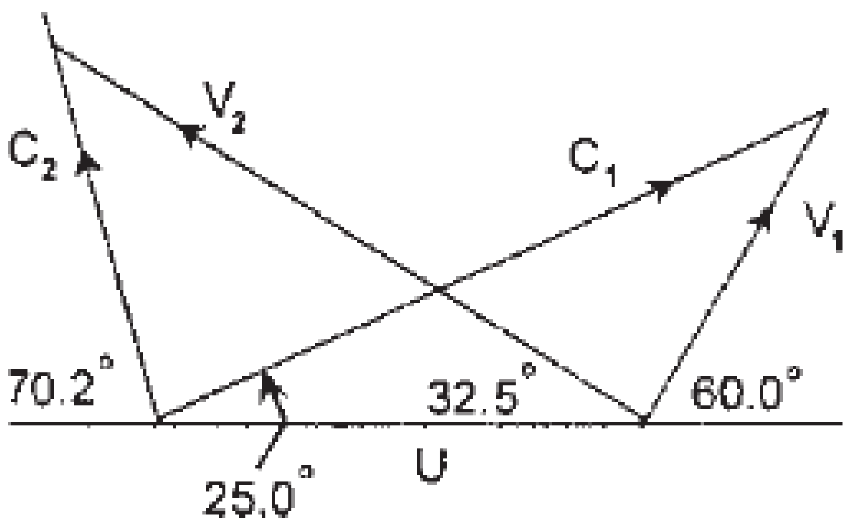

Figure 6.34 Velocity diagram for Example 6.17.

Figure 6.15: Series of stages

```
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 6, Example 17")
disp("Using the given data, the velocity triangles
    for the inlet and outlet are shown in Fig Ex617")
C2 = 225;//m/s
V2 = 375;//m/s
C1 = 400;//m/s
V1 = 200;//m/s
disp("Work done per unit mass flow: in J/kg")
U = 250;
Wt = U*(C1*cos(25*%pi/180)+C2*cos(70.2*%pi/180))
disp("Degree of reaction DOR")
DOR = (V2^2 - V1^2)/(2*Wt) *100
disp("Power output: in kW")
m = 5.2;
P = m*Wt/1000
disp("Isentropic static enthalpy drop in the stator:
     in kJ/kg")
etas = 0.93;
Deltahs = (C1^2 - 0.89*C2^2)/etas /1000
disp("Isentropic static enthalpy drops in the rotor:
     in kJ/kg")
etaf = 0.94;
Deltahr = Wt/(etas*etaf) /1000
disp("Since the state of the steam at the stage
    entry is given as 10 bar, 300 degree Celsicus,")
disp("Enthalpy at nozzle exit: in kJ/kg")
Hn = 3051.5 - Deltahs
disp("Enthalpy at rotor exit: in kJ/kg")
Hr = 3051.5 - Deltahr
disp("The rotor inlet and outlet conditions can be
    found by using the Mollier Chart.")
disp("Rotor inlet conditions: P1 = 7 bar, T1 = 235
    Degree Celsius")
```

```
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

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

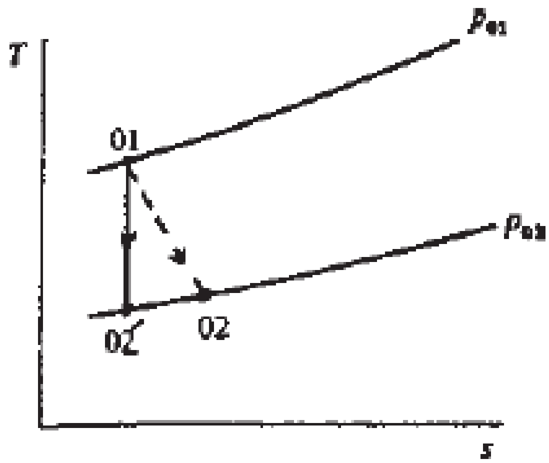

Figure 7.6 *T-s* diagram for Example 7.1.

Figure 7.1: Impulse gas turbine

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

Scilab code Exa 7.2 `Nozzle efflux angle 68`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 7, Example 2")
disp("The specific work output in kJ/kg")
etats = 0.85;
Cpg = 1.147;
T01 = 800 + 273;
gam = 1.33;
W = etats*Cpg*T01*(1-(1/4)^((gam-1)/gam))
disp("Since alpha1 = 0, alpha3 = 0, Cw1 = 0 and
    specific work output is given by")
U = 480;
Cw2 = W*1000/U//m/s
disp("From velocity triangle")
alpha2 = 68;
C2 = Cw2/sin(alpha2*%pi/180)//m/s
disp("Axial velocity is given by in m/s")
Ca2 = C2*cos(alpha2*%pi/180)//m/s
disp("Total-to-total efficiency, etatt, is")
disp("etatt = (T01-T03)/(T01-T03a)")
disp("      = W/(T01-(T3+C3^2 /(2Cpg)))")
disp("      = W/((W/etats) - (C3^2 /(2Cpg)))")
C3 = Ca2;//m/s
etatt = W/((W/etats) - (C3^2 / (2*Cpg*1000))) *100//
    in %
disp("The degree of reaction DOR")
disp("DOR = Ca*(tan(beta3) - tan(beta2))/(2U)")
DOR = (1- Ca2*tan(alpha2*%pi/180) / (2*U))*100//%
```

