Scilab Textbook Companion for Gas Dynamics and Jet Propulsion by P. Murugaperumal[1]

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Book Description

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

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Chapter 1

Compressible Flow Fundamentals

Scilab code Exa 1.1 To calculate the work done

```
clc
clear

//Input data
m=0.75 //Mass of air in kg
T1=800 //Intial Temperature in K
P1=400 //Initial Pressure in kPa
P2=150 //Final Pressure in kPa
k=1.4 //Adiabatic constant
R=0.287 //Specific Gas constant in J/kg-K

//Calculation
p1=P2/P1 //pressure ratio of process
T2=T1*p1^((k-1)/k) //Final temperature in K
W=((m*R*(T1-T2))/(k-1)) //Workdone in kJ

//P-V Diagram
scf()
clf()
```

```
V1=(((m*R*T1)/P1)^(1/k))*10^3 //Inlet volume in cc
V2=(((m*R*T2)/P2)^(1/k))*10^3 //Final volume in cc
V = V1:(V2-V1)/100:V2   //Representing volume on graph, adiabatic expansion
P = P1*V1^k./V^k //Representing pressure on graph
plot(V, P) //Plotting
legend('P*V^k=C') //Defining curve
xtitle("PV Diagram", "V (cc)", "P (kPa)") //Titles of axes

//Output
printf('Workdone is %3.2f kJ',W)
```

Scilab code Exa 1.2 To calculate heat transfer internal energy change and work done

```
clc
clear

//Input data
V1=0.35 //Volume of gas in m^3
P1=110 //Initial Pressure in kPa
T1=300 //Intial Temperature in K
P2=600 //Final Pressure in kPa,missing data
k=1.4 //Adiabatic constant
Cv=718 //Specific heat at constant volume in J/kg-K
R=287 //Specific Gas constant in J/kg-K

//Calculation
dQ=0 //Heat transfer in J, Since Adiabatic process
m=(P1*10^3*V1)/(R*T1) //Mass of air in kg
p1=P2/P1 //Pressure ratio
T2=T1*p1^((k-1)/k) //Final temperature in K
dU=(m*Cv*(T2-T1))*10^-3 //Change in internal energy in kJ
```

```
dW=-dU //Workdone in kJ, Since dQ=0

//P-V Diagram
scf()
clf()
V1cc=V1*10^3 //Inlet volume in cc
V2cc=V1cc*(T2/T1)^(1/(k-1)) //Final volume in cc
V = V1cc:(V2cc-V1cc)/100:V2cc    //Representing volume on graph, adiabatic expansion
P = P2*V1cc^k./V^k //Representing pressure on graph
plot(V, P) //Plotting
legend('P*V^k=C') //Defining curve
xtitle("PV Diagram", "V (cc)", "P (kPa)") //Titles of axes

//Output
printf('(A)Heat transfer is %3i J\n (B)Change in internal energy is %3.3f kJ\n (C)Workdone is %3.3f kJ\n',dQ,dU,dW)
```

Scilab code Exa 1.3 To determine temperature enthalpy drop and internal energy change

```
clc
clear

//Input data
P1=3.2 //Initial Pressure in bar
P2=1 //Final Pressure in bar
T1=475 //Initial temperature in K
Mol=44 //Molecular weight of carbondioxide in kg/mol
Ri=8314 //Ideal gas constant in J/mol-K
k=1.3 //Adiabatic constant

//Calculation
```

```
R=Ri/Mol //Specific gas constant in J/kg-K
Cp=(k*R)/(k-1) //Specific heat capacity at constant pressure in J/kg-K
Cv=Cp/k //Specific heat capacity at constant volume in J/kg-K
p1=P2/P1 //Pressure ratio
T2=T1*p1^((k-1)/k) //Final Temperature
dh=Cp*(T1-T2)*10^-3 //Enthalpy drop in kJ/kg
dU=Cv*(T2-T1)*10^-3 //Change in internal energy in kJ/kg, -ve sign indicates loss

//Output
printf('(A)Temperature is %3.3f K\n (B)Enthalpy drop is %3.3f kJ/kg\n (C)Change in internal energy is %3.2f kJ/kg i.e. %3.2f kJ/kg(loss)',T2,dh,dU,abs(dU))
```

Scilab code Exa 1.4 To determine properties at outlet and area ratio of diffuser

```
clc
clear

//Input data
P1=0.5 //Initial Pressure in bar
T1=50+273 //Intial Temperature in K
C1=240 //Inlet velocity in m/s
C2=120 //Outlet velocity in m/s, missing data
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K
k=1.4 //Adiabatic constant

//Calculation
T2=T1+((C1^2-C2^2)/(2*Cp)) //Final Temperature in K
t1=T2/T1 //Temperature ratio
```

```
P2=P1*t1^(k/(k-1)) //Final Pressure in bar
ar=(P1*T2*C1)/(P2*T1*C2) //Ratio of outlet to inlet
    area

//Output
printf('(A)At outlet:\n     Temperature is %3.2f K\n
      Pressure is %3.4f bar\n (B)Ratio of outlet to
    inlet area is %3.4f',T2,P2,ar)
```

Scilab code Exa 1.5 To determine static pressure and axial force of turbojet engine

```
clc
clear

//Input data
m=25 //Mass flow rate of air in kg/s
C2=115 //Outlet velocity in m/s
P1=100 ////Initial Pressure in kPa
T1=300 //Intial Temperature in K
C1=40 //Inlet velocity in m/s
R=0.287 //Specific gas constant in kJ/kg-K
Cp=1005 //Specific heat capacity at constant
    pressure in J/kg-K
k=1.4 //Adiabatic constant

//Calculation
T2=T1+((C1^2-C2^2)/(2*Cp)) //Final Temperature in K
t1=T2/T1 //Temperature ratio
P2=P1*t1^(k/(k-1)) //Final Pressure in bar
A1=(m*R*T1)/(P1*C1) //Area at inlet in m^2
A2=(m*R*T2)/(P2*C2) //Area at outlet in m^2
F=((P1*A1)-(P2*A2))+(m*(C1-C2))*10^-3 //Axial force
    on mouthpiece resulting from acceleration of air
    in kN
```

```
//Output
printf('(A)Static pressure at intake face is %3.3f
   kPa\n (B)Magnitude of axial force on mouthpiece
   resulting from acceleration of air is %3.3f kN',
   P2,F)
```

Scilab code Exa 1.6 To determine mach number at a point

```
clc
clear

//Input data
P=200 //Pressure in kPa
C=50 //Velocity of air in m/s
d=2.9 //Density in kg/m^3
Mol=32 //Molecular weight of oxygen in kg/mol
k=1.4 //Adiabatic constant
Ri=8314 //Ideal gas constant in J/mol-K

//Calculator
R=Ri/Mol //Specific gas constant in J/kg-K
T=P*10^3/(R*d) //Temperature in K
a=sqrt(k*R*T) //Velocity of sound in m/s
M=C/a //Mach number

//Output
printf('Mach number is %3.2f',M)
```

Scilab code Exa 1.7 To find direction of flow

```
clc
clear
```

```

//Input data
Pa=1.3 //Pressure at section-A in bar
Ta=50+273 //Temperature at section-A in K
Pb=1 //Pressure at section-B in bar
Tb=13+273 //Temperature at section-B in K
Cp=1005 //Specific heat capacity at constant
    pressure in J/kg-K
R=287 //Specific gas constant in J/kg-K

//Calculation
ds=((Cp*log(Tb/Ta))-(R*log(Pb/Pa)))*10^-3 //The
    change in the entropy is kJ/kg
//+ve sign indicates A to B
//-ve sign indicates B to A

//Output
printf('The change in the entropy is %3.4f kJ/kg\n
    Since value is -ve, process must takes place from
     B to A',ds)
```

Scilab code Exa 1.8 To calculate the bulk modulus

```
clc
clear

//Input data
V1=8 //Intial volume in litre
V2=7.8 //Final volume in litre
P1=0.7 //Intial Pressure in MPa
P2=2.7 //Final Pressure in MPa

//Calculations
K=(P2-P1)/(log(V1/V2)) //Bulk modulus of liquid in
    kPa
```

```

//Output
printf('Bulk modulus of liquid is %3.3f kPa',K)
```

Scilab code Exa 1.9 To calculate mass of water to be pumped to obtain desired pressure

```
clc
clear

//Input data
V1=0.5 //Voume of Water required to fill pressure
   vessel in m^3
P=3000 //Test pressure in bar
dv=0.6 //Change of empty volume of container due to
   pressurisation in percentage
K=20000 //Bulk modulus of water in MPa

//Calculation
m1=V1*10^3 //Mass of water required to fill pressure
    vessel in kg
Vr=(P*V1)/K //Reduced volume of water due to
   compression in m^3
Vi=dv*V1/100 //Increased volume of container in m^3
V=Vr+Vi //Volume of additional water required in m^3
m=V*10^3 //Mass of additional water required in kg
mt=m1+m //Total mass of water required in litre ,
   Since 1kg=1Lit

//Output
printf('Mass of water to be pumped into the vesel to
    obtain the desired pressure is %3i lit',mt)
```

Scilab code Exa 1.10 To find sonic velocity

```
clc
clear

//Input data
SG_oil=0.8 //Specific gravity of crude oil
K_oil=153036*10^4 //Bulk modulus of Oil in N/m^2
K_hg=2648700*10^4 //Bulk modulus of Mercury in N/m^2
d_steel=7860 //Density of steel in kg/m^3
E_steel=200*10^9 //Modulus of elasticity in Pa
d_hg=13600 //Density of mercury in kg/m^3
d_water=1000 //Density of water in kg/m^3

//Calculation
d_oil=SG_oil*d_water //Density of oil in kg/m^3
a_oil=sqrt(K_oil/d_oil) //Sonic velocity of crude
    oil in m/s
a_hg=sqrt(K_hg/d_hg) //Sonic velocity of mercury in
    m/s
a_steel=sqrt(E_steel/d_steel) //Sonic velocity of
    steel in m/s

//Output
printf('(A)Sonic velocity of crude oil is %3.2f m/s\
    n (B)Sonic velocity of mercury is %3.2f m/s\n (A)
    Sonic velocity of steel is %3.1f m/s\n',a_oil,
    a_hg,a_steel)
```

Scilab code Exa 1.11 To find velocity of sound

```
clc
clear

//Input data
```

```
T=20+273 //Temperarture of medium in K
Cp_fr=678 //Specific heat capacity at constant
    pressure of freon in J/kg-K
Cv_fr=543 //Specific heat capacity at constant
    volime of freon in J/kg-K
T_air=0+273 //Temperature of air in K
Ri=8314 //Ideal gas constant in J/mol-K
mol_h=2 //Molecular weight of Hydrogen in kg/mol
mol_water=18 //Molecular weight of water in kg/mol
R_air=287 //Specific gas constant of air in J/kg-K
k=1.4 //Adiabatic constant of hydrogen
k_water=1.3 //Adiabatic constant of water

//Calculation
R_h=Ri/mol_h //Specific gas constant of hydrogen in
    J/kg-K
a_h=sqrt(k*R_h*T) //Velocity of sound in hydrogen in
     m/s
R_water=Ri/mol_water //Specific gas constant of
    water in J/kg-K
a_water=sqrt(k_water*R_water*T) //Velocity of sound
    in water vapour in m/s
k_fr=Cp_fr/Cv_fr //Adiabatic constant of feoan
R_fr=Cp_fr-Cv_fr //Specific gas constant of freon in
     J/kg-K
a_fr=sqrt(k_fr*R_fr*T) //Velocity of sound in freon
    in m/s
a_air=sqrt(k*R_air*T_air) //Sonic Velocity of air at
     in m/s

//Output
printf('(A)Velocity of sound in hydrogen is %3.2f m/
    s\n (B)Velocity of sound in water vapour is %3.2f
     m/s\n (C)Velocity of sound in freon is %3.2f m/s
    \n (D)Sonic Velocity of air at %3i K is %3.4f m/s
    ',a_h,a_water,a_fr,T_air,a_air)
```

Scilab code Exa 1.12 To find highest pressure acting on surface of a body

```
clc
clear

//Input data
M=0.85 //Mach number
P=80 //Pressure in kPa
k=1.4 //Adiabatic Constant

//Calculation
Po=P*(1+(((k-1)/2)*M^2))^(k/(k-1)) //Pressure acting on the surface of the body in kPa

//Output
printf('The highest pressure acting on the surface of the body is %3.1f kPa',Po)
```

Scilab code Exa 1.13 To find air velocity for different types of flow

```
clc
clear

//Input data
P=96 //Pressure in kPa
T=27+273 //Temperature in K
dP=32 //Difference between pivot and static pressure
k=1.4 //Adiabatic Constant
R=287 //Specific Gas constant in J/kg-K

//Calculation
d=(P*10^3)/(R*T) //Density in kg/m^3
```

```
Ci=sqrt((2*(dP*10^3))/d) //Velocity of
   incompressible flow in m/s
pr=(dP)/P //Pressure ratio
p1=pr+1 //Stagnation to static pressure ratio
M=sqrt(((p1^((k-1)/k)-1)*2)/(k-1)) //Mach number
Cc=M*sqrt(k*R*T) //Velocity of compressible flow in
   m/s

//Output
printf('(A)Air velocity in incompressible flow is %3
   .1f m/s\n (B)Air velocity if flow is compressible
    is %3.3f m/s',Ci,Cc)
```

Scilab code Exa 1.14 To find number of nozzles

```
clc
clear

//Input data
T1=200+273 //Intial Temperature in K
P1=1.7 //Initial Pressure in bar
P2=1 //Final Pressure in bar
C1=30 //Inlet velocity in m/s
m=1 //Mass flow rate in kg/s
D=0.025 //Nozzle diameter in m
k=1.4 //Adiabatic Constant
R=287 //Specific Gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant
   pressure in J/kg-K

//Calculation
p1=P2/P1 //Pressure ratio
T2=T1*p1^((k-1)/k) //Final temperature in K
E1=T1+(C1^2/(2*Cp)) //LHS of Steady flow energy
   equation
```

```
C2=sqrt((E1-T2)*2*Cp) //Exit velocity of the air in
    m/s
d2=(P2*10^5)/(R*T2) //Density at outlet in kg/m^3
A2=%pi*D^2/4 //Area at outlet in m^2
n=ceil(m/(d2*A2*C2)) //Number of nozzles to be used

//Output
printf('(A)Exit velocity of the air is %3.2f m/s\n (
    B)Number of nozzles to be used are %1.0f',C2,n)
```

Scilab code Exa 1.15 To find properties of a gas in vessel at a point

```
clc
clear

//Input data
Po=300 //Pressure in the vessel in kPa
To=50+273 //Temperature in vessel in K
M=1 //Mach number
k=1.667 //Adiabatic constant
Ri=8314 //Ideal gas constant in J/mol-K
Mol=4 //Molecular weight of helium in kg/mol

//Calculation
R=Ri/Mol //Specific gas constant in J/kg-K
Cp=(k*R)/(k-1) //Specific heat capacity at constant
    pressure in J/kg-K
p1=(2/(k+1))^(k/(k-1)) //Pressure ratio
Pt=Po*p1 //Pressure at test condition in kPa
t1=(2/(k+1)) //Temperature ratio
Tt=To*t1 //Temperature at test condition in K
at=sqrt(k*R*Tt) //Velocity of sound in m/s
Ct=at //Velocity of gas at test condition in m/s
Cmax=sqrt(2*Cp*To) //Maximum velocity due to
    expanding of gases through nozzle system in m/s
```

```

//Output
printf('(A)At test point:\n    Pressure is %3.2f kPa
   \n    Temperature is %3.2f K\n    Velocity is %3
   .1f m/s\n (B)Maximum velocity due to expanding of
    gases through nozzle system is %3.2f m/s',Pt,Tt,
   Ct,Cmax)
```

Scilab code Exa 1.16 To find mach number and velocity of flow

```
clc
clear

//Input data
T=40+273 //Temperature in K
p1=0.5 //Static to Stagnation pressure ratio
k=1.67 //Adiabatic constant
Ri=8314 //Ideal gas constant in J/mol-K
Mol=39.94 //Molecular weight of argon in kg/mol

//Calculation
R=Ri/Mol //Specific gas constant in J/kg-K
p2=1/p1 //Pressure ratio
M=sqrt(((p2^((k-1)/k)-1)*2)/(k-1)) //Mach number
C=M*sqrt(k*R*T) //Velocity in the flow in m/s

//Output
printf('(A)Mach number is %3.3f\n (B)Velocity in the
    flow is %3.1f m/s',M,C)
```

Scilab code Exa 1.17 To find distance covered before sonic boom is heard on ground

```
clc
clear

//Input data
M=2.5 //Mach number
h=10 //Height in km

//Calculation
alp=asind(1/M) //Mach cone angle in degree
d=10/tand(alp) //Distance the jet would cover before
    a sonic boom is heard on ground in km

//Output
printf('Distance the jet would cover before a sonic
   boom is heard on ground is %3.2f km',d)
```