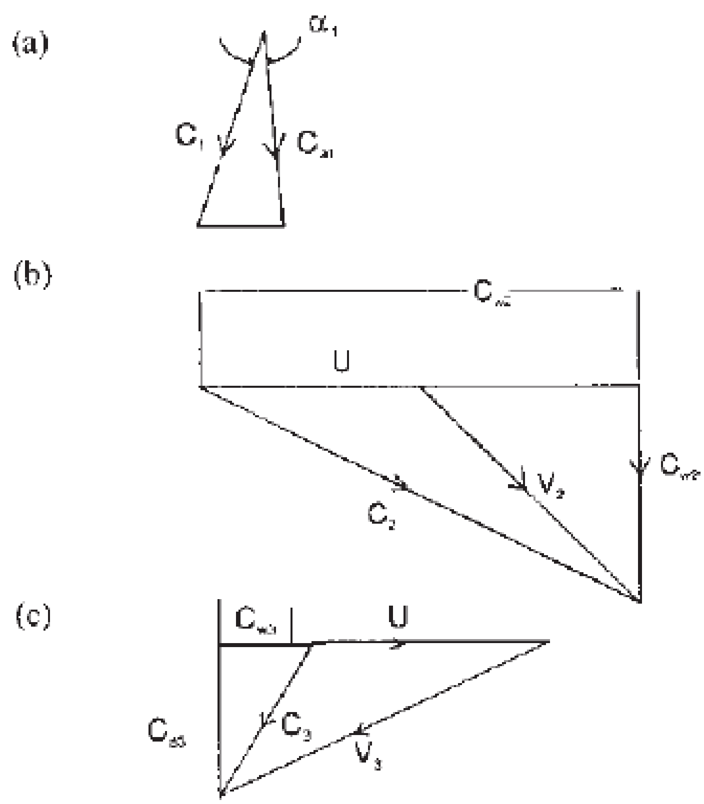

Figure 7.7 Velocity triangles for Example 7.3.

Figure 7.2: Stagnation temperature of 1100K

Scilab code Exa 7.3 Stagnation temperature of 1100K

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 7, Example 3")
disp("From Figure Ex73")
Ca = 250 //m/s
Ca3 = Ca;//m/s
Ca2 = Ca3;//m/s
Ca1 = Ca2;//m/s
U = 350;//m/s
disp("From velocity triangle (b)")
alpha2 = 63;
C2 = Ca2/cos(alpha2*%pi/180)//m/s
disp("From Figure (c)")
alpha3 = 9;
C3 = Ca3/cos(alpha3*%pi/180)//m/s
Cw3 = Ca3*tan(alpha3*%pi/180)//m/s
beta3 = atan((U+Cw3)/Ca3)*180/%pi
disp("From Figure(b)")
Cw2 = Ca2*tan(alpha2*%pi/180)//m/s
beta2 = atan((Cw2-U)/Ca2)*180/%pi
disp("Power output in kW")
m = 15;
W = m*U*Ca*(tan(beta2*%pi/180) + tan(beta3*%pi/180))
   /1000
disp("The degree of reaction is given by")
DOR = Ca*(tan(beta3*%pi/180) - tan(beta2*%pi/180))
   /(2*U) *100
```

Scilab code Exa 7.4 Throat area for 73

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 7, Example 4")
disp("Nozzle Throat area in m2, A = m/(rho2*Ca2)")
disp("rho2 = P2/(RT2)")
disp("T2 = T02 - C2^2 /(2Cp)")
T02 = 1100;//Kelvin
C2 = 550.67;//m/s
Cp = 1.147;
T2 = T02 - C2^2 /(2*Cp*1000)
disp("From nozzle loss coefficient")
lambdaN = 0.05;
T2a = T2 - lambdaN *C2^2 /(2*Cp*1000)
disp("Using isentropic p T relation for nozzle
    expansion")
P01 = 5;//bars
gam = 1.33;
T01 = T02;
P2 = P01/((T01/T2a)^(gam/(gam-1)))
disp("Critical Pressure ratio = r = P01/Pc")
r = ((gam+1)/2)^(gam/(gam-1))
disp("P01/P2 = r1")
r1 = P01/P2
disp("Since r1<r, and therefore nozzle is unchoked."
    )
C2 = (2*Cp*1000*(T01-T2))^0.5//m/s
disp("Therefore, nozzle throat area in m2")
R = 0.287;
rho2 = P2*100/(R*T2)//kg/m3
m = 15;//ks
A = m/(rho2*C2)//m2
```

Scilab code Exa 7.5 Inlet stagnation temperature is 1000 K

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 7, Example 5")
disp("Velocities are in m/s, temperature in Kelvin,
    Angles in degrees.")
disp("Degree of reaction DOR = 0")
disp("DOR = (T2-T3)/(T1-T3)")
disp("Therefore T2 = T3")
disp("From isentropic  p T  relation for expansion")
T01 = 1000;
disp("P01/P03 = r")
r = 1.8
T03a = T01/(r^0.249)
disp("Using turbine efficiency")
disp("T03 = T01-etat*(T01-T03a)")
etat = 0.85;
T03 = T01 - etat*(T01-T03a)
disp("In order to find static temperature at turbine
     outlet, using static and stagnation temperature
    relation")
C3 = 270;
Cpg = 1.147;
T3 = T03- C3^2 / (2*Cpg*1000)
T2 = T3;
disp("Dynamic Temperature in K is C^2 /2Cpg = Td")
Td = 1000-T2
C2 = (2*Cpg*1000*Td)^0.5//m/s
```

```
disp("Since Cpg*DeltaTos = U*(Cw3+Cw2) = U*Cw2 (Cw3=0)")
U = 290;
Cw2 = Cpg*1000*(1000-884)/U//m/s
disp("From velocity triangle")
alpha2 = asin(Cw2/C2)*180/%pi
Ca2 = C2;
beta2 = atan((Cw2-U)/(Ca2*cos(alpha2*%pi/180)))*180/%pi
```

Scilab code Exa 7.6 `Inlet stagnation temperature is 1150 K`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 7, Example 6")
disp("Annulus area A is given by")
disp("A = 2 pi*rm*h")
disp("where h = blade height")
disp("rm = mean radius")
disp("As we have to find the blade height from the outlet conditions, in this case annulus area is A3.")
disp("h = A3/2pi*rm")
disp("Um = pi*Dm*N")
Um = 300;//m/s
N = 240;//rps
Dm = Um/(%pi*N)
rm = Dm/2
disp("Temperature drop in the stage is given by Drop = T01-T03")
```

```
Drop = 145//Kelvins
T01 = 1150;
T03 = T01-Drop
C3 = 390;
Cpg = 1.147;
T3 = T03-C3^2 / (2*Cpg*1000)
disp("Using turbine efficiency to find isentropic
    temperature drop")
eta = 0.88;
T03a = T01-Drop/eta
disp("Using isentropic  p T  relation for expansion
    process")
P01 = 8;
P03 = P01/(T01/T03a)^(4)
disp("Also from isentropic relation")
P3 = P03/(T03a/T3)^4
disp("where P01,P3;P03 are in bars")
R = 0.287;
rho3 = P3/(R*T3) *100//kg/m3
m = 34;//kg/s
Ca3 = C3;
A3 = m/(rho3*Ca3)
h = A3/(2*%pi*rm)
disp("where h is in m")
```