Scilab code Exa 1.18 To calculate time elapsed to feel disturbance due to aircraft

```
clc
clear

//Input data
h=1100 //Height in m
M1=2.5 //Mach number of aircraft @h
T=280 //Temperature @h
M2=0.5 //Mach number of observer
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K

//Calculation
alp=asind(1/M1) //Mach cone angle in degree
a=sqrt(k*R*T) //Velocity of sound in m/s
C1=M1*a //Velocity of aircraft when the observer is
   stationary in m/s
```

```
t1=h/(C1*tand(alp)) //Time elapsed when the observer is stationary in sec
C2=(M1-M2)*a //Velocity of aircraft when the observer is moving in the direction of aircraft in m/s
t2=h/(C2*tand(alp)) //Time elapsed when the observer is moving in the direction of aircraft in sec
C3=(M1+M2)*a //Velocity of aircraft when the observer is moving in the opposite direction in m/s
t3=h/(C3*tand(alp)) //Time elapsed when the observer is moving in the opposite direction in sec

//Output
printf('(A)Time elapsed when the observer is stationary is %3.3f sec\n (B)Time elapsed when the observer is moving in the direction of aircraft with M=%3.1f is %3.2f sec\n (C)Time elapsed when the observer is moving in the opposite direction is %3.2f sec\n',t1,M2,t2,t3)
```

Scilab code Exa 1.19 To find mach number at a point

```
clc
clear

//Input data
P=200 //Pressure in kPa
d=2.9 //Density in kg/m^3
C=50 //Velocity in m/s
mol=32 //Molecular weight of oxygen in kg/mol
k=1.4 //Adiabatic constant
Ri=8314 //Ideal gas constant in J/mol-K

//Calculation
```

```
R=Ri/mol //Specific gas Constant in J/kg-k
T=(P*10^3)/(R*d) //Temperature in K
a=sqrt(k*R*T) //Velocity of sound in m/s
M=C/a //Mach number

//Output
printf('Mach number is %3.4f',M)
```

Scilab code Exa 1.20 To find Mach number

```
clc
clear

//Input data
C=200 //Velocity of object in m/s
mol=4 //Molecular weight of helium in kg/mol
k=1.67 //Adiabatic constant
Ri=8314 //Ideal gas constant in J/mol-K
T=288 //Temperature in K

//Calculation
R=Ri/mol //Specific gas Constant in J/kg-k
a=sqrt(k*R*T) //Velocity of sound in m/s
M=C/a //Mach number

//Output
printf('Mach number is %3.1f',M)
```

Scilab code Exa 1.21 To find speed of sound and Mach number

```
clc
clear

```

```
//Input data
Z1=0 //Height from sea level in m
Z2=11 //Height from sea level in m
T1=288 //Temperature @Z1 in K, from gas tables
T2=216.5 //Temperature @Z2 in K, from gas tables
C=1000*(5/18) //Velocity in m/s
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-k

//Calculation
a1=sqrt(k*R*T1) //Sound velocity @Z1 in m/s
M1=C/a1 //Mach number @Z1
a2=sqrt(k*R*T2) //Sound velocity @Z2 in m/s
M2=C/a2 //Mach number @Z2

//Output
printf('(A)Speed of sound at:\n    sea level is %3.2
   f\n    an altitude of %3i km is %3.2f m/s\n (B)
   Mach numbeer at:\n    sea level is %3.2f\n    an
   altitude of %3i km is %3.2f',a1,Z2,a2,M1,Z2,M2)
```

Scilab code Exa 1.22 To find maximum possible velocity of air

```
clc
clear

//Input data
T=300+273 //Static Temperature in K
C=200 //Velocity in m/s
Cp=1005 //Specific heat capacity at constant
   pressure in J/kg-K

//Calculation
To=T+(C^2/(2*Cp)) //Stagnation Temperature in K
C_max=sqrt(2*Cp*To) //Maximum possible velocity
```

```
obtained by air in m/s

//Output
printf('Maximum possible velocity obtained by air is %3.2f m/s',C_max)
```

Scilab code Exa 1.23 To find exit velocity of air

```
clc
clear

//Input data
dT=37 //Temperature difference between air inside the tyre and nozzle exit
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K

//Calculation
C=sqrt(2*Cp*dT) //Exit velocity of air in m/s

//Output
printf('Exit velocity of air is %3.1f m/s',C)
```

Scilab code Exa 1.24 To find static conditions and Flight Mach number

```
clc
clear

//Input data
C=800*(5/18) //Velocity in m/s
Po=105 //Stagnation pressure in kPa
To=35+273 //Stagnation temperature in K
```

```
Cp=1005 //Specific heat capacity at constant
    pressure in J/kg-K
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-k

//Calculation
T=To-(C^2/(2*Cp)) //Static temperature in K
P=Po*(T/To)^(k/(k-1)) //Static pressure in kPa
a=sqrt(k*R*T) //Sound Velocity in m/s
M=C/a //Mach number

//Output
printf('(A)Static conditions:\n     Pressure is %3.2f
     kPa\n     Temperature is %3.2f K\n     Sound
    Velocity is %3.2f m/s\n (B)Mach number is %3.2f',
    P,T,a,M)
```

Scilab code Exa 1.25 To find stagnation pressure and mach number

```
clc
clear

//Input data
C=215 //Velocity in m/s
T=30+273 //Static temperature in K
P=5 //Static pressure in bar
R=287 //Specific gas constant in J/kg-k
k=1.4 //Adiabatic Constant

//Calculations
a=sqrt(k*R*T) //Sound Velocity in m/s
M=C/a //Mach number
To=T*(1+(((k-1)/2)*M^2)) //Stagnation temperature in
     K
Po=P*(To/T)^(k/(k-1)) //Stagnation pressure in kPa
```

```

//Output
printf('(A)Stagnation Pressure is %3.4f bar\n (B) Mach number is %3.3f',Po,M)
```

Scilab code Exa 1.26 To determine different velocities stagnation enthalpy and crocco number

```
clc
clear

//Input data
T=400 //Static temperature in K
k=1.4 //Adiabatic Constant
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K
R=287 //Specific gas constant in J/kg-k

//Calculation
a=sqrt(k*R*T) //Sound velocity in m/s
C=a //Velocity of jet in m/s, Since jet has sonic velocity
To=T+(C^2/(2*Cp)) //Stagnation temperature in K
ao=sqrt(k*R*To) //Sound velocity at Stagnation condition in m/s
ho=(Cp*To)*10^-3 //Stagnation enthalpy in kJ/kg
C_max=sqrt(2*Cp*To) //Maximum velocity of jet in m/s
cr=C/C_max //Crocco number

//Output
printf('(A)Velocity of sound at %3i K is %3.3f m/s\n (B)Velocity of sound at stagnation condition is %3.3f m/s\n (C)Maximum velocity of jet is %3.3f m/s\n (D)Stagnation enthalpy is %3.3f kJ/kg\n (E) Crocco number is %3.4f',T,C,ao,C_max,ho,cr)
```

Scilab code Exa 1.27 To find stagnation conditions and mass flow rate

```
clc
clear

//Input data
C=250 //Velocity of air in m/s
D=10 //Diameter in duct in cm
T=5+273 //Static temperature in K
P=40 //Static pressure in kPa
k=1.4 //Adiabatic constant
Cp=1005 //Specific heat capacity at constant
    pressure in J/kg-K
R=287 //Specific gas constant in J/kg-k

//Calculation
To=T+(C^2/(2*Cp)) //Stagnation temperature in K
Po=P*(To/T)^(k/(k-1)) //Stagnation pressure in kPa
d=(P*10^3)/(R*T) //Density in kg/m^3
A=(%pi*D^2/4)*10^-4 //Area in m^2
m=d*A*C //Mass flow rate in kg/s

//Output
printf('(A)Stagnation pressure is %3.2f kPa\n (B)
    Stagnation temperature is %3.2f K\n (C)Mass flow
    rate is %3.4f kg/s',Po,To,m)
```

Scilab code Exa 1.28 To find stagnation conditions and velocity at dynamic condition

```
clc
```

```
clear

//Input data
C=300 //Velocity of air in m/s
P=1 //Static pressure in kPa
T=290 //Static temperature in K
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-k
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K

//Calculation
To=T+(C^2/(2*Cp)) //Stagnation temperature in K
Po=P*(To/T)^(k/(k-1)) //Stagnation pressure in kPa
a=sqrt(k*R*T) //Sound velocity in m/s
Co=sqrt(k*R*To) //Sound velocity at Stagnation condition in m/s

//Output
printf('(A)Stagnation pressure and temperature are %3.4f bar and %3.2f K\n (B)Velocity of sound in the dynamic and stagnation conditions are %3.2f m/s and %3.2f m/s',Po,To,a,Co)
```

Scilab code Exa 1.29 To find flow velocity for compressible and incompressible flow

```
clc
clear

//Input data
dP=490*(1.01325/760) //Pressure in pivot tube in bar
P=0.3546+1.01325 //Static pressure(absolute) in bar
To=25+273 //Stagnation temperature in K
k=1.4 //Adiabaatic constant
```

```
R=287 //Specific gas constant in J/kg-k
Cp=1005 //Specific heat capacity at constant
    pressure in J/kg-K

//Calculation
Po=dP+P //Stagnation pressure in bar
T=To*(P/Po)^((k-1)/k) //Static temperature
C1=sqrt(2*Cp*(To-T)) //Flow velocity for
    Compressible flow in m/s
di=Po/(R*To) //Density in kg/m^3
C2=sqrt((2*dP)/di) //Flow velocity for
    incompressible flow in m/s

//Output
printf('Flow velocity for:\n (A)Compressible flow is
     %3.2f m/s\n (B)Incompressible flow is %3.2f m/s'
    ,C1,C2)
```

Scilab code Exa 1.30 To find Mach number velocity and area at a point

```
clc
clear

//Input data
To=27+273 //Stagnation temperature in K
Po=8 //Stagnation Pressure in bar
P=5.6 //Static pressure in bar, taken from diagram
    given
m=2 //Mass flow rate in kg/s
k=1.4 //Adiabaatic constant
Cp=1005 //Specific heat capacity at constant
    pressure in J/kg-K
R=287 //Specific gas constant in J/kg-k

//Calculation
```

```
T=To*(P/Po)^((k-1)/k) //Static temperature in K
a=sqrt(k*R*T) //Sound velocity in m/s
C=sqrt(2*Cp*(To-T)) //Velocity in m/s
M=C/a //Mach number
A=((m*R*T)/(P*10^5*C))*10^4 //Area at a point in the
    channal in cm^2

//Output
printf('(A)Mach number is %3.4f\n (B)Velocity is %3
    .1f m/s\n (C)Area at a point in the channal is %3
    .3f cm^2',M,C,A)
```

Scilab code Exa 1.31 To find velocity and mass flow rate

```
clc
clear

//Input data
Po=1.8 //Stagnation pressure in atm
To=20+273 //Stagnation temperature in K
P=1 //Surrounding pressure in atm
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-k

//Calculation
p1=0.528 //Static to Stagnation pressure ratio @Mach
    number=1, from gas tables
Pt=p1*Po //Critical pressure in atm, Since Pt<P the
    flow is not chocked
di=(Po*10^5)/(R*To) //Density in kg/m^3
ao=sqrt(k*R*To) //Sound velocity at Stagnation
    condition in m/s
Cp=(k*R)/(k-1) //Specific heat capacity at constant
    pressure in J/kg-K
C=sqrt(2*Cp*To*(1-(P/Po)^((k-1)/k))) //Velocity of
```

```
    air flow which will take place from chamber to
    the outside through a unit area hole in m/s
G=di*ao*sqrt(2/(k-1))*(P/Po)^(1/k)*sqrt((1-(P/Po)^((
    k-1)/k))) //Mass flow rate per unit area in kg/s-
    m^2

//Output
printf('(A)Velocity of air flow which will take
    place from chamber to the outside through a unit
    area hole is %3.3f m/s\n (B)Mass flow rate per
    unit area is %3.3f kg/s-m^2',C,G)
```

Scilab code Exa 1.32 To find various properties at one section in duct

```
clc
clear

//Input data
A1=465.125 //Cross sectional area at entry in cm^2
T1=26.66+273 //Static temperature at section-1 in K
P1=3.4473 //Static Pressure at section-1 in bar
C1=152.5 //Velocity at section-1 in m/s
P2=2.06838 //Static Pressure at section-2 in bar
T2=277.44 //Static temperature at section-2 in K
C2=260.775 //Velocity at section-2 in m/s
Cp=1005 //Specific heat capacity at constant
    pressure in J/kg-K
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-k

//Calculations
To1=T1+(C1^2/(2*Cp)) //Stagnation temperature at
    entry in K
To2=T2+(C2^2/(2*Cp)) //Stagnation temperature at
    exit in K
```

```
//here To1=To2 from answers
d1=(P1*10^5)/(R*T1) //Density at section -1
d2=(P2*10^5)/(R*T2) //Density at section -2
ar=(d2*C2)/(d1*C1) //Ratio of inlet to outlet area
A2=A1/ar //Cross sectional area at exit in cm^2
C_max=sqrt(2*Cp*To1) //Maximum velocity at exit in m
    /s
m=d1*A1*C1*10^-4 //Mass flow rate in kg/s
F=((P1*10^5*A1*10^-4)-(P2*10^5*A2*10^-4))+(m*(C1-C2)
    ) //Force acting on the duct wall between two
    sections in N

//Output
printf('(A)Maximum velocity and stagnation
    temperature at exit are %3.2f m/s and %3.2f K\n (
    B)Since Stagnation temperature %3i K at entry and
     %3i K at exit are equal, the flow is adiabatic\n
     (C)Cross sectional area at exit is %3.2f cm^2\n
    (D)Force acting on the duct wall between two
    sections is %3.2f N',C_max,To2,To1,To2,A2,F)
```

Scilab code Exa 1.33 To find various properties at one section in duct

```
clc
clear

//Input data
P1=250 //Static Pressure at section -1 in kPa
T1=26+273 //Static temperature at section -1 in K
M1=1.4 //Mach number at entry
M2=2.5 //Mach number at exit
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-k

//Calculation
```

```
C1=sqrt(k*R*T1)*M1 //Air velocity at entry in m/s
To=T1*(1+(((k-1)/2)*M1^2)) //Stagnation temperature in K
t1=(1+(((k-1)/2)*M2^2)) //Stagnation to exit Temperature ratio
T2=To/t1 //Exit temperature in K
C2=sqrt(k*R*T2)*M2 //Air velocity at exit in m/s
P2=P1*(T2/T1)^(k/(k-1)) //Exit static pressure in kPa
d2=(P2*10^3)/(R*T2) //Density at section-2 in kg/m^3
G=d2*C2 //)Mass flow rate through the duct per square metre in kg/s-m^2

//Output
printf('(A)At second section:\n    Temperature is %3.2f K\n    Pressure is %3.2f kPa\n    Velocity is %3.4f m/s\n (B)Mass flow rate through the duct per square metre is %3.1f kg/s-m^2',T2,P2,C2,G)
```

Scilab code Exa 1.34 To find maximum temperature encountered by skin

```
clc
clear

//Input data
M=2 //Mach number
h=20 //Altitude in km
Tc=-56 //Ambient temperature in degree Centigrade
Ta=-56+273 //Ambient temperature in K
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-k
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K

//Calculation
```

```
a=sqrt(k*R*Ta) //Sound velocity in m/s
C=M*a //Velocity of flight in m/s
To=Tc+(C^2/(2*Cp)) //The maximum temperature
    encountered is %3.1f degree Centigrade

//Output
printf('The maximum temperature encountered is %3.1f
    degree Centigrade',To)
```

Scilab code Exa 1.35 To find rate of heat transfer

```
clc
clear

//Input data
W=20000 //Power developed in kW
m=12 //Mass flow rate in kg/s
C1=50 //Velocity of air entering in m/s
T1=700+273 //Temperature of air entering in K
T2=298 //Temperature of air leaving in K
C2=125 //Velocity of air leaving in m/s
Cp=1.005 //Specific heat capacity at constant
    pressure in kJ/kg-K

//Calculation
dh=Cp*(T2-T1) //Change in enthalpy in kJ/kg
Q=((m*dh)+W-(m*(1/2000)*(C2^2-C1^2))) //The rate of
    heat transfer in kJ/s

//Output
printf('The rate of heat transfer is %3.2f kJ/s',Q)
```

Scilab code Exa 1.36 To find various properties in a nozzle

```
clc
clear

//Input data
mol=39.9 //Molecular weight of gas in kg/mol
k=1.67 //Adiabatic constant
Po=500 //Pressure in chamber in kPa
To=30+273 //Temperature in chamber in K
P1=80 //Pressure of nozzle at given section in kPa
D=0.012 //Cross section diameter of nozzle in m
Ri=8314 //Ideal gas constant in J/mol-K

//Calculation
R=Ri/mol //Specific gas constant in J/kg-K
p1=Po/P1 //Stagnation to static pressure ratio
M1=sqrt((((p1^((k-1)/k))-1)*2)/(k-1)) //Mach number
    at section
T1=To*((1+(((k-1)/2)*M1^2))^(-1)) //Temperature at
    section in K
a=sqrt(k*R*T1) //Sound Velocity in m/s
C1=M1*a //Gas Velocity at section in m/s
d=(P1*10^3)/(R*T1) //Density in kg/m^3
A1=%pi*D^2/4 //Cross-sectional Area
m=d*A1*C1 //Mass flow rate through nozzle in kg/s

//Output
printf('(A)At section:\n    Mach number is %3.1f\n
      Temperature is %3.1f K\n    Velocity is %3.3f
   m/s\n (B)Mass flow rate through nozzle is %3.3f
   kg/s',M1,T1,C1,m)
```