Scilab code Exa 7.7 Rotation 14500rpm

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

```
Cpg = 1147;
disp("Temperature Drop = T01 -T03")
Drop = 145;
U = 345;
psi = Cpg*(Drop)/U^2
disp("Using velocity diagram")
disp("U/Ca = tan(beta3) - tan(alpha3)")
disp("tan(beta3) = 1/phi + tan(alpha3)")
alpha3 = 12;
phi = 0.75;
beta3 = atan(1/phi + tan(alpha3*%pi/180))*180/%pi
disp("Psi = phi*(tan(beta2) +tan(beta3))")
disp("DOR = phi/2 *(tan(beta3) - tan(beta2))")
disp("tan(beta3) = (psi + 2*DOR)/(2*phi)")
DOR = (tan(beta3*%pi/180) *2*phi - psi)/2 *100
disp("tan(beta2) = (psi-2*DOR)/(2*phi)")
beta2 = atan((psi-2*DOR/100)/(2*phi))*180/%pi
alpha2 = atan(tan(beta2*%pi/180)+(1/phi))*180/%pi
Ca1 = U*phi//m/s
C2 = Ca1/cos(alpha2*%pi/180)//m/s
disp("R2 = T02-T2 = C2^2 /2Cp")
R2 = C2^2 /(2*Cpg)
disp("R3 = T2-T2s = Tn*C2^2/(2Cpg)")
Tn = 0.05;
R3 = Tn*C2^2 /(2*Cpg)
T2 = 1100-R2//K
T2s = T2 - R3//K
P01 = 4;//bars
T01 = 1100;
P2 = P01*(T2s/T01)^4
R = 0.287;
rho2 = P2*100/(R*T2)//kg/m3
disp("Nozzle Throat area in A in m2")
C1 = C2;//m/s
rho1 = 0.907;//kg/m3
m = 24;
A = m/(rho1*C1)
A1 = m/(rho1*Ca1)
```

Scilab code Exa 7.8 Equal stage inlet and outlet velocities

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 7, Example 8")
disp("From Velocity tiangles")
disp("C is velocity in m/s, angles are in degrees")
Ca = 255;//m/s
alpha2 = 60;
Cw2 = Ca * tan(alpha2*%pi/180)
alpha3 = 12;
Cw3 = Ca * tan(alpha3*%pi/180)
U = 345;//m/s
Vw2 = Cw2-U//m/s
beta2 = atan(Vw2/Ca)*180/%pi
Vw3 = Cw3+U//m/s
beta3 = atan(Vw3/Ca)*180/%pi
disp("Degree of Reaction DOR")
phi = Ca/U;
DOR = phi*(tan(beta3*%pi/180) - tan(beta2*%pi/180))
   /2 *100
psi = Ca*(tan(beta2*%pi/180) + tan(beta3*%pi/180))/U
m = 20;
disp("W in kW")
W = m*U*(Cw2+Cw3)
disp("lambdaN = 2Cp(T2-T2a)/C2^2")
lambdaN = Ca*sec(alpha2*%pi/180)
C2 = lambdaN;
disp("T2-T2a = R")
```

```
Cp = 1147;
Ra = 0.05*0.5*lambdaN^2 /Cp
T02 = 1150;//K
T01 = T02;//K
T2 = T02 - C2^2 /(2*Cp)//K
T2a = T02-C2^2 /(2*Cp) - Ra
P01 = 4//bars
P2 = P01/(T01/T2)^4
R = 0.287;
disp("rho2 is density in kg/m3")
rho2 = P2/(R*T2) *100
disp("Area in m2")
m = 20;
A2 = m/(rho2*C2)
```

Scilab code Exa 7.9 Turbine inlet temperature 900C

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
    Gorla and Aijaz A. Khan, Chapter 7, Example 9")
disp("At 50%.  alpha2 = beta3; alpha3 = beta2")
U = 340;
disp("C2 in m/s")
C2 = U/cos(15*%pi/180)
disp("Heat drop in blade moving row in Hdrop K")
C3 = 105;//m/s
Cp = 1147;
Hdrop = (C2^2 - C3^2)/(2*Cp)
disp("Therefore heat drop in a stage")
Hdropstage = Hdrop *2
```

```
disp("Number of stages n = ")
n = (1173-943)/Hdropstage
disp("Therefore No. of stages = 2")
```

Scilab code Exa 7.10 Gas leaving stage in axial direction

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 7, Example 10")
disp("For no loss up to throat Ps in bars")
P01 = 4;//bar
gam = 1.33;
Ps = P01*(2/(gam+1))^(gam/(gam-1))
T01 = 1100;//K
Ts = 944;//K
Cpg = 1147;
U = 300;//m/s
C = (2*Cpg*(T01-Ts))^0.5//m/s
R = 0.287;
rhos = Ps*100/(R*Ts)//kg/m3
disp("Throat area in m2")
m=20;//kg/s
A = m/(rhos*C)
disp("Angle alpha1, at any radius r and alpha1m at
   the design radius rm are related by the equation"
   )
disp("tan(alpha1) = rm*tan(alpha1m)/r")
disp("Given")
disp("Tip radius/Root radius = rt/rr = 1.4")
disp("Therefore mean radius/root radius = 1.2")
```

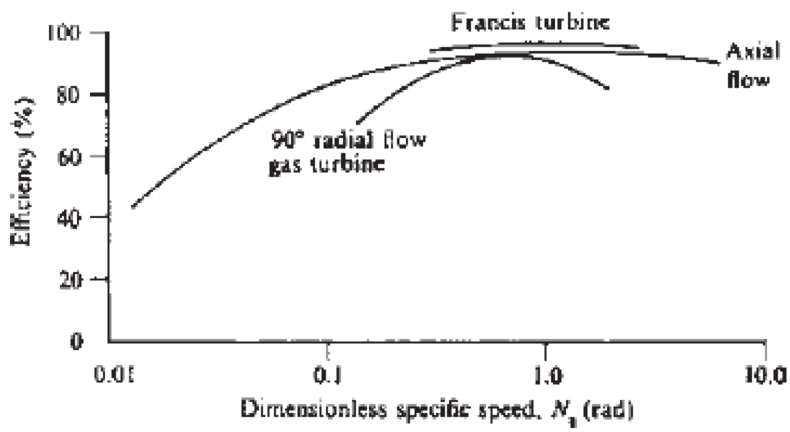

Figure 7.13 Variation of efficiency with dimensionless specific speed.

Figure 7.3: Inward radial flow gas turbine

```
alpha1m = 25
alpha1r = atan(1.2*tan(alpha1m*%pi/180))*180/%pi
alpha1t = atan(tan(alpha1r*%pi/180)/1.4)*180/%pi
disp("Velocity in m/s")
disp("Cw2 = rm*x*Cw2m/rr = rm*Ca2/(rr*tan(alpha2m))"
    )
Cw2 = 1.2*250/tan(alpha1m*%pi/180)
disp("Power developed in kW")
W = m*U*Cw2/1000
```

Scilab code Exa 7.11 `Inward radial flow gas turbine`

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