Scilab code Exa 1.37 To find Mach number velocity and pressure at a section in duct

```
clc
```

```
clear

//Input data
mol=4 //Molecular weight of gas in kg/mol
k=1.3 //Adiabatic constant
C1=150 //Gas Velocity at section-1 in m/s
P1=100 //Pressure of duct at section-1 in kPa
T1=15+273 //Temperature at section-1 in K
T2=-10+273 //Temperature at section-2 in K
Ri=8314 //Ideal gas constant in J/mol-K

//Calculation
R=Ri/mol //Specific gas constant in J/kg-K
a1=sqrt(k*R*T1) //Sound velocity at section-1 in m/s
M1=C1/a1 //Mach number at section-1
t1=0.9955 //Static to Stagnation temperature ratio
    at entry from gas tables @M1,k=1.3
To=T1/t1 //Stagantion temperature in K
p1=0.9815 //Static to Stagnation pressure ratio at
    entry from gas tables @M1,k=1.3
Po=P1/p1 //Stagnation pressure in kPa
t2=T2/To //Static to Stagnation temperature ratio at
     exit
M2=0.82 //Amch number at section-2 from gas tables
    @t2,k=1.3
p2=0.659 //Static to Stagnation pressure ratio at
    exit from gas tables @M2,k=1.3
P2=Po*p2 //Pressure at section-2 in kPa
a2=sqrt(k*R*T2) //Sound velocity at section-2 in m/s
C2=M2*a2 //Gas Velocity at section-2 in m/s

//Output
printf('At the second point:\n    Mach number is %3
    .2f\n    Pressure is %3.3f kPa\n    Velocity is
    %3.2f m/s',M2,P2,C2)
```

Scilab code Exa 1.38 To find mass flow rate and velocity at exit

```
clc
clear

//Input data
A1=10 //Inlet area in cm^2
C1=80 //Inlet Air velocity in m/s
T1=28+273 //Inlet temperature in K
P1=700 //Inlet Pressure in kPa
P2=250 //Exit pressure in kPa
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
a1=sqrt(k*R*T1) //Sound velocity at inlet in m/s
M1=C1/a1 //Mach number at inlet
t1=0.989 //Static to Stagnation temperature ratio at entry from gas tables @M1,k=1.4
To=T1/t1 //Stagantion temperature in K
p1=0.964 //Static to Stagnation pressure ratio at entry from gas tables @M1,k=1.4
Po=P1/p1 //Stagnation pressure in kPa
p2=P2/Po //Static to Stagnation pressure ratio
M2=1.335 //Mach number at exit
t2=0.737 //Static to Stagnation temperature ratio at exit from gas tables @M2,k=1.4
T2=To*t2 //Stagnation temperatur in K
a2=sqrt(k*R*T2) //Sound velocity at exit in m/s
C2=M2*a2 //Exit Air velocity in m/s
d1=(P1*10^3)/(R*T1) //Density at inlet in kg/m^3
m=d1*A1*C1*10^-4 //Mass flow rate in kg/s

//Output
```

```
printf('(A)Mass flow rate is %3.3f kg/s\n (B)
    Velocity at the exit is %3.2f m/s',m,C2)
```

Scilab code Exa 1.39 To find time required for a value of pressure decrease

```
clc
clear

//Input data
V=5 //Volume of air in m^3
Ae=10*10^-4 //Exit area in cm^2
To=60+273 //Temperature inside in the tank in K
Po1=40 //Intial total pressure in bar
Po2=2 //Final total pressure in bar
P=1 //Discharge pressure in bar
R=287 //Specific gas constant in J/kg-K

//Calculation
//Here pressure ratios P/Po1 and P/Po2 are always
    less than critical pressure ratio therefore flow
    is choked i.e. M=1 at exit
Gp=(0.0404184*Ae)/sqrt(To) //Mass flow rate by
    Stagnation pressure i.e. m/Po
//Differentiating m=(P*V)/(R*To) w.r.t. time and
    intrgrating resulting equation we get following
    expression.
t=-(V/(R*To*Gp))*log(Po2/Po1) //The time required
    for tank pressure to decrease from Po1 to Po2 in
    sec

//Output
printf('The time required for tank pressure to
    decrease from %i bar to %i bar is %3.2f sec',Po1,
    Po2,t)
```

Chapter 2

Flow through Variable Area Ducts

Scilab code Exa 2.1 To find mass flow rate temperature and pressure at throat

```
clc
clear

//Input data
do1=1.12 //Density of air i reservoir in kg/m^3
ao1=500 //Velocity of sound in reservoir in m/s
d=0.01 //Throat diameter in m
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K

//Calculation
To1=ao1^2/(k*R) //Stagnation temperature in K
Po1=do1*R*To1 //Stagnation pressure in Pa
p1=0.528 //Ratio of critical pressure to Stagnation
    pressure from gas tables @M=1
Pt=(Po1*p1)*10^-5 //Throat pressure in bar
t1=0.834 //Ratio of critical temperature to
    Stagnation temperature from gas tables @M=1
```

```
Tt=To1*t1 //critical temperature in K
d_t=(Pt*10^5)/(R*Tt) //Density of air at throat in
    kg/m^3
a_t=sqrt(k*R*Tt) //Sound velocity at throat in m/s
Ct=a_t //Air velocity t throat in m/s, Since M=1
A_t=%pi*d^2/4 //Throat area in m^2
m=d_t*A_t*Ct //Maximum mass flow rate in kg/s

//Output
printf('(A)Maximum mass flow rate is %3.5f kg/s\n (B
    )Pressure and temperarature at the throat are %3
    .3f bar and %3.4f K',m,Pt,Tt)
```

Scilab code Exa 2.2 To find properties at throat and exit in Convergent Divergent nozzle

```
clc
clear

//Input data
P1=2 //Intial pressure in bar
C1=170 //Initial velocity of air in m/s
T1=473 //Intial temperature in K
A1=1000 //Inlet area in mm^2
P2=0.95 //Exit pressure in bar
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K

//Calculation
a_1=sqrt(k*R*T1) //Velocity of sound at inlet in m/s
M1=C1/a_1 //Inlet mach number
t1=0.970 //Ratio of inlet temperature to Stagnation
    temperature from gas tables @M=1
To1=T1/t1 //Stagnation temperature in K
p1=0.900 //Ratio of inlet pressure to Stagnation
```

```
pressure from gas tables @M=1
Po1=P1/p1 //Stagnation pressure in bar
a1=1.623 //Ratio of inlet area to critical area from isentropic gas tables @M=1
At=A1/a1 //critical area in mm^2
p2=0.528 //Pressure ratio at critical state from isentropic gas tables @M=1
Pt=Po1*p2 //Throat pressure in bar
t2=0.834 //Temperature ratio at critical state from isentropic gas tables @M=1
Tt=To1*t2 //Throat temperature in K
a_t=sqrt(k*R*Tt) //Velocity of sound at throat in m/s
C_t=a_t //Critical velocity of air in m/s
p3=P2/Po1 //Pressure ratio at exit
M2=1.17 //Mach number at exit from isentropic gas tables @p3
t3=0.785 //Temperature ratio at exit from isentropic gas tables @M2
T2=To1*t3 //Exit temperature in K
a3=1.022 //Area ratio at exit from isentropic gas tables @M2
A2=At*a3 //Exit area in mm^2, wrong answer in textbook
C2=M2*sqrt(k*R*T2) //Exit velocity in m/s

//Output
printf('(A)Stagnation temperature and pressure are %3.2f K and %3.3f bar\n (B)Sonic velocity and mach number at entry are %3.2f m/s and %3.2f\n (C)Velocity, Mach number and flow area at outlet section are %3.2f m/s, %3.2f and %3.2f mm^2\n (D)Pressure, area at throat of the nozzle are %3.5f bar and %3.3f mm^2',To1,Po1,a_1,M1,C2,M2,A2,Pt,At)
```

Scilab code Exa 2.3 To find properties at throat and exit maximum possible velocity of gas and type of nozzle

```
clc
clear

//Input data
Po1=10 //Stagnation pressure in bar
To1=798 //Stagnation temperature in K
Pt=7.6 //Throat pressure in bar
m=1.5 //Mass flow rate in kg/s
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant
    pressure in J/kg-K

//Calculation
p1=0.528 //Ratio of critical pressure to Stagnation
    pressure from isentropic gas tables @M=1,k=1.4
Pc=p1*Po1 //Critical pressure in bar
P2=Pt //Exit pressure in bar, Since Pc<P2
p2=P2/Po1 //Pressure ratio
M2=0.64 //Exit mach number from isentropic gas
    tables @p2
t1=0.924 //Ratio of exit temperature to Stagnation
    temperature from isentropic gas tables @M2
T2=t1*To1 //exit temperature in K
C2=sqrt(k*R*T2)*M2 //Exit velocity in m/s
C_max=sqrt(2*Cp*To1) //Maximum possible velocity in
   m/s
d2=(P2*10^5)/(R*T2) //Density at exit in kg/m^3
At=(m/(d2*C2))*10^6 //Throat area in mm^2

//Output
```

```
printf('(A)At the nozzle throat/exit:\n     Pressure
   is %3.2f bar\n     Temperature is %3.2f K\n
   Velocity is %3.2f\n (B)Maximum possible velocity
   is %3.2f m/s\n (C)Type of the nozzle is a
   convergent nozzle and its throat area is %3.3f mm
   ^2',P2,T2,C2,C_max,At)
```

Scilab code Exa 2.4 To find properties at exit in Convergent Divergent nozzle

```
clc
clear

//Input data
Po1=3.344 //Stagnation pressure in bar
To1=900 //Stagnation temperature in K
P2=1.05 //Exit pressure in bar
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant
   pressure in J/kg-K

//Calculation
p1=P2/Po1 //Pressure ratio
M2=1.40 //Exit mach number from gas tables @p1,k=1.4
t1=0.718 //Ratio of exit temperature to Stagnation
   temperature from isentropic gas tables @M2,k=1.4
T2=To1*t1 //exit temperature in K
C2=sqrt(k*R*T2)*M2 //Exit velocity in m/s
d2=(P2*10^5)/(R*T2) //Density at exit in kg/m^3
a1=1.115 //Ratio of exit area to critical area from
   isentropic gas tables @M2
M_2=0.6733 //Exit mach number when it acts as
   diffuser
t2=0.91633 //Ratio of exit temperature to Stagnation
```

```
    temperature from isentropic gas tables @M2
T_2=t2*To1 //exit temperature in K
C_2=sqrt(k*R*T_2)*M_2 //Exit velocity in m/s
p2=0.738 //Ratio of exit pressure to Stagnation
    pressure from isentropic gas tables @M2
P_2=Po1*p2 //exit pressure in bar
d_2=(P_2*10^5)/(R*T_2) //Density at exit in kg/m^3

//Output
printf('(A)At exit:\n    Temperaure is %3i K\n
    Velocity is %3.2f m/s\n    Density is %3.3f kg/m
    ^3\n (B)At diffuser:\n    Temperaure is %3.3f K\n
        Velocity is %3.3f m/s\n    Density is %3.4f
    kg/m^3\n    Pressure is %3.4f bar\n',T2,C2,d2,T_2
    ,C_2,d_2,P_2)
```

Scilab code Exa 2.5 To find mass flow rate and pressure of a CD nozzle

```
clc
clear

//Input data
Po1=8 //Stagnation pressure in bar
To1=273+15 //Stagnation temperature in K
At=25 //Throat area in cm^2
A2=100 //Exit area in cm^2
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K

//Calculation
a1=A2/At //Area ratio
M2=2.94 //Exit mach number from gas tables @a1,k=1.4
p1=0.0298 //Ratio of exit pressure to Stagnation
    pressure from isentropic gas tables @M2,k=1.4
P2=Po1*p1 //exit pressure in bar
```

```
M_2=0.146 //Exit mach number when it acts as diffuser
p2=0.9847 //Ratio of exit pressure to Stagnation pressure from isentropic gas tables @M2
P_2=Po1*p2 //exit pressure in bar
p3=0.528 //Ratio of critical pressure to Stagnation pressure from isentropic gas tables @M=1,k=1.4
Pc=(Po1*p3) //Critical pressure in bar
t1=0.834 //Ratio of critical temperature to Stagnation temperature from isentropic gas tables @M=1,k=1.4
Tt=To1*t1 //critical temperature in K
d_t=(Pc*10^5)/(R*Tt) //Density at critical state in kg/m^3
a_t=sqrt(k*R*Tt) //Velocity of sound at critical state in m/s
Ct=a_t //Velocity of air at critical state in m/s
m=d_t*At*Ct*10^-4 //Mass flow rate in kg/s

//Output
printf('(A)Maximum mass flow rate is %3.3f kg/s\n (B)As nozzle:\n     Pressure is %3.4f bar\n     Mach number is %3.2f\n As diffuser:\n     Pressure is %3.4f bar\n     Mach number is %3.3f',m,P2,M2,P_2,M_2)
```

Scilab code Exa 2.6 To find exit properties and force exerted on diffuser walls

```
clc
clear

//Input data
D1=15 //Entry diameter in cm
D2=30 //Exit diamater in cm
```

```
P1=0.96 //Inlet pressure in bar
T1=340 //Inlet temperature in K
C1=185 //INlet velocity in m/s
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K

//Calculation
A1=%pi*D1^2/4 //Entry area in cm^2
A2=%pi*D2^2/4 //Exit area in cm^2
a_1=sqrt(k*R*T1) //Sound velocity in m/s
M1=C1/a_1 //Inlet mach number
p1=0.843 //Ratio of inlet pressure to Stagnation pressure from gas tables @M1,k=1.4
Po1=P1/p1 //Stagnation pressure in bar
t1=0.952 //Ratio of inlet temperature to Stagnation temperature from gas tables @M1,k=1.4
To1=T1/t1 //Stagnation temperature in K
a1=1.34 //Ratio of inlet area to critical area from isentropic gas tables @M1,k=1.4
At=A1/a1 //critical area in cm^2
a2=A2/At //Area ratio
M2=0.1088  //Exit mach number from gas tables @a2,k=1.4
p2=0.992 //Ratio of exit pressure to Stagnation pressure from isentropic gas tables @M2,k=1.4
P2=Po1*p2 //exit pressure in bar
t2=0.9976 //Ratio of exit temperature to Stagnation temperature from isentropic gas tables @M2,k=1.4
T2=To1*t2 //exit temperature in K
C2=sqrt(k*R*T2)*M2 //Exit velocity in m/s
F1=P1*10^5*A1*10^-4*(1+(k*(M1^2))) //Force exerted at entry in kN
F2=P2*10^5*A2*10^-4*(1+(k*(M2^2))) //Force exerted at exit in kN
F=(F2-F1)*10^-3 //Force exerted on the diffuser walls in kN, wrong answer in textbook

//Output
```

```
printf('(A)Exit pressure is %3.3f bar\n (B)Exit
    velocity is %3.2f m/s\n (C)Force exerted on the
    diffuser walls is %3.3f kN',P2,C2,F)
```

Scilab code Exa 2.7 To find properties at inlet and exit of diffuser

```
clc
clear

//Input data
M1=3.6 //Inlet mach number
M2=2 //Exit mach number
m=15 //Mass flow rate in kg/s
P1=1.05 //Inlet pressure in bar
T1=313 //Inlet temperature in K
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K

//Calculation
p1=11.38*10^-3 //Ratio of inlet pressure to
    Stagnation pressure from gas tables @M1,k=1.4
Po=P1/p1 //Stagnation pressure in bar
t1=0.278 //Ratio of inlet temperature to Stagnation
    temperature from gas tables @M1,k=1.4
To=T1/t1 //Stagnation temperature in K
C1=sqrt(k*R*T1)*M1 //Inlet velocity in m/s
d1=(P1*10^5)/(R*T1) //Density at inlet in kg/s, P1
    in Pa
A1=(m/(d1*C1))*10^4 //Inlet area in cm^2
p2=0.128 //Ratio of exit pressure to Stagnation
    pressure from isentropic gas tables @M2,k=1.4
P2=Po*p2 //exit pressure in bar
t2=0.555 //Ratio of exit temperature to Stagnation
    temperature from isentropic gas tables @M2,k=1.4
T2=To*t2 //exit temperature in K
```

```
C2=sqrt(k*R*T2)*M2 //Exit velocity in m/s
d2=(P2*10^5)/(R*T2) //Density at exit in kg/s
A2=(m/(d2*C2))*10^4 //Exit area in cm^2

//Output
printf('(A)At Inlet:\n     Area is %3.1f cm^2\n
   Total pressure %3.2f bar\n     Total temperature
   is %3.1f K\n (B)At Exit:\n     Area is %3.1f cm^2\
   n     Total pressure %3.2f bar\n     Total
   temperature is %3.2f K\n     Static temperature is
    %3.2f K\n     Static pressure is %3.2f bar',A1,Po
   ,To,A2,Po,To,T2,P2)
```

Scilab code Exa 2.8 To find properties at throat and exit and maximum possible velocity of nozzle

```
clc
clear

//Input data
Po=6.91 //Stagnation pressure in bar
To=325+273 //Stagnation temperature in K
P2=0.98 //exit pressure in bar
m=3600/3600 //Mass flow rate in kg/s
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant
   pressure in J/kg-K

//Calculation
p1=0.528 //Ratio of critical pressure to Stagnation
   pressure from gas tables @M=1
Pt=Po*p1 //critical pressure in bar
t1=0.834 //Ratio of critical temperature to
   Stagnation temperature from gas tables @M=1
```

```
Tt=To*t1 //critical temperature in K
at=sqrt(k*R*Tt) //Sound velocity at throat in m/s
Ct=at //Air velocity t throat in m/s, Since M=1
dt=(Pt*10^5)/(R*Tt) //Density of air at throat in kg/m^3, Pt in Pa
At=(m/(dt*Ct))*10^4 //Throat area in m^2 x10^-4
p2=P2/Po //Pressure ratio
M2=1.93 //Exit mach number from gas tables @p2,k=1.4
t2=0.573 //Ratio of exit temperature to Stagnation temperature from isentropic gas tables @M2,k=1.4
T2=To*t2 //exit temperature in K
a2=1.593 //Ratio of exit area to critical area from isentropic gas tables @M2,k=1.4
A2=a2*At //Exit area in m^2, At in m^2 x10^-4
C_max=sqrt(2*Cp*To) //Maximum possible velocity in m/s

//Output
printf('(A)At throat:\n    Area is %3.2fx10^-4 m^2\n    Pressure is %3.2f bar\n    Velocity is %3.1f m/s\n (B)At Exit:\n    Area is %3.3fx10^-4 m^2\n    Mach number is %3.2f\n (C)Maximum possible velocity is %3.2f m/s',At,Pt,Ct,A2,M2,C_max)
```

Scilab code Exa 2.9 To find Stagnation temperature properties at exit and mass flow rate

```
clc
clear

//Input data
P1=2.45 //Inlet pressure in bar
T1=26.5+273 //Inlet temperature in K
M1=1.4 //Inlet mach number
M2=2.5 //Exit mach number
```

```
k=1.3 //Adiabatic Constant
R=469 //Specific gas constant in J/kg-K

//Calculation
t1=0.773 //Ratio of inlet temperature to Stagnation
    temperature from gas tables @M1,k=1.3
To=T1/t1 //Stagnation temperature in K
t2=0.516 //Ratio of exit temperature to Stagnation
    temperature from isentropic gas tables @M2,k=1.3
T2=To*t2 //exit temperature in K
C2=sqrt(k*R*T2)*M2 //Exit velocity in m/s
a1=sqrt(k*R*T1) //Sound velocity at inlet in m/s
G=(P1*10^5*a1*M1)/(R*T1) //)Flow rate per square
    meter of the inlet cross section in kg/s-m^2

//Output
printf('(A)Stagnation temperature is %3.2f K\n (B)At
     Exit:\n     Temperature is %3.3f K\n     Velocity
    is %3.2f m/s\n (C)Flow rate per square meter of
    the inlet cross section is %3.2f kg/s-m^2',To,T2,
    C2,G)
```

Scilab code Exa 2.10 To determine throat and exit conditions mass flow rate through nozzle

```
clc
clear

//Input data
Po=1000 //Stagnation pressure in kPa
To=800 //Stagnation temperature in K
k=1.4 //Adiabatic Constant
M2=2 //Exit mach number
At=20 //Throat area in cm^2
R=287 //Specific gas constant in J/kg-K
```

```

//Calculation
t1=0.834 //Ratio of critical temperature to Stagnation temperature from isentropic gas tables @M=1,k=1.4
Tt=To*t1 //critical temperature in K
at=sqrt(k*R*Tt) //Velocity of sound at critical state in m/s
Ct=at //Velocity of air at critical state in m/s, Since M=1
p1=0.528 //Ratio of critical pressure to Stagnation pressure from isentropic gas tables @M=1,k=1.4
Pt=Po*p1 //Critical pressure in bar
dt=(Pt*10^3)/(R*Tt) //Density at critical state in kg/m^3, Pt in Pa
m=dt*At*10^-4*Ct //Mass flow rate in kg/s, At in m^2
p2=0.128 //Ratio of exit pressure to Stagnation pressure from isentropic gas tables @M2,k=1.4
P2=Po*p2 //exit pressure in kPa
t2=0.555 //Ratio of exit temperature to Stagnation temperature from isentropic gas tables @M2,k=1.4
T2=To*t2 //exit temperature in K
a2=1.687 //Ratio of exit area to critical area from isentropic gas tables @M2,k=1.4
A2=At*a2 //Exit area in cm^2
C2=sqrt(k*R*T2)*M2 //Exit velocity in m/s
d2=P2*10^3/(R*T2) //Density at exit in kg/m^3, P2 in Pa

//Output
printf('(A)At throat:\n    Temperature is %3.1f K\n    Velocity is %3.2f m/s\n    Pressure is %3i kPa\n (B)At Exit:\n    Temperature is %3i K\n    Pressure is %3i kPa\n    Area is %3.2f m^2\n    Mass flow rate is %3.4f kg/s',Tt,Ct,Pt,T2,P2,A2,m)
```

Scilab code Exa 2.11 To find properties at throat and test section mass flow rate and Power required in nozzle of wind tunnel

```
clc
clear

//Input data
M2=2 //Exit mach number
At=1000 //Throat area in cm^2
Po=0.69 //Stagnation pressure in bar
To=310 //Stagnation temperature in K
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K
Cp=1.005 //Specific heat capacity at constant
    pressure in kJ/kg-K

//Calculation
t1=0.834 //Ratio of critical temperature to
    Stagnation temperature from isentropic gas tables
     @M=1,k=1.4
Tt=To*t1 //critical temperature in K
at=sqrt(k*R*Tt) //Velocity of sound at critical
    state in m/s
Ct=at //Velocity of air at critical state in m/s,
    Since M=1
p1=0.528 //Ratio of critical pressure to Stagnation
    pressure from isentropic gas tables @M=1,k=1.4
Pt=Po*p1 //Critical pressure in bar
dt=(Pt*10^5)/(R*Tt) //Density at critical state in
    kg/m^3, Pt in Pa
m=dt*At*10^-4*Ct //Mass flow rate in kg/s, At in m^2
p2=0.128 //Ratio of exit pressure to Stagnation
    pressure from isentropic gas tables @M2,k=1.4
P2=Po*p2 //exit pressure in bar
```

```
t2=0.555 //Ratio of exit temperature to Stagnation temperature from isentropic gas tables @M2,k=1.4
T2=To*t2 //exit temperature in K
C2=sqrt(k*R*T2)*M2 //Exit velocity in m/s
d2=(P2*10^5)/(R*T2) //Density at exit in kg/m^3, P2 in Pa
A2=(m/(d2*C2))*10^4 //Exit area in cm^2
P=m*Cp*(To-T2) //Power required to drive the compressor in kW

//Output
printf('(A)At throat:\n    Temperature is %3.2f K\n    Velocity is %3.2f m/s\n    Pressure is %3.3f bar\n    At Test section:\n    Temperature is %3.2f K\n    Velocity is %3.3f m/s\n    Pressure is %3.3f bar\n (B)Area of cross section at test section is %3i cm^2\n (C)Mass flow rate is %3.3f kg/s\n (D)Power required to drive the compressor is %3.2f kW',Tt,Ct,Pt,T2,C2,P2,A2,m,P)
```

Scilab code Exa 2.12 To find cross section at throat and exit

```
clc
clear

//Input data
Po=10 //Stagnation pressure in bar
To=100+273 //Stagnation temperature in K
m=15 //mass flow rate in kg/s
P2s=1 //Back pressure in isentropic state in bar
eff=0.95 //efficiency of diverging nozzle
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K
```

```
//Calculation
//case I: isentropic
t1=0.834 //Ratio of critical temperature to Stagnation temperature from isentropic gas tables @M=1,k=1.4
Tt=To*t1 //critical temperature in K
at=sqrt(k*R*Tt) //Velocity of sound at critical state in m/s
Ct=at //Velocity of air at critical state in m/s, Since M=1
p1=0.528 //Ratio of critical pressure to Stagnation pressure from isentropic gas tables @M=1,k=1.4
Pt=Po*p1 //Critical pressure in bar
dt=(Pt*10^5)/(R*Tt) //Density at critical state in kg/m^3, Pt in Pa
At=(m/(dt*Ct))*10^4 //Throat area in cm^2
p2=P2s/Po //Pressure ratio
M2s=2.15 //Exit mach number from gas tables (isentropic state) @p2,k=1.4
t2=0.519 //Ratio of exit temperature to Stagnation temperature from isentropic gas tables @M2s,k=1.4
T2s=t2*To //exit temperature in K
a2s=sqrt(k*R*T2s) //Velocity of sound at exit in m/s
C2s=M2s*a2s //Exit air velocity in m/s
d2s=(P2s*10^5)/(R*T2s) //Density at exit in kg/m^3, P2 in Pa
A2s=(m/(d2s*C2s))*10^4 //Exit area in cm^2
//case II: isentropic upto throat
T2=To-(eff*(To-T2s)) //Exit tempareture in K
C2=sqrt(2*Cp*(To-T2)) //Exit air velocity in m/s
P2=P2s //Exit pressure in bar, Since it is diffuser
d2=(P2*10^5)/(R*T2) //Density at exit in kg/m^3, P2 in Pa
A2=(m/(d2*C2))*10^4 //Exit area in cm^2

//Output
printf('(A)The nozzle cross section at throat in
```

```
both cases is %3.2f cm^2\n (B)The nozzle cross section at exit in case I is %3.3f cm^2 and in case II is %3.2f cm^2',At,A2s,A2)
```

Scilab code Exa 2.13 To find ratio of areas velocity and back pressure in CD nozzle

```
clc
clear

//Input data
Po=600 //Stagnation pressure in kPa
To=40+273 //Stagnation temperature in K
P2=100 //exit pressure in kPa
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K

//Calculation
p1=P2/Po //pressure ratio
M2=1.82 //Exit mach number from gas tables @p2,k=1.4
ar=1.461 //Ratio of nozzle exit area to nozzle throat area from gas tables @M2
t1=0.602 //Ratio of exit temperature to Stagnation temperature from isentropic gas tables @M2,k=1.4
T2=To*t1 //exit temperature in K
C2=sqrt(k*R*T2)*M2 //Exit air velocity in m/s
p2=3.698 //Ratio of static pressures after shock to before shock from normal shock gas tables @M2
Py=p2*P2 //The back pressure at which normal shock acts at the exit plane of the nozzle in kPa

//Output
printf('(A)Ratio of nozzle exit area to nozzle throat area is %3.3f\n (B)The discharge velocity from nozzle is %3.2f m/s\n (C)The back pressure
```

```
    at which normal shock acts at the exit plane of
    the nozzle is %3.1f kPa',ar,C2,Py)
```

Scilab code Exa 2.14 To find how duct acts

```
clc
clear

//Input data
ar=2 //Ratio of nozzle exit area to nozzle throat
    area
Po=700 //Stagnation pressure in kPa
P2=400 //exit pressure in kPa

//Calculation
p1=0.528 //Ratio of critical pressure to Stagnation
    pressure from gas tables @M=1
Pt=Po*p1 //critical pressure in bar
p2=P2/Po //Pressure ratio
M2=0.93 //Exit mach number from gas tables @p2,k=1.4

//Output
printf('Since pressure decreases from %3i kPa to %3
    .1f kPa from inlet to throat, it acts as nozzle\n
     Since exit pressure %3i kPa is above critical
    pressure %3.1f kPa, it acts as diffuser with M=%3
    .2f\n Hence the duct acts as Venturi',Po,Pt,P2,Pt
    ,M2)
```

Scilab code Exa 2.15 To find mass flow rate static and stagnation conditions and entropy change of subsonic diffuser

```
clc
```

```
clear

//Input data
A1=0.15 //Inlet area in m^2
C1=240 //Inlet velocity in m/s
T1=300 //Inlet temperature in K
P1=0.7 //Inlet pressure in bar
C2=120 //Exit velocity in m/s
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant
    pressure in J/kg-K

//Calculations
a1=sqrt(k*R*T1) //Velocity of sound at inlet in m/s
M1=C1/a1 //Inlet mach number
d1=(P1*10^5)/(R*T1) //Density at inlet in kg/s, P1
    in Pa
m=d1*A1*C1 //Mass flow rate in kg/s
t1=0.913 //Ratio of inlet temperature to Stagnation
    temperature from gas tables @M1,k=1.4
To=T1/t1 //Stagnation temperature in K
p1=0.727 //Ratio of inlet pressure to Stagnation
    pressure from gas tables @M1,k=1.4
Po=P1/p1 //Stagnation pressure in bar
T2=To-(C2^2/(2*Cp)) //Exit temperature in K
t2=T2/To //Temperature ratio
M2=0.33 //Exit mach number from gas tables @t2,k=1.4
p2=0.927 //Ratio of exit pressure to Stagnation
    pressure from isentropic gas tables @M2,k=1.4
P2=Po*p2 //exit pressure in bar
d2=(P2*10^5)/(R*T2) //Density at exit in kg/s, P2 in
    Pa
A2=(m/(d2*C2)) //Exit area in m^2
ds=0 //Entropy change in kJ/kg-K, since process is
    isentropic

//Output
```

```
printf('(A)Mass flow rate is %3.3f kg/s\n (B) Stagnation pressure at exit is %3.4f bar\n (C) Stagnation Temperature at exit is %3.3f K\n (D) Static exit pressure is %3.3f bar\n (E)Entropy change is %3i kJ/kg-K\n (F)Exit area is %3.3f m^2 ',m,Po,To,P2,ds,A2)
```

Scilab code Exa 2.16 To find throat area reservoir conditions and mass flow rate

```
clc
clear

//Input data
A2=645 //Exit area in mm^2
M2=2 //Exit mach number
P2=1 //exit pressure in bar
T2=185 //Exit temperature in K
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K

//Calculation
t1=0.555 //Ratio of exit temperature to Stagnation temperature from gas tables @M2,k=1.4
To=T2/t1 //Stagnation temperature in K
p1=0.128 //Ratio of exit pressure to Stagnation pressure from isentropic gas tables @M2,k=1.4
Po=P2/p1 //Stagnation pressure in bar
a1=1.687 //Ratio of exit area to critical area from isentropic gas tables @M2,k=1.4
At=A2/a1 //Critical area in mm^2
d2=(P2*10^5)/(R*T2) //Density at exit in kg/s, P2 in Pa
C2=sqrt(k*R*T2)*M2 //Exit air velocity in m/s
m=d2*A2*C2*10^-6 //Mass flow rate in kg/s, A2 in m^2
```

```

//Output
printf('(A)Throat area is %3.2f mm^2\n (B)Reservoir pressure is %3.4f bar\n (C)Reservoir temperature is %3.2f K\n (D)Mass flow rate is %3.4f kg/s',At,Po,To,m)
```

Scilab code Exa 2.17 To find throat conditions ratio of velocities and mass flow rate

```
clc
clear

//Input data
Po=20 //Stagnation pressure in kPa
To=1000 //Stagnation temperature in K
P2=3 //exit pressure in bar
A2=100 //Exit area in cm^2
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K

//Calculations
p1=P2/Po //Pressure ratio
M2=1.9 //Exit mach number from gas tables @p1,k=1.4
t1=0.581 //Ratio of exit temperature to Stagnation temperature from isentropic gas tables @M2,k=1.4
T2=To*t1 //exit temperature in K
C2=M2*sqrt(k*R*T2) //Exit velocity in m/s
a1=1.555 //Ratio of exit area to critical area from isentropic gas tables @M2,k=1.4
At=A2/a1 //critical area in cm^2
p1=0.528 //Ratio of critical pressure to Stagnation pressure from gas tables @M=1
```

```
Pt=Po*p1 //critical pressure in bar
t1=0.834 //Ratio of critical temperature to
    Stagnation temperature from gas tables @M=1
Tt=To*t1 //critical temperature in K
at=sqrt(k*R*Tt) //Sound velocity at throat in m/s
Ct=at //Air velocity t throat in m/s, Since M=1
dt=(Pt*10^5)/(R*Tt) //Density of air at throat in kg
    /m^3, Pt in Pa
m=dt*At*10^-4*Ct //Mass flow rate in kg/s, At in m^2
C_max=sqrt(2*Cp*To) //Maximum possible velocity in m
    /s
cr=C2/C_max //Ratio of velocities

//Output
printf('(A)At Throat:\n     Area is %3.2f cm^2\n
    Pressure is %3.2f bar\n     Temperature is %3i K\n
     (B)Exit velocity is %3.4f times C_max in m/s\n (
    C)Mass flow rate is %3.2f kg/s',At,Pt,Tt,cr,m)
```