```
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R. Gorla and Aijaz A. Khan, Chapter 7, Example 11")
disp("The overall efficiency of turbine from nozzle inlet to diffuser outlet is given by")
disp("etatt = (T01 - T03)/(T01 - T03ss)")
disp("Turbine work per unit mass flow")
disp("W = U2^2 = Cp(T01 - T03); (Cw3 = 0)")
disp("Now using isentropic  p T  relation")
disp("T01 (1 - T03ss/T01) = T01(1 - (P03/P01)((gamma-1)/gamma)")
disp("Therefore")
disp("U2^2 = etatt*Cp*T01(1 - (P03/P01)^((gamma-1)/gamma)")
etatt = 0.9;
Cp = 1147;
T01 = 1145;
P03 = 100;
P01 = 310;
U2 = (etatt*Cp*T01*(1 - (P03/P01)^0.2498))^0.5
disp("Impeller tip speed, U2 = 539.45 m/s")
disp("The Mach number of the absolute flow velocity at nozzle exit is given by")
disp("M = C1/a1 = U1/alpha1*sin(alpha1)")
disp("Since the flow is adiabatic across the nozzle, we have")
disp("T01 = T02 = T2 + C2^2/2Cp = T2 + U2^2/2Cp(sin(alpha2))^2")
disp("or T2/T01 = 1 - U2^2/2CpT01(sin(alpha2))^2; but Cp = gamma*R/(gamma - 1)")
disp("Therefore; T2/T01 = 1 - U2^2*(gamma - 1)/(2gammaRT01(sin(alpha2))^2")
disp("  =  1- U2^2*(gammaa-1)/(2*a01^2 * (sin(alpha2))^2)")
disp("But (T2/T01)^2 = a2/a01 = a2/a02; since T01 = T02")
disp("and a2/a02 = U2/M2*a02*sin(alpha2)")
```

```
disp(" Therefore (U2/M2*a02*sin(alpha2))^2 = 1 - U2
   ^2*(gammaa-1)/(2*a01^2 * (sin(alpha2))^2)")
disp("and 1 = (U2/a02*sin(alpha2))^2 *((gamma - 1)/2
    + 1/M2^2)")
disp("or (sin(alpha2))^2 = (U2/a02)^2 * ((gamma - 1)
   /2 + 1/M2^2)")
disp("Therefore nozzle angle alpha2 = 75 degrees")
```

Scilab code Exa 7.12 `Rotation 30500rpm`

```
// Display mode
mode(0);
// Display warning for floating point exception
ieee(1);
clear;
clc;
disp("Turbomachinery Design and Theory,Rama S. R.
   Gorla and Aijaz A. Khan, Chapter 7, Example 12")
disp("Dimensionless specific speed is")
disp("Ns = 0.336*(C3/C0)^0.5*(A3/Ad)^0.5   in rev")
disp("A3 and Ad are in m2")
D3t = 0.064;//m
D3h = 0.026;//m
A3 = %pi*(D3t^2 - D3h^2)/4
D2 = 0.092;//m
Ad = %pi*D2^2/4
disp("Dimensionless specific speed Ns in rev and Nsa
    in rad")
Ns = 0.336*(0.447*A3/Ad)^0.5//rev
Nsa = 0.904
disp("The flow rate at outlet for the ideal turbine
   is given by Q3 in m3/s")
disp("Ns = 0.18*(Q3/(N*D2^3))^0.5")
N = 30500;
Q = (Ns/0.18)^2*N*D2^3/60
```

```
disp("The power developed by the turbine is given by in kW")
disp("W = m*U3^2")
disp("   = rho3*Q3*U3^2")
rho3 = 1.75;//kg/m3
Wt = rho3*Q*(%pi*N*D2/60)^2 /1000
```

Chapter 8

Cavitation in Hydraulic Machinery

Scilab code Exa 8.0 Theory

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