Scilab code Exa 2.18 To find mass flow rate and exit conditions

```
clc
clear

//Input data
Po=7 //Stagnation pressure in bar
To=100+273 //Stagnation temperature in K
At=12 //Critical area in cm^2
A2=25.166 //Exit area in cm^2
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K

//Calculation
a1=A2/At //Ratio of areas
//subsonic
```

```
M2=0.29 //Exit mach number from gas tables @a1,k=1.4
p1=0.943 //Ratio of exit pressure to Stagnation
    pressure from isentropic gas tables @M2,k=1.4
P2=Po*p1 //exit pressure in bar
t1=0.983 //Ratio of exit temperature to Stagnation
    temperature from gas tables @M2,k=1.4
T2=To*t1 //Exit temperature in K
C2=M2*sqrt(k*R*T2) //Exit air velocity in m/s
//supersonic
M_2=2.25 //Exit mach number from gas tables @a1,k
    =1.4
p2=0.0865 //Ratio of exit pressure to Stagnation
    pressure from isentropic gas tables @M2,k=1.4
P_2=Po*p2 //exit pressure in bar
t2=0.497 //Ratio of exit temperature to Stagnation
    temperature from gas tables @M2,k=1.4
T_2=To*t2 //Exit temperature in K
C_2=M_2*sqrt(k*R*T_2) //Exit air velocity in m/s
d2=(P2*10^5)/(R*T2) //Density at exit in kg/s, P2 in
     Pa
m=d2*A2*10^-4*C2 //Mass flow rate in kg/s, A2 in m^2

//Output
printf('(A)Maximum mass flow rate is %3.3f kg/s\n (B
    )Subsonic exit condition:\n    Temperature is %3
    .3f K\n    Velocity is %3.2f m/s\n    Pressure is
     %3.3f bar\n    Mach number is %3.2f\n
    Supersonic exit condition:\n    Temperature is %3
    .3f K\n    Velocity is %3.2f m/s\n    Pressure is
     %3.4f bar\n    Mach number is %3.2f\n',m,T2,C2,
    P2,M2,T_2,C_2,P_2,M_2)
```

Scilab code Exa 2.19 To find mach number change in stagnation pressure entropy change and static temperature and efficiency of nozzle

```
clc
clear

//Input data
T1=335 //Inlet temperature in K
P1=655 //Inlet pressure in kPa
C1=150 //Inlet velocity in m/s
P2=138 //Exit pressure in kPa
T2=222 //Exit temperature in K
m=9 //Mass flow rate in kg/s
Mol=32 //Molar mass of oxygen in kg/mol
Ri=8314 //Ideal gas constant in J/kg-k
k=1.4 //Adiabatic Constant
Cp=915 //Specific heat capacity at constant pressure in J/kg-K

//Calculation
R=Ri/Mol //Specific gas constant in J/kg-K
a1=sqrt(k*R*T1) //Sound velocity at inlet in m/s
M1=C1/a1 //Inlet mach number
t1=0.964 //Ratio of inlet temperature to Stagnation temperature from gas tables @M1,k=1.4
To1=T1/t1 //Stagnation temperature at inlet in K
p1=0.881 //Ratio of inlet pressure to Stagnation pressure at entry from gas tables @M1,k=1.4
Po1=P1/p1 //Stagnation pressure at entry in kPa
t2=0.834 //Ratio of critical temperature to Stagnation temperature from gas tables @M=1
Tt=To1*t2 //critical temperature in K
C2=sqrt(C1^2+(2*Cp*(T1-T2))) //Exit velocity in m/s,
a2=sqrt(k*R*T2) //Sound velocity at exit in m/s
M2=C2/a2 //Exit mach number
p2=0.208 //Ratio of exit pressure to Stagnation pressure at exit from isentropic gas tables @M2,k=1.4
Po2=P2/p2 //Stagnation pressure at exit in kPa
SPC=(Po1-Po2) //Change in the stagnation pressure between inlet and exit in kPa
```

```
ds=R*log(Po1/Po2) //Change in entropy in J/kg-K
T2s=T1*((P2/P1)^((k-1)/k)) //Exit temperature at isentropic state in K
eff=((T1-T2)/(T1-T2s))*100 //Nozzle efficiency in percent

//Output
printf('(A)Exit mach number is %3.2f\n (B)Change in the stagnation pressure between inlet and exit is %3.2f kPa\n (C)Change in entropy is %3.3f J/kg-K\n (D)Static temperature at throat is %3.1f K\n (E)Nozzle efficiency is %3.2f percent',M2,SPC,ds,Tt,eff)
```

Scilab code Exa 2.20 To find pressure rise coefficient and ratio of area

```
clc
clear

//Input data
C1=200 //Inlet velocity in m/s
Po1=400 //Stagnation pressure at entry in kPa
To1=500 //Stagnation temperature at inlet in K
C2=100 //Exit velocity in m/s
eff=0.9 //Nozzle efficiency
k=1.4 //Adiabatic Constant
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K

//Calculation
T1=To1-(C1^2/(2*Cp)) //Inlet temperature in K
t1=T1/To1 //Temperature ratio
P1=Po1*t1^(k/(k-1)) //Inlet pressure in kPa
To2s=(eff*(To1-T1))+T1 //Exit Stagnation temperature at isentropic state in K
```

```
To2=To2s //Exit Stagnation temperature in K, Since adiabatic
T2=To2-(C2^2/(2*Cp)) //Exit temperature in K
t2=To2s/T1 //Temperature ratio
Po2=P1*t2^(k/(k-1)) //Stagnation pressure at exit in kPa
t3=T2/To2 //Temperature ratio
P2=Po2*t3^(k/(k-1)) //Exit pressure in kPa
Cpr=(P2-P1)/(Po1-P1) //Pressure raise coefficient
ar=(P1*T2*C1)/(P2*T1*C2) //Ratio of exit to inlet area

//Output
printf('(A)Pressure raise coefficient is %3.3f\n (B) Ratio of exit to inlet area is %3.3f',Cpr,ar)
```

Scilab code Exa 2.21 To find area at throat and exit Mach number total pressure loss and entropy change

```
clc
clear

//Input data
Po1=4.9 //Stagnation pressure at entry in bar
P2=1.4 //Exit pressure in bar
To=810 //Stagnation temperature in K
m=1 //Mass flow rate in kg/s
eff=0.9 //Nozzle efficiency
k=1.4 //Adiabatic Constant
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K

//Calculations
t1=0.834 //Ratio of critical temperature to
```

```
    Stagnation temperature from gas tables @M=1
Tt=To*t1 //critical temperature in K
at=sqrt(k*R*Tt) //Sound velocity at critical state in m/s
Ct=at //Air velocity t throat in m/s, Since M=1
p1=0.528 //Ratio of critical pressure to Stagnation pressure from gas tables @M=1
Pt=Po1*p1 //critical pressure in bar
dt=(Pt*10^5)/(R*Tt) //Density of air at throat in kg/m^3, Pt in Pa
At=(m/(dt*Ct))*10^4 //Throat area in cm^2
p2=P2/Po1 //Pressure ratio
T2s=To*p2^((k-1)/k) //Exit temperature in K (at isentropic state)
T2=To-(eff*(To-T2s)) //Exit temperature in K
d2=(P2*10^5)/(R*T2) //Density at exit in kg/m^3, P2 in Pa
C2=sqrt(2*Cp*(To-T2)) //Exit air velocity in m/s
A2=(m/(d2*C2))*10^4 //Exit area in cm^2
a2=sqrt(k*R*T2) //Sound velocity at exit in m/s
M2=C2/a2 //Exit mach number
p3=0.332 //Static to stagnation pressure ratio at exit from isentropic gas tables @M2,k=1.4
Po2=P2/p3 //stagnation pressure in bar
TPL=Po1-Po2 //Loss in total pressure is %3.3f bar
ds=R*log(Po1/Po2) //Increase in entropy in kJ/kg-K

//Output
printf('(A)Throat and exit area are %3.2f cm^2 and %3.3f cm^2\n (B)Exit mach number is %3.2f\n (C) Loss in total pressure is %3.3f bar\n (D)Increase in entropy is %3.2f kJ/kg-K',At,A2,M2,TPL,ds)
```

Scilab code Exa 2.22 To find required throat and exit area of nozzle

```
clc
clear

//Input data
Po=3.5 //Stagnation pressure in bar
To=425+273 //Stagnation temperature in K
P2=0.97 //Exit pressure in bar
m=18 //Mass flow rate in kg/s
Kd=0.99 //Coefficient of discharge
eff=0.94 //Nozzle efficiency
k=1.33 //Adiabatic Constant
Cp=1110 //Specific heat capacity at constant
    pressure in J/kg-K

//Calculations
Pt=Po*(2/(k+1))^(k/(k-1)) //critical pressure in bar
Tt=To*(2/(k+1)) //critical temperature in K
R=Cp/(k/(k-1)) //Specific gas constant in J/kg-K
m_s=m/Kd //Isentropic mass
at=sqrt(k*R*Tt) //Sound velocity at throat in m/s
Ct=at //Air velocity t throat in m/s, Since M=1
dt=(Pt*10^5)/(R*Tt) //Density of air at throat in kg
    /m^3, Pt in Pa
At=(m_s/(dt*Ct))*10^4 //Throat area in cm^2
p2=P2/Po //Pressure ratio
T2s=To*p2^(1/(k/(k-1))) //Exit temperature in K (at
    isentropic state)
T2=To-(eff*(To-T2s)) //Exit temperature in K
d2=(P2*10^5)/(R*T2) //Density at exit in kg/m^3, P2
    in Pa
C2=sqrt(2*Cp*(To-T2)) //Exit air velocity in m/s
A2=(m_s/(d2*C2))*10^4 //Exit area in cm^2

//Output
printf('Throat area and Exit area of nozzle are %3.1
    f cm^2 and %3.1f cm^2',At,A2)
```

Chapter 3

Flow Through Constant Area Duct Adiabatic Flow

Scilab code Exa 3.1 To find length of pipe

```
clc
clear

//input data
M1=0.25 //Mach number at entrance
M2=1 //Mach number at exit
D=0.04 //inner tude diameter in m
f=0.002 //frictional factor

//calculation
X1=8.537 //frictional constant fanno parameter at
    entry from gas tables @M1=0.25
X2=0 //frictional constant fanno parameter at exit
    from gas tables @M2=1
X=X1-X2 //overall frictional constant fanno
    parameter i.e. (4*f*L)/D
L=(X*D)/(4*f) //Length of the pipe in m

//output
```

```
printf('(A)Length of the pipe is %3.3f m',L)
```

Scilab code Exa 3.2 To find length of required duct and length required to obtain critical condition

```
clc
clear

//input data
M1=0.1 //Mach number at entrance
M2=0.5 //Mach number at a section
M3=1 //Mach number at critical condition
D=0.02 //Diameter of duct in m
f=0.004 //Frictional factor

//calculation
X1=66.922 //frictional constant fanno parameter from
    gas tables @M1=0.1
X2=1.069 //frictional constant fanno parameter from
    gas tables @M2=0.5
X3=0 //frictional constant fanno parameter from gas
    tables @M3=1
X4=X1-X3 ////frictional constant fanno parameter
    from M2=0.1 to M3=1
L1=(X4*D)/(4*f) //Length of the pipe in m
X5=X2-X3 //frictional constant fanno parameter from
    M2=0.5 to M3=1
L2=(X5*D)/(4*f) //Addition length of the pipe
    required to accelerate into critical condition in
    m
L=L1-L2 //Length of the pipe required to accelerate
    the flow from M1=0.1 to M2=0.5 in m

//output
printf('(A)Length of the pipe required to accelerate
```

```
the flow from M1=%3.1f to M2=%3.1f is %3.3f m\n(B)Additional length required to accelerate into critical condition is %3.5f m',M1,M2,L,L2)
```

Scilab code Exa 3.3 To find length of pipe and mass flow rate

```
clc
clear

//input data
D=0.05 //inner pipe diameter in m
Po=10 //Stagnation Pressure at reservoir in bar
To=400 //Stagnation temperature at reservoir in K
f=0.002 //frictional factor
M1=3 //Mach number at entrance
M2=1 //Mach number at end of pipe
R=287 //Gas constant in J/kg-K
k=1.4 //Adiabatic constant

//calculation
X1=0.522 //frictional constant fanno parameter from gas tables @M1=3
X2=0 //frictional constant fanno parameter from gas tables @M2=1
X=X1-X2 //overall frictional constant fanno parameter
L=(X*D)/(4*f) //Length of the pipe in m
p1=0.0272 //Pressure ratio from gas tables (M=3,k=1.4,isentropic)
P1=p1*Po //Static pressure at entrance in bar
t1=0.3571 //Temperature ratio from gas tables (M=3,k=1.4,isentropic)
T1=t1*To //Static temperature at entrance in K
d1=(P1*10^5)/(R*T1) //Density of air in kg/m^3, P1 in Pa
```

```
a1=sqrt(k*R*T1) //Sound velocity in m/s
C1=a1*M1 //air velocity in m/s
A1=(%pi*D^2)/4 //Cross sectional area of pipe in m^2
m=d1*A1*C1 //Mass flow rate in kg/s

//output
printf('(A)Length of the pipe is %3.2f m\n (B)Mass flow rate is %3.4f kg/s',L,m)
```

Scilab code Exa 3.4 To find temperature velocity at a section and distance between two sections

```
clc
clear

//input data
C1=235 //Velocity at entrance in m/s
P1=13 //Static Pressure at entry in bar
P2=10 //Static Pressure at a point in duct in bar
T1=543 //Static temperature at entry in Kelvin
D=0.15 //inner duct diameter in m
f=0.005 //frictional factor
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
a1=sqrt(k*R*T1) //Sound velocity in m/s
M1=C1/a1 //Mach number at entry
p1=2.138 //Static Pressure ratio from gas tables (fanno flow tables,k=1.4,M=0.5)
Pt=P1/p1 //Static critical pressure in bar
t1=1.143 //Static temperature ratio from gas tables (fanno flow tables,k=1.4,M=0.5)
Tt=T1/t1 //Static critical temperature in K
c1=0.534 //Velocity ratio from gas tables (fanno
```

```
    flow tables ,k=1.4 ,M=0.5)
Ct=C1/c1 //Critical velocity in m/s
p2=1.644 //Pressure ratio from gas tables (fanno
    flow tables ,k=1.4)
M2=0.64 //Mach number from gas tables (fanno flow
    tables ,k=1.4,p2)
c2=0.674 //Velocity ratio from gas tables (fanno
    flow tables ,k=1.4,p2)
C2=Ct*c2 //Air velocity at P2 in m/s
t2=1.109 //Temperature ratio from gas tables (fanno
    flow tables ,k=1.4,p2)
T2=t2*Tt //Satic temperature at P2 is K
X1=1.06922 //frictional constant fanno parameter
    from gas tables @M1
X2=0.353 //frictional constant fanno parameter from
    gas tables @M2
X=X1-X2 //overall frictional constant fanno
    parameter
L=(X*D)/(4*f) //Length of the pipe in m

//output
printf('(A)Temperature and velocity at section of
    the duct where the pressure has dropped to %3i
    bar due to friction are %3.1f K and %3.2f m/s\n (
    B)The distance between two section is %3.3f m',P2
    ,T2,C2,L)
```

Scilab code Exa 3.5 To find length of pipe and properties of air at exit

```
clc
clear

//input data
P1=120 //Static pressure at entrance in bar
T1=313 //Static temperature at entry in Kelvin
```

```
M1=2.5 //Mach number at entrance
M2=1.8 //Mach number at exit
D=0.2 //inner pipe diameter in m
f=0.01/4 //frictional factor
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
a1=sqrt(k*R*T1) //Sound velocity in m/s
C1=a1*M1 //air velocity in m/s
p1=0.292 //Static Pressure ratio from gas tables (
    fanno flow tables ,k=1.4,M=2.5)
Pt=P1/p1 //Static critical pressure in kPa
t1=0.533 //Static temperature ratio from gas tables
    (fanno flow tables ,k=1.4,M=2.5)
Tt=T1/t1 //Static critical temperature in K
c1=1.826 //Velocity ratio from gas tables (fanno
    flow tables ,k=1.4,M=2.5)
Ct=C1/c1 //Critical velocity in m/s
X1=0.432 //frictional constant fanno parameter from
    gas tables ,fanno flow tables @M1=3
X2=0 //frictional constant fanno parameter from gas
    tables @M2=1
X3=X1-X2 //overall frictional constant fanno
    parameter
L1=(X3*D)/(4*f) //Maximum length of the pipe in m
p2=0.474 //Static Pressure ratio from gas tables (
    fanno flow tables ,k=1.4,M=1.8)
P2=Pt*p2 //Static pressure in kPa
t2=0.728 //static temperature ratio from gas tables
    (fanno flow tables ,k=1.4,M=1.8)
T2=Tt*t2 //Static temperature in K
c2=1.536 //Velocity ratio from gas tables (fanno
    flow tables ,k=1.4,M=1.8)
C2=c2*Ct //Critical velocity in m/s
X4=0.242 //frictional constant fanno parameter from
    gas tables ,fanno flow tables @M=1.8
X5=X4-X2 //overall frictional constant fanno
```

```
    parameter
L2=(X5*D)/(4*f) //Length between sonic and oulet section
L=L1-L2 //Length of the pipe in m

//output
printf('(A)Maximum length of the pipe is %3.2f m\n (B)Properties of air at sonic condition:\n    Pressure is %3i kPa\n    Temperature is %3.2f K\n    Velocity is %3.1f m/s\n (C)Length of the pipe is %3.1f m\n (D)Properties of air at M2=%3.1f:\n    Pressure is %3i kPa\n    Temperature is %3.2f K\n    Velocity is %3.2f m/s\n',L1,Pt,Tt,Ct,L,M2,P2,T2,C2)
```

Scilab code Exa 3.6 To find mach number properties at a section and critical section and length of the duct

```
clc
clear

//input data
M1=0.25 //Mach number at entrance
ds=0.124 //Change in entropy in kJ/kg-K
P1=700 //Static pressure at entrance in bar
T1=333 //Static temperature at entry in Kelvin
D=0.05 //inner pipe diameter in m
f=0.006 //frictional factor
k=1.4 //Adiabatic constant
R=0.287 //Gas constant in kJ/kg-K

//calculation
p1=exp(ds/R) //Ratio of Stagnation pressure at inlet to outlet
t1=0.987 //Ratio of Static Temperature to Stagnation
```

```
temperature at entry from gas tables @M1
To1=T1/t1 //Stagnation temperature at entry in K
p2=0.957 //Ratio of Static pressure to Stagnation pressure at entry from gas tables @M1
Po1=P1/p2 //Stagnation pressure at entry in kPa
Po2=Po1/p1 //Stagnation pressure at exit in kPa
a1=sqrt(k*R*10^3*T1) //Sound velocity in m/s, R in J/kg
C1=a1*M1 //air velocity in m/s
p3=4.3615 //Static Pressure ratio from gas tables (fanno flow tables,k=1.4,M=0.25)
Pt=P1/p3 //Static critical pressure in kPa
t1=1.185 //Static temperature ratio from gas tables (fanno flow tables,k=1.4,M=0.25)
Tt=T1/t1 //Static critical temperature in K
c1=0.272 //Velocity ratio from gas tables (fanno flow tables,k=1.4,M=0.25)
Ct=C1/c1 //Critical velocity in m/s
p4=2.4065 //Pressure ratio at entry from gas tables @M1,k
Pot=Po1/p4 //Stagnation pressure at critical state in kPa
X1=8.537 //frictional constant fanno parameter from gas tables,fanno flow tables @M1,k
p5=Po2/Pot //Pressure ratio
M2=0.41 //Mach number at exit from gas tables @p5
p6=2.629 //Pressure ratio at exit from gas tables @p5
P2=Pt*p6 //Exit pressure in kPa
t2=1.161 //Temperature ratio at exit from gas tables @p5
T2=Tt*t2 //Exit temperature in K
c2=0.4415 //Velocity ratio at exit from gas tables @p5
C2=Ct*c2 //Exit velocity in m/s
X2=2.141 //frictional constant fanno parameter from gas tables,fanno flow tables @M2,k
X3=X1-X2 //overall frictional constant fanno
```

```
    parameter
L=(X3*D)/(4*f) //Length of the pipe in m

//output
printf('(A)Mach number at exit(section 2) is %3.2f \
    n (B)Properties at exit(section 2):\n      Pressure
     is %3.2f kPa\n      Temperature is %3i K\n
    Velocity is %3.3f m/s\n (C)Length of the duct is
    %3.3f m',M2,P2,T2,C2,L)
```

Scilab code Exa 3.7 TO find final pressure and velocity of duct

```
clc
clear

//input data
M1=0.25 //Initial Mach number
M2=0.75 //Final mach number
P1=1.5 //Inlet pressure in bar
T1=300 //Inlet temperature in K
k=1.4 //Adiabatic constant
R=0.287 //Gas constant in kJ/kg-K

//calculation
a1=sqrt(k*R*10^3*T1) //Sound velocity in m/s, R in J
    /kg
C1=a1*M1 //air velocity in m/s
p1=4.3615 //Pressure ratio at entry from gas tables
    @M1,k
Pt=P1/p1 //Static critical pressure in kPa
c1=0.272 //Velocity ratio from gas tables (fanno
    flow tables,k=1.4,M1)
Ct=C1/c1 //Critical velocity in m/s
p2=1.385 //Pressure ratio at exit from gas tables
    @M2,k
```

```
P2=Pt*p2 //Exit pressure in bar
c2=0.779 //Velocity ratio at exit from gas tables
    @M2, k
C2=Ct*c2 //Exit velocity in m/s

//output
printf('Final pressure and velocity are %3.4f bar
    and %3.2f m/s',P2,C2)
```

Scilab code Exa 3.8 To find inlet mach number mass flow rate and exit temperature

```
clc
clear

//input data
T1=333 //Inlet temperature in K
D=0.05 //inner duct diameter in m
f=0.005/4 //frictional factor
L=5 //Length of the pipe in m
Pt=101 //Exit pressure in kPa, Pt=P2 Since flow is
    choked
M2=1 //Mach number at exit since pipe is choked
k=1.4 //Adiabatic constant
R=0.287 //Gas constant in kJ/kg-K

//calculation
X=(4*f*L)/D //frictional constant fanno parameter
M1=0.6 //Inlet mach number
t1=1.119 //Temperature ratio at entry from fanno
    flow gas tables @M1,k
Tt=T1/t1 //Static critical temperature in K
at=sqrt(k*R*10^3*Tt) //Sound velocity in m/s, R in J
    /kg
Ct=at //air velocity in m/s
```

```
d_t=Pt/(R*Tt) //Density at exit in kg/m^3
At=%pi*D^2/4 //Critical area in m^2
m=d_t*At*Ct //Mass flow rate in kg/s

//output
printf('(A)Mach number at inlet is %3.1f \n (B)Mass
    flow rate is %3.5f kg/s\n (C)Exit temperature is
    %3.3f K',M1,m,Tt)
```

Scilab code Exa 3.9 To find length diameter of the duct pressure at exit Stagnation pressure lose and to verify exit mach number

```
clc
clear

//input data
m=8.25 //Mass flow rate in kg/s
M1=0.15 //Mach number at entrance
M2=0.5 //Mach number at exit
P1=345 //Static pressure at entrance in kPa
T1=38+273 //Static temperature at entry in Kelvin
f=0.005 //frictional factor
k=1.4 //Adiabatic constant
R=0.287 //Gas constant in kJ/kg-K

//calcu;ation
d1=(P1*10^3)/(R*10^3*T1) //Density of air in kg/m^3,
    P1 in Pa
a1=sqrt(k*R*10^3*T1) //Sound velocity in m/s, R in J
   /kg
C1=a1*M1 //air velocity in m/s
A1=m/(d1*C1) //Inlet area in m^2
D=(sqrt((4*A1)/(%pi)))*10^3 //inner duct diameter in
   mm
p1=7.3195 //Static Pressure ratio from gas tables (
```

```
fanno flow tables,k=1.4,M=0.15)
Pt=P1/p1 //Static critical pressure in kPa
t1=1.1945 //Static temperature ratio from gas tables (fanno flow tables,k=1.4,M=0.15)
Tt=T1/t1 //Static critical temperature in K
c1=0.164 //Velocity ratio from gas tables (fanno flow tables,k=1.4,M=0.15)
Ct=C1/c1 //Critical velocity in m/s
p2=0.984 //Pressure ratio at entry from gas tables (fanno flow tables,k=1.4,M=0.15)
Po1=P1/p2 //Stagnation pressure at entry in kPa
p3=3.928 //Stagnation pressure ratio at entry from gas tables (fanno flow tables,k=1.4,M=0.15)
Pot=Po1/p3 //Stagnation pressure at critical state in kPa
X1=28.354 //frictional constant fanno parameter from gas tables,fanno flow tables @M1,k
p5=2.138 //Pressure ratio at exit from gas tables (fanno flow tables,k=1.4,M2)
P2=Pt*p5 //Exit pressure in kPa
t2=1.143 //Temperature ratio at exit from gas tables (fanno flow tables,k=1.4,M2)
T2=Tt*t2 //Exit temperature in K
c2=0.534 //Velocity ratio at exit from gas tables (fanno flow tables,k=1.4,M2)
C2=Ct*c2 //Exit velocity in m/s
p6=1.34 //Stagnation pressure ratio at exit from gas tables (fanno flow tables,k=1.4,M2)
Po2=Pot*p6 //Stagnation pressure at exit in kPa
SPL=Po1-Po2 //Stagnation Pressure lose in kPa
X2=1.069 //frictional constant fanno parameter from gas tables,fanno flow tables @M2,k
X3=X1-X2 //overall frictional constant fanno parameter
L=(X3*D*10^-3)/(4*f) //Length of the duct in m

//verification
a2=sqrt(k*R*10^3*T2) //Sound velocity in m/s, R in J
```

```
/kg
M2_v=C2/a2 //air velocity in m/s

//output
printf('(A)Length of the duct is %3.2f m\n (B) Diameter of the duct is %3i mm\n (C)Pressure and diameter at exit are %3.2f kPa, and %3i mm respectively\n (D)Stagnation Pressure lose is %3i kPa\n (E)Using exit velocity %3.2f m/s, temperature %3.2f K Mach number is found to be %3.2f',L,D,P2,D,SPL,C2,T2,M2_v)
```

Scilab code Exa 3.10 To find length of the pipe Mach number percent of stagnation pressure loss and length required to reach choking condition

```
clc
clear

//input data
M1=0.25 //Mach number at entrance
f=0.01/4 //frictional factor
D=0.15 //inner pipe diameter in m
p1=0.8 //Stagnation pressure ratio at exit to entry when loss in stagnation pressure is 20%
M3=0.8 //Mach number at a section

//calculation
p2=2.4065 //Ratio of Stagnation pressure at entry from gas tables @M1,k=1.4
X1=8.537 //frictional constant fanno parameter from gas tables,fanno flow tables @M1
p3=p1*p2 //Ratio of Stagnation pressure at exit
M2=0.32 //Exit mach number at p1=0.8
X2=4.447 //frictional constant fanno parameter from gas tables,fanno flow tables @M2
```

```
L1=(X1*D)/(4*f) //Length of the pipe in m
L2=(X2*D)/(4*f) //Length of the pipe in m
L=L1-L2 //Overall length of the duct in m
p4=1.038 //Stagnation pressure ratio from M=1 to M3
PL=(1-(p4/p2))*100 //Percentage of stagnation
    pressure from inlet to section at which M3 in
    percent

//output
printf('(A)Length of the pipe is %3.2f m\n (B)Mach
    number at this exit is %3.2f\n (C)Percentage of
    stagnation pressure from inlet to section at
    which M=%3.1f is %3.2f percent\n (D)Maximum
    length to reach choking condition is %3.3f m',L,
    M2,M3,PL,L1)
```

Scilab code Exa 3.11 To find length of the pipe and mass flow rate

```
clc
clear

//input data
D=0.3 //inner duct diameter in m
P1=10 //Static pressure at entrance in bar
T1=400 //Static temperature at entry in Kelvin
M1=3 //Mach number at entrance
M2=1 //Mach number at exit
k=1.3 //Adiabatic constant
R=287 //Specific Gas constant in J/kg-K, wrong
    printing in question
f=0.002 //frictional factor

//calculation
p1=0.233 //Pressure ratio from gas tables (M=3,k
    =1.4,isentropic)
```

```
Pt=P1/p1 //Static pressure at entrance in bar
t1=0.489 //Temperature ratio from gas tables (M=3,k
    =1.4,isentropic)
Tt=T1/t1 //Static temperature at entrance in K
X1=0.628 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.3
L1=(X1*D)/(4*f) //Length of the pipe in m
d_t=(Pt*10^5)/(R*Tt) //Density at critical state in
    kg/m^3, Pt in Pa
at=sqrt(k*R*Tt) //Sound velocity in m/s, R in J/kg
Ct=at //air velocity in m/s
At=(%pi*D^2)/4 //Critical area in m^2
m=d_t*At*Ct //Mass flow rate in kg/s

//output
printf('(A)Length of the pipe is %3.2f m\n (B)Mass
    flow rate is %3.3f kg/s',L1,m)
```

Scilab code Exa 3.12 To find length and Mach number of given pipe and at required section

```
clc
clear

//input data
M1=0.25 //Mach number at entrance
f=0.04/4 //frictional factor
D=0.15 //inner duct diameter in m
p1=0.9 //Stagnation pressure ratio at exit to entry
    when loss in stagnation pressure is 10%
ds=190 ///Change in entropy in J/kg-K
k=1.3 //Adiabatic constant
R=287 //Specific Gas constant in J/kg-K, wrong
    printing in question

```

```
//calculation
p2=2.4064 //Ratio of stagnation pressures at inlet
    to critical state from gas tables fanno flow
    tables @M1,k=1.3
X1=8.537 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.3
p3=p1*p2 //Ratio of stagnation pressures at exit to
    critical state from gas tables fanno flow tables
    @M1,k=1.3
M2=0.28 //Mach number at p1=0.9 from gas tables @p3
X2=6.357 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M2,k=1.3
X3=X1-X2 //overall frictional constant fanno
    parameter
L1=(X3*D)/(4*f) //Length of the pipe in m
p4=exp(ds/R) //Ratio of Stagnation pressure at entry
     to Stagnation pressure where ds=190
p5=p1/p4 //Ratio of Stagnation pressures where ds
    =190 to critical state
M3=0.56 //Mach number where ds=190
X4=0.674 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M3,k=1.3
X5=X1-X4 //overall frictional constant fanno
    parameter
L2=(X5*D)/(4*f) //Length of the pipe in m

//output
printf('(A)Length of the pipe is %3.3f m\n (B)Length
     of the pipe would require to rise entropy by %3i
     J/kg-K is %3.5f m\n (C)Mach number is %3.2f',L1,
    ds,L2,M3)
```

Scilab code Exa 3.13 To find length of the pipe percent of stagnation pressure change and entropy change

```
clc
clear

//input data
Po1=200 //Stagantion pressure at inlet in kPa
To1=303 //Stagnation temperature at inlet in K
M1=0.2 //Inlet Mach number from diagram
D=0.025 //inner tude diameter in m(missing data)
M2=0.8 //Outlet Mach number
f=0.005/4 //frictional factor
R=287 //Gas constant in J/kg-K

//calculation
t1=0.992 //Static to Stagnation temperature ratio at
    entry from gas tables (M1,k=1.4,isentropic)
T1=To1*t1 //Static temperature in K
p1=0.973 //Static to Stagnation pressure ratio at
    entry from gas tables (M1,k=1.4,isentropic)
P1=Po1*p1 //Static pressure in kPa
p2=2.964 //Stagnation pressure ratio at inlet to
    critical state from gas tables (M1,k=1.4,fanno
    flow)
Pot=Po1/p2 //Stagnation pressure at critical state
    in kPa
X1=14.533 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.4
p3=1.038 //Stagnation pressure ratio at outlet to
    critical state from gas tables (M1,k=1.4,fanno
    flow)
Po2=Pot*p3 //Stagnation pressure at exit in kPa
X2=0.073 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M2,k=1.4
X3=X1-X2 //overall frictional constant fanno
    parameter
L1=(X3*D)/(4*f) //Length of the pipe in m
SPL=(1-(p3/p2))*100 //Percentage decrease in
    stagnation pressure in percent
ds=R*log(Po1/Po2) //Change of entropy in kJ/kg-K
```

```
//output
printf('(A)Length of the pipe is %3.1f m\n (B)
    Percentage decrease in stagnation pressure is %3
    .2f percent\n (C)Change of entropy is %3.3f kJ/kg
    -K',L1,SPL,ds)
```

Scilab code Exa 3.14 To find maximum length of pipe and conditions of air at exit

```
clc
clear

//input data
D1=0.03 //Inlet duct diameter in m
D2=0.015 //Throat diameter of  duct in m
Po1=750 //Stagantion pressure at inlet in kPa
To1=450 //Stagnation temperature at inlet in K
f=0.02/4 //frictional factor
L=0.25 //Length of the duct in m
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
ar=(D1/D2)^2 //Ratio of areas
M1=2.94 //Mach number at inlet from gas tables (ar,k
    =1.4,isentropic)
p1=0.0298 //Static to Stagnation pressure ratio at
    entry from gas tables (M1,k=1.4,isentropic)
P1=Po1*p1 //Static pressure at inlet in kPa
t1=0.367 //Static to Stagnation temperature ratio at
     entry from gas tables (M1,k=1.4,isentropic)
T1=To1*t1 //Static temperature at inlet in K
a1=sqrt(k*R*T1) //Sound velocity in m/s
C1=a1*M1 //Air velocity at inlet in m/s
```

```
X1=0.513 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.4
p2=0.226 //Static to Critical pressure ratio at
    inlet from gas tables,fanno flow tables @M1,k=1.4
Pt=P1/p2 //Critical pressure in kPa
c1=1.949 //Static to Critical velocity ratio at
    inlet from gas tables,fanno flow tables @M1,k=1.4
Ct=C1/c1 //Critical velocity in m/s
t2=0.439 //Static to Critical temperature ratio at
    inlet from gas tables,fanno flow tables @M1,k=1.4
Tt=T1/t2 //Critical temperature in K
L1=(X1*D1)/(4*f) //Length of the pipe from inlet to
    critical state in m
L2=L1-L //Length of the pipe from required point to
    critical state in m
X2=(4*f*L2)/D2 //frictional constant fanno parameter
M2=2.14 //Mach number at inlet from gas tables (X2,k
    =1.4,fanno flow)
p3=0.369 //Static to Critical pressure ratio at
    outlet from gas tables,fanno flow tables @M2,k
    =1.4
P2=Pt*p3 //Exit pressure in kPa
c2=1.694 //Static to Critical velocity ratio at
    outlet from gas tables,fanno flow tables @M2,k
    =1.4
C2=Ct*c2 //Exit velocity in m/s
t3=0.623 //Static to Critical temperature ratio at
    outlet from gas tables,fanno flow tables @M2,k
    =1.4
T2=t3*Tt //Exit temperature in K

//output
printf('(A)Maximum length of the pipe is %3.4f m\n (
   B)Condition of air at exit:\n    Pressure is %3.2
   f kPa\n    Velocity is %3.2f m/s\n    Temperature
    is %3.2f K\n',L1,P2,C2,T2)
```

Scilab code Exa 3.15 To find Maximum and required length of the pipe and properties of air at a section

```
clc
clear

//input data
f=0.002 //frictional factor
C1=130 //Air velocity at inlet in m/s
T1=400 //Inlet temperature at inlet in K
P1=250 //Inlet pressure at inlet in kPa
D=0.16 //Inlet duct diameter in m
p1=0.8 //Stagnation pressure ratio at exit to entry
    when loss in stagnation pressure is 20%
L1=35 //Length of duct from inlet to required
    section
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
a1=sqrt(k*R*T1) //Sound velocity in m/s
M1=C1/a1 //Mach number at inlet
p2=0.9295 //Static to Stagnation pressure ratio at
    entry from gas tables (M1,k=1.4,isentropic)
Po1=P1/p2 //Stagantion pressure at inlet in kPa
Po2=0.8*Po1 //Stagantion pressure at outlet in kPa
p3=1.89725 //Stagnation pressure ratio at inlet to
    critical state from gas tables (M1,k=1.4,fanno
    flow)
Pot=Po1/p3 //Stagnation pressure at critical state
    in kPa
X1=4.273 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.4
p4=3.33725 //Static Pressure ratio from gas tables (
```

```
    fanno flow tables ,k=1.4 ,M=0.5)
Pt=P1/p4 //Static critical pressure in kPa
t1=1.175 //Static temperature ratio from gas tables
    (fanno flow tables ,k=1.4 ,M=0.5)
Tt=T1/t1 //Static critical temperature in K
c1=0.347 //Velocity ratio from gas tables (fanno
    flow tables ,k=1.4 ,M=0.5)
Ct=C1/c1 //Critical velocity in m/s
p5=Po2/Pot //Pressure ratio
M2=0.43 //Mach number at p1=0.8
X2=1.833 //frictional constant fanno parameter from
    gas tables ,fanno flow tables @M2,k=1.4
X3=X1-X2 //overall frictional constant fanno
    parameter
L2=(X3*D)/(4*f) //Length of the pipe in m, (from
    required section to critical state)
L3=(X1*D)/(4*f) //Length of the pipe in m, (from
    required inlet to critical state)
L4=L3-L1 //Length of the pipe in m
X4=(4*f*L3)/D //frictional constant fanno parameter
M3=0.39 //Mach number at L1=35m
p6=2.767 //Static to Critical pressure ratio at
    outlet from gas tables ,fanno flow tables @M3,k
    =1.4
P2=Pt*p6 //Exit pressure in kPa
t2=1.1645 //Static to Critical temperature ratio at
    outlet from gas tables ,fanno flow tables @M3,k
    =1.4
T2=Tt*t2 //Exit temperature in K
c2=0.42087 //Static to Critical velocity ratio at
    outlet from gas tables ,fanno flow tables @M3,k
    =1.4
C2=Ct*c2 //Exit velocity in m/s

//output
printf('(A)Length of pipe required for p=%3.1f m is
   %3.3f m\n (B)Properties of air at section %3i
   from inlet:\n      Temperature is %3.3f K\n
```

```
    Pressure is %3.2f kPa\n     Velocity is %3.1f m/s\
    n (C)Maximum length of the pipe is %3.2f m',p1,L2
    ,L1,T2,P2,C2,L3)
```

Scilab code Exa 3.16 To find exit mach number and inlet temperature and pressure

```
clc
clear

//input data
D=0.3 //inner pipe diameter in m
Q=1000 //Discharge in m^3/min
P2=150 //Exit pressure in kPa
T2=293 //Exit temperature in K
L1=50 //Length of the pipe in m
f=0.005 //frictional factor
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
A=%pi*D^2/4 //Area of duct in m^2
C2=Q/(A*60) //Exit air velocity in m/s
a2=sqrt(k*R*T2) //Sound velocity in m/s
M2=C2/a2 //Exit mach number
p1=1.54 ////Static to Critical pressure ratio at
    outlet from gas tables,fanno flow tables @M2,k
    =1.4
Pt=P2/p1 //Critical pressure in kPa
t1=1.10 //Static to Critical temperature ratio at
    outlet from gas tables,fanno flow tables @M2,k
    =1.4
Tt=T2/t1 //Critical temperature in K
X1=0.228 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M2,k=1.4
```

```
L2=(X1*D)/(4*f) //Length of the pipe in m
L2=L1+L2 //Overall length of pipe from inlet to
    critical state in m
X2=(4*f*L2)/D //frictional constant fanno parameter
    for M1
M1=0.345 //Inlet Mach number from gas tables fanno
    flow tables @X2,k=1.4
p2=3.14 //Static to Critical pressure ratio at inlet
     from gas tables,fanno flow tables @M1,k=1.4
P1=Pt*p2 //Static pressure at inlet in kPa
t2=1.17 //Static to Critical temperature ratio at
    inlet from gas tables,fanno flow tables @M1,k=1.4
T1=Tt*t2 //Static temperature at inlet in K

//output
printf('(A)Mach number at the exit is %3.3f\n (B)
    Inlet pressure and temperature are %3.3f kPa and
    %3.2f K',M2,P1,T1)
```

Scilab code Exa 3.17 To find Static and Stagnation conditions velocity length and mass flow rate of air in pipe

```
clc
clear

//input data
D=0.0254 //inner pipe diameter in m
f=0.003 //frictional factor
M1=2.5 //Inlet Mach number
To1=310 //Stagnation temperature at inlet in K
P1=0.507 //Static pressure at inlet in kPa
M2=1.2 //Exit mach number
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

```

```
//calculation
t1=0.4444 //Static to Stagnation temperature ratio
   at entry from gas tables (M1,k=1.4,isentropic)
T1=To1*t1 //Static temperature at inlet in K
p1=0.05853 //Static to Stagnation pressure ratio at
   entry from gas tables (M1,k=1.4,isentropic)
Po1=P1/p1 //Stagantion pressure at inlet in kPa
a1=sqrt(k*R*T1) //Sound velocity at inlet in m/s, R
   in J/kg
C1=a1*M1 //air velocity at inlet in m/s
c1=2.95804 //Static to Critical velocity ratio at
   inlet from gas tables,isothermal tables @M1,k=1.4
Ctt=C1/c1 //Critical velocity at isothermal state in
    m/s
p2=0.33806 //Static to Critical pressure ratio at
   inlet from gas tables,isothermal @M1,k=1.4
Ptt=P1/p2 //Critical pressure at isothermal state in
    bar
p3=3.61691 //Stagnation pressure ratio at inlet to
   isothermal state from gas tables,isothermal
   tables @M1,k=1.4
Pott=Po1/p3 //Critical pressure at isothermal state
   in K
t2=1.968748 //Stagnation temperature ratio at inlet
   to isothermal state from gas tables,isothermal
   tables @M1,k=1.4
Tott=To1/t2 //Critical temperature at isothermal
   state in K
X1=1.28334 //frictional constant fanno parameter
   from gas tables,fanno flow tables @M1,k=1.4
c2=1.4186 //Static to Critical velocity ratio at
   exit from gas tables,isothermal tables @M2,k=1.4
C2=Ctt*c2 //Exit velocity in m/s
p4=0.7043 //Static to Critical pressure ratio at
   inlet from gas tables,isothermal @M2,k=1.4
P2=Ptt*p4 //Exit pressure in bar
p5=1.07026 //Stagnation pressure ratio at inlet to
   isothermal state from gas tables,isothermal
```

```
tables @M2,k=1.4
Po2=Pott*p5 //Stagnation pressure at exit in bar
t3=1.127 //Stagnation temperature ratio at inlet to isothermal state from gas tables,isothermal tables @M2,k=1.4
To2=Tott*t3 //Stagnation temperature at exit in bar
T2=T1 //Exit temperature in K, Since isothermal flow
X2=0.19715 //frictional constant fanno parameter from gas tables,fanno flow tables @M2,k=1.4
X3=X1-X2 //Overall frictional constant fanno parameter
L1=(X3*D)/(4*f) //Length of the pipe in m
d1=(P1*10^5)/(R*T1) //Density of air in kg/m^3, P1 in Pa
A1=(%pi*D^2)/4 //Cross sectional area of pipe in m^2
m=d1*A1*C1 //Mass flow rate in kg/s

//output
printf('At M=%3.1f :\n (A)Static pressure and static temperature are %3.5f bar and %3.3f K respectively\n (B)Stagnation pressure and temperature are %3.4f bar and %3.3f K respectively\n (C)Velocity of air is %3.3f m/s\n (D)Distance of the section from innlet is %3.3f m\n (E)Mass flow rate is %3.5f kg/s',M2,P2,T2,Po2,To2,C2,L1,m)
```

Scilab code Exa 3.18 To find length of pipe and properties of air at a section and limiting mach number

```
clc
clear

//input data
D=0.12 //inner duct diameter in m
```

```
f=0.004 //frictional factor
M1=0.4 //Inlet Mach number
P1=300 //Static pressure at inlet in kPa
T1=310 //Static temperature at inlet in K
M2=0.6 //Exit mach number
k=1.4 //Adiabatic constant

//calculation
p1=2.118 //Static to Critical pressure ratio at
    inlet from gas tables,fanno flow tables @M1,k=1.4
Pt=P1/p1 //Critical pressure in kPa
X1=1.968 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.4
p2=1.408 //Static to Critical pressure ratio at
    outlet from gas tables,fanno flow tables @M2,k
    =1.4
P2=Pt*p2 //Exit pressure in kPa
X2=0.299 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M2,k=1.4
X3=X1-X2 //Overall frictional constant fanno
    parameter
L1=(X3*D)/(4*f) //Length of the pipe in m
T2=T1 //Exit temperature in K, Since isothermal flow
Ttt=T1 //Critical temperature at critical state,
    Since isothermal flow
Mtt=1/sqrt(k) //Limiting Mach number
L2=(X1*D)/(4*f) //Length of the duct required to
    attain limiting mach number in m

//output
printf('(A)Length of the duct required to chnage the
     mach number to %3.1f is %3.4f m\n (B)Pressure
    and temperature at M=%3.1f is %3i kPa and %3i K
    respectively\n (C)Length of the duct required to
    attain limiting mach number is %3.3f m\n (D)State
     of air at limiting mach number %3.3f is subsonic
    ',M2,L1,M2,P2,T2,L2,Mtt)
```

Scilab code Exa 3.19 To find diameter of pipe

```
clc
clear

//input data
m=0.32 //Mass flow rate in kg/s
L=140 //Length of the pipe in m
P1=800 //Inlet pressure in N/m^2, wrong units in textbook
T1=288 //Inlet temperature in K
P2=600 //Outlet pressure in N/m^2, wrong units in textbook
f=0.006 //frictional factor
R=287 //Gas constant in J/kg-K

//calculation
//Using Adiabatic Equation d=1/((((((%pi*(d/2)^2)^2)/(2*m^2*R*T))*(P1^2-P2^2))-(log(P1/P2)))/(2*f*L)) and converting into 5th degree polynomial of d
a=(%pi^2*(P1^2-P2^2))/(32*m^2*R*T1) //Coefficient of power 5
b=log(P1/P2) //Coefficient of power 1
c=2*f*L //Coefficient of constant
p5=poly([-c -b 0 0 0 a],'d','coeff') //Solving polynomial of degree 5
d=roots(p5,"e") //Command to find roots

//output
disp("Possible values for diameter of pipe are:\n") //Displays whatever within paranthesis
disp([d]) //To display roots
printf('\nTherefore Diameter of the pipe is 0.7 m')
```

Scilab code Exa 3.20 To determine required inlet conditions

```
clc
clear

//input data
Q=225/60 //Discharge in m^3/s
T2=293 //Exit temperature in K
P2=1.25 //Exit pressure in bar
L1=30 //Length of the pipe in m
D=0.15 //Duct diameter in m
f=0.02/4 //frictional factor
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
A=%pi*D^2/4 //area in m^2
C2=Q/A //Exit air velocity in m/s
a2=sqrt(k*R*T2) //Exit sound velocity in m/s
M2=C2/a2 //Exit mach number
p1=1.703 //Static to Critical pressure ratio at
    outlet from gas tables,fanno flow tables @M2,k
    =1.4
Pt=P2/p1 //Critical pressure in bar
c1=0.654 //Static to Critical velocity ratio at
    outlet from gas tables,fanno flow tables @M2,k
    =1.4
Ct=C2/c1 //Critical velocity in m/s
t1=1.114 //Static to Critical temperature ratio at
    outlet from gas tables,fanno flow tables @M2,k
    =1.4
Tt=T2/t1 //Critical temperature in K
X1=0.417 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.4
```

```
X2=(4*f*L1)/D //frictional constant fanno parameter
X3=X1+X2 //overall frictional constant fanno parameter
M1=0.32 //Mach number at entrance
p2=3.385 //Static to Critical pressure ratio at inlet from gas tables,fanno flow tables @M1,k=1.4
P1=Pt*p2 //Static pressure at inlet in bar
c2=0.347 //Static to Critical velocity ratio at inlet from gas tables,fanno flow tables @M1,k=1.4
C1=Ct*c2 //Air velocity at inlet in m/s
t2=1.176 //Static to Critical temperature ratio at inlet from gas tables,fanno flow tables @M1,k=1.4
T1=Tt*t2 //Static temperature at inlet in K

//output
printf('Required Inlet Condition:\n    Pressure is %3.4f bar\n    Velocity is %3.3f m/s\n    Temperature is %3.1f K',P1,C1,T1)
```

Scilab code Exa 3.21 To find mach number at sections and mean value of friction

```
clc
clear

//input data
D1=0.134 //Inlet duct diameter in m
Po1=7 //Stagnation pressure at inlet in bar
P1=0.245 //Static pressure at 5*D1 i.e. L1 in bar
P2=0.5 //Static pressure at 33*D1 i.e. L2 in bar
D2=0.0646 //throat diameter in m
L1=5*D1 //Length of nozzle till section-1 in m
L2=33*D1 //Length of nozzle till section-2 in m

//calculation
```

```
ar=(D1/D2)^2 //Ratio of areas
p1=P1/Po1 //Pressure ratio
APR1=p1*ar //Area Pressure ratio i.e. (A1*P1)/(At*
    Po1)
M1=2.54 //Mach number at inlet from isentropic gas
    tables @APR1
X1=0.44 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.4
APR2=0.3073 //Area Pressure ratio i.e. (A2*P2)/(At*
    Po1)
M2=1.54 //Exit mach number
X2=0.151 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M2,k=1.4
X3=X1-X2 //overall frictional constant fanno
    parameter
L3=L2-L1 //Length of the nozzle (Section-1 to
    Section-2) in m
f=(X3*D1)/(4*L3) //frictional factor

//output
printf('(A)Mach number at %3.3f m and %3.3f m are %3
    .2f and %3.2f respectively\n (B)Mean value of
    friction between two sections is %3.5f',L1,L2,M1,
    M2,f)
```

Chapter 4

Flow Through Constant Area Ducts Rayleigh Flow

Scilab code Exa 4.1 To find heat transferred per unit mass flow and temperature change

```
clc
clear

//input data
Pa=1*10^5 //Pressure of dry air in Pa
To1=288 //Total stagnation temperature at inlet in K
M1=1 //Mach number at inlet of pipe
M2=0.8 //Mach number at exit o pipe
Cp=1.005 //Specific heat of dry air in kJ/kg-K

//calculation
t1=0.834 //Temperature ratio at entry, i.e.entry
    static temperature to total temperature from gas
    tables at isentropic ,M1=1 & adiabatic constant
    =1.4
T1=t1*To1 //Static temperature at entry in Kelvin
t2=0.964 //Temperature ratio at critical state, i.e.
     exit stagnation temperature to critical state
```

```
temperature from gas tables at Rayleigh, M2=0.8 & adiabatic constant=1.4
To2=t2*To1 //Total stagnation temperature at exit in K
t3=1.025 //Temperature ratio at exit, i.e. exit static temperature to total temperature from gas tables at isentropic,M1=1 & adiabatic constant=1.4
T2=t3*T1 //Static temperature at exit in Kelvin
q=Cp*(To1-To2) //The heat transferred per unit mass flow in kJ/kg
dT=To1-T2 //Change in temperature in K

//output
printf('(A)The heat transferred per unit mass flow is %3.3f kJ/kg (rejected)\n (B)Change in temperature is %3.3f K',q,dT)
```

Scilab code Exa 4.2 To calculate flow properties at the exit

```
clc
clear

//input data
M1=3 //Mach number at entry
P1=1 //Static Pressure at entry in atm
T1=300 //Static Temperature at entry in K
q=300 //The heat transferred per unit mass flow in kJ/kg
R=287 //Gas constant in J/kg-K
Cp=1.005 //Specific heat of dry air in kJ/kg-K

//calculation
t1=2.8 //Temperature ratio at entry from gas tables (M=3,k=1.4,isentropic)
```

```
To1=t1*T1 //Total stagnation temperature at inlet in K
p1=0.0272 //Pressure ratio  at entry from gas tables (M=3,k=1.4,isentropic)
Po1=P1/p1 //Stagnation Pressure at entry in atm
p2=0.176 //Static Pressure ratio  at critical state from gas tables (Rayleigh,k=1.4,M=3)
Pt=P1/p2 //Static critical pressure in atm
p3=3.424 //Stagnation Pressure ratio at critical state from gas tables (Rayleigh,k=1.4,M=3)
Pot=Po1/p3 //Stagnation critical pressure in atm
t2=0.281 //Static temperature ratio at critical state from gas tables (Rayleigh,k=1.4,M=3)
Tt=T1/t2 //Static critical temperature in K
t3=0.654 //Stagnation temperature ratio at critical state from gas tables (Rayleigh,k=1.4,M=3)
Tot=To1/t3 //Stagnation critical temperature in K
To2=(q/Cp)+To1 //Stagnation exit temperation in K
t4=(To2/Tot) //Stagnation Temperature ratio at exit
M2=1.6 //Mack number at exit from gas tables (Rayleigh,t4)
p4=0.524 //Static Pressure ratio  at exit from gas tables (Rayleigh,t4=0.866,M=1.6)
P2=p4*Pt //Static Pressure at exit in atm
p5=1.176 //Stagnation Pressure ratio at exit from gas tables (Rayleigh,t4=0.866,M=1.6)
Po2=p5*Pot //Stagnation Pressure at exit in atm
t5=0.702 //Static temperature ratio at exit from gas tables (Rayleigh,t4=0.866,M=1.6)
T2=t5*Tt //Static exit temperature in K
d2=P2*101325/(R*T2) //density of air at exit in kg/m^3, P2 in N/m^2

//outpur
printf('(A)The Mach numer at exit is %3.1f\n (B)Static Pressure at exit is %3.3f atm\n (C)Static exit temperature is %3.2f K\n (D)density of air at exit is %3.4f kg/m^3\n (E)Stagnation exit
```

```
    temperation is %3.2f K\n (F)Stagnation Pressure
    at exit is %3.2f atm',M2,P2,T2,d2,To2,Po2)
```

Scilab code Exa 4.3 To find mass flow rate per unit area Final temperature and heat added per kg of air flow

```
clc
clear

//input data
M1=2 //Mach number at entry
P1=1.4 //Static Pressure at entry in bar
T1=323 //Static Temperature at entry in K
Cp=1.005 //Specific heat of dry air in kJ/kg-K
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
t1=0.555 //Temperature ratio at entry from gas
    tables (M=2,k=1.4,isentropic)
To1=T1/t1 //Total stagnation temperature at inlet in
     K
p1=0.364 //Pressure ratio  at entry from gas tables
    (M=2,k=1.4,isentropic)
Po1=P1/p1 //Stagnation Pressure at entry in bar
t2=0.529 //Static temperature ratio at critical
    state from gas tables (Rayleigh,k=1.4,M=2)
Tt=T1/t2 //Static critical temperature in K
t3=0.793 //Stagnation temperature ratio at critical
    state from gas tables (Rayleigh,k=1.4,M=2)
Tot=To1/t3 //Stagnation critical temperature in K
To2=Tot //Stagnation exit temperation in K
q=Cp*(To2-To1) //The heat transferred per unit mass
    flow in kJ/kg
a1=sqrt(k*R*T1) //Sound velocity in m/s
```

```
C1=M1*a1 //Air velocity in m/s
d1=(P1*10^5)/(R*T1) //density of air in kg/m^3
ma=d1*C1 //Mass flow rate per unit area in kg/s-m^3

//output
printf('(A)Mass flow rate per unit area is %3.2f kg/s-m^2\n (B)Final temperarure is %3.3f K\n (C)Heat added is %3.2f kJ/kg',ma,Tt,q)
```

Scilab code Exa 4.4 To calculate pressure and Mach number after combustion in combustion chamber

```
clc
clear

//input data
C1=100 //Air velocity into combustion chamber in m/s
P1=3 //Static Pressure at entry in bar
T1=318 //Static Temperature at entry in K
q=630 //The heat transferred per unit mass flow in kJ/kg
Cp=1.005 //Specific heat of dry air in kJ/kg-K
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
a1=sqrt(k*R*T1) //Sound velocity in m/s
M1=C1/a1 //Mach number at entry
t1=0.985 //Temperature ratio at entry from gas tables (M1,k=1.4,isentropic)
To1=T1/t1 //Total stagnation temperature at inlet in K
p1=0.947 //Pressure ratio  at entry from gas tables (M1,k=1.4,isentropic)
Po1=P1/p1 //Stagnation Pressure at entry in bar
```

```
To2=(q/Cp)+To1 //Stagnation exit temperation in K
p2=2.163 //Static Pressure ratio  at critical state
    from gas tables (Rayleigh,k=1.4,M=0.28)
Pt=P1/p2 //Static critical pressure in bar
p3=2.206 //Stagnation Pressure ratio at critical
    state from gas tables (Rayleigh,k=1.4,M=0.28)
Pot=Po1/p3 //Stagnation critical pressure in bar
t2=0.310 //Stagnation temperature ratio at critical
    state from gas tables (Rayleigh,k=1.4,M=0.28)
Tot=To1/t2 //Stagnation critical temperature in K
t3=(To2/Tot) //Stagnation Temperature ratio at exit
M2=0.7 //Mack number at exit from gas tables (
    Rayleigh,t3)
p4=1.423 //Static Pressure ratio  at exit from gas
    tables (Rayleigh,t3,M2)
P2=p4*Pt //Static Pressure at exit in bar

//output
printf('(A)Pressure after combustion is %3.3f bar\n
    (B)Mach number after combustion is %3.1f',P2,M2)
```

Scilab code Exa 4.5 To find total temperature static pressure at exit Stagnation pressure and exponent of polytropic equation

```
clc
clear

//input data
M1=3 //Mach number at entry
To1=295 //Total stagnation temperature at inlet in K
P1=0.5 //Static Pressure at entry in bar
M2=1.5 //Mack number at exit
Cp=1.005 //Specific heat of dry air in kJ/kg-K
R=287 //Gas constant in J/kg-K

```

```
//calculation
p1=0.0272 //Pressure ratio  at entry from gas tables (M=3,k=1.4,isentropic)
Po1=P1/p1 //Stagnation Pressure at entry in bar
t1=0.357 //Temperature ratio at entry from gas tables (M=3,k=1.4,isentropic)
T1=t1*To1 //Static temperature at entry in Kelvin
p2=0.176 //Static Pressure ratio  at critical state from gas tables (Rayleigh,k=1.4,M=3)
Pt=P1/p2 //Static critical pressure in bar
p3=3.424 //Stagnation Pressure ratio at critical state from gas tables (Rayleigh,k=1.4,M=3)
Pot=Po1/p3 //Stagnation critical pressure in bar
t2=0.654 //Stagnation temperature ratio at critical state from gas tables (Rayleigh,k=1.4,M=3)
Tot=To1/t2 //Stagnation critical temperature in K
t3=0.280 //Static temperature ratio at critical state from gas tables (Rayleigh,k=1.4,M=3)
Tt=T1/t3 //Static critical temperature in K
p4=0.578 ////Static Pressure ratio  at exit from gas tables (Rayleigh,M=1.5)
P2=p4*Pt //Static Pressure at exit in bar
p5=1.122 //Stagnation Pressure ratio at exit from gas tables (Rayleigh,M=1.5)
Po2=p5*Pot //Stagnation Pressure at exit in bar
t4=0.753 ////Static temperature ratio at exit from gas tables (Rayleigh,M=1.5)
T2=t4*Tt //Static exit temperature in K
t5=0.909 //Stagnation temperature ratio at exit from gas tables (Rayleigh,M=1.5)
To2=t5*Tot //Total stagnation temperature at exit in K
q=Cp*(To1-To2) //The heat transferred per unit mass flow in kJ/kg
SPC=Po1-Po2 //Change in stagnation pressure in bar
n=log(Po1/Po2)/(log(Po1/Po2)-log(To1/To2)) //Exponent of polytropic equation
qmax=Cp*(Tot-To1) //Maximum possible heat transfer
```

```
    in kJ/kg
ds=Cp*log(T2/T1)-(R*log(P2/P1)) //Change in entropy
    in kJ/kg-K

//output
printf('(A)Total temperature at exit is %3.2f K\n (B
    )Static pressure at exit is %3.3f bar \n (C)
    Change in stagnation pressure is %3.2f bar\n (D)
    Exponent of polytropic equation is %3.2f',To2,P2,
    SPC,n)
```

Scilab code Exa 4.6 To determine Mach number pressure temperature of gas at entry and amount of heat added and maximum heat can be added

```
clc
clear

//input data
M2=0.9 //Mack number at exit
P2=2.5 //Static Pressure at exit in bar
T2=1273 //Static exit temperature in K
t1=3.74 //ratio of stagnation temperatures at and
    exit entry
Cp=1.218 //Specific heat of dry air in kJ/kg-K
k=1.3 //Adiabatic constant

//calculation
t2=0.892 //Temperauture ratio at exit from gas
    tables (isentropic,k=1.3,M=0.9)
To2=T2/t2 //Total stagnation temperature at exit in
    K
To1=To2/t1 //Total stagnation temperature at inlet
    in K
p1=1.12 //Static pressure ratio at critical state
    from gas tables (Rayleigh,k=1.3,M=1.5)
```

```
Pt=P2/p1 //Static critical pressure in bar
t3=1.017 //Static temperature ratio at critical state from gas tables (Rayleigh ,k=1.3,M=1.5)
Tt=T2/t3 //Static critical temperature in K
t4=0.991 //Stagnation temperature ratio at critical state from gas tables (Rayleigh ,k=1.3,M=1.5)
Tot=To2/t4 //Stagnation critical temperature in K
t5=To1/Tot //Ratio of stagnation temperature at entry and critical state
M1=0.26 //Mach number at entry from gas tables (Rayleigh ,t5 ,k=1.3)
p2=2.114 //Static Pressure ratio  at entry from gas tables (Rayleigh ,t5 ,k=1.3)
P1=Pt*p2 //Static Pressure at entry in bar
t6=0.302 //Static temperature ratio  at entry from gas tables (Rayleigh ,t5 ,k=1.3)
T1=Tt*t6 //Static temperature at entry in Kelvin
q=Cp*(To2-To1) //The heat transferred per unit mass flow in kJ/kg
qmax=Cp*(Tot-To1) //Maximum possible heat transfer in kJ/kg

//output
printf('(A)Mach number at entry is %3.2f\n (B) Pressure at entry is %3.3f bar \n (C)Temperature of gas is %3i K\n (D)Amount of heat added is %3.2f kJ/kg\n (E)Maximum heat that can be heated is %3.3f kJ/kg',M1,P1,T1,q,qmax)
```

Scilab code Exa 4.7 To determine Mach number pressure temperature and velocity of gas at exit

```
clc
clear

```

```
//input
P1=0.343 //Static Pressure at entry in bar
T1=310 //Static temperature at entry in Kelvin
C1=60 //Velocity at entrance in m/s
q=1172.5 //The heat transferred per unit mass flow in kJ/kg
Cp=1.005 //Specific heat of dry air in kJ/kg-K
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
a1=sqrt(k*R*T1) //Sound velocity in m/s
M1=C1/a1 //Mach number at entry
t1=0.9943 //Temperature ratio at entry from gas tables (M=0.17,k=1.4,isentropic)
To1=T1/t1 //Total stagnation temperature at inlet in K
p1=2.306 //Static Pressure ratio at critical state from gas tables (Rayleigh,k=1.4,M=0.17)
Pt=P1/p1 //Static critical pressure in bar
t2=0.154 //Static temperature ratio at critical state from gas tables (Rayleigh,k=1.4,M=0.17)
Tt=T1/t2 //Static critical temperature in K
t3=0.129 //Stagnation temperature ratio at critical state from gas tables (Rayleigh,k=1.4,M=0.17)
Tot=To1/t3 //Stagnation critical temperature in K
c1=0.0665 //Velocity ratio at critical state from gas tables (Rayleigh,k=1.4,M=0.17)
Ct=C1/c1 //Critical velocity in m/s
To2=(q/Cp)+To1 //Stagnation exit temperation in K
t4=To2/Tot //Ratio of stagnation temperature at exit and critical state
M2=0.45 //Mach number at exit from gas tables (Rayleigh,t4,k=1.4)
p2=1.87 //Static Pressure ratio  at exit from gas tables (Rayleigh,t4,k=1.4)
P2=p2*Pt //Static Pressure at exit in bar
t5=0.7075 //Static temperature ratio  at exit from
```

```
    gas tables (Rayleigh,t4,k=1.4)
T2=t5*Tt //Static exit temperature in K
c2=0.378 //Velocity ratio at critical state from gas
     tables (Rayleigh,k=1.4,t4)
C2=Ct*c2 //exit velocity in m/s

//output
printf('At exit conditions :\n (A)Mach number is %3
    .2f\n (B)Pressure is %3.3f bar\n (C)Temperature
    is %3.2f K\n (D)Exit velocity is %3.2f m/s',M2,P2
    ,T2,C2)
```

Scilab code Exa 4.8 To find Mach number pressure and temperature after cooling

```
clc
clear

//input data
M1=2 //Mach number at entry
To1=523 //Total stagnation temperature at inlet in K
Po1=6 //Stagnation Pressure at entry in bar
To2=423 //Stagnation exit temperation in K

//calculation
t1=0.555 //Temperature ratio at entry from gas
    tables (M=2,k=1.4,isentropic)
T1=t1*To1 //Static temperature at entry in Kelvin
p1=0.128 //Pressure ratio  at entry from gas tables
    (M=2,k=1.4,isentropic)
P1=Po1*p1 //Static Pressure at entry in bar
p2=0.364 //Static pressure ratio at critical state
    from gas tables (Rayleigh,k=1.4,M=2)
p3=1.503 ////Stagnation pressure ratio at critical
    state from gas tables (Rayleigh,k=1.4,M=2),
```

```
printing mistake in textbook
t2=0.529 //Static Temperature ratio at critical
    state from gas tables (Rayleigh,k=1.4,M=2)
t3=0.793 //Stagnation temperature ratio at critical
    state from gas tables (Rayleigh,k=1.4,M=2)
t4=(To2/To1)*t3 //Ratio of stagnation temperature at
     exit and critical state
M2=3.15 //Mach number at exit from gas tables (
    Rayleigh,t4,k=1.4)
p4=0.161 //Static Pressure ratio  at exit from gas
    tables (Rayleigh,t4,k=1.4), printing mistake in
    textbook
t5=0.258 //Static temperature ratio  at exit from
    gas tables (Rayleigh,t4,k=1.4)
P2=(p4/p2)*P1 //Static Pressure at exit in bar
T2=(t5/t2)*T1 //Static exit temperature in K

//output
printf('After Cooling :\n (A)Mach number is %3.2f\n
    (B)Pressure is %3.4f bar\n (C)Temperature is %3.2
    f K',M2,P2,T2)
```

Scilab code Exa 4.9 To determine heat added per kg of air flow maximum possible heat transfer and heat transfer required to get maximum static temperature

```
clc
clear

//input data
M2=0.8 //Mack number at exit
t1=4 //Ratio of stagnation temperature at exit and
    entry
T1=288 //Atmospheric temperature in K
P1=1 //Atmospheric Pressure in atm
```

```
Cp=1.005 //Specific heat of dry air in kJ/kg-K

//calculation
t2=0.964 //Ratio of stagnation temperature at exit and critical state from gas tables
t3=t2/t1 //Ratio of stagnation temperature at entry and critical state
M1=0.24 ////Mach number at entry from gas tables (Rayleigh,t3,k=1.4)
t5=0.988 //Temperature ratio at entry from gas tables (M1,k=1.4,isentropic)
To1=T1/t5 //Total stagnation temperature at inlet in K
To2=t1*To1 //Stagnation exit temperation in K
Tot=To1/t3 //Stagnation critical temperature in K
q=Cp*(To2-To1) //The heat transferred per unit mass flow in kJ/kg
qmax=Cp*(Tot-To1) //Maximum possible heat transfer in kJ/kg
t6=0.9775 //Ratio of stagnation temperature for maximum static temperature (M=1/sqrt(k),Rayleigh)
To3=Tot*t6 //maximum stagnation temperature in K
q_req=Cp*(To3-To1) //Heat transfer required to get maximum static temperature in kJ/kg

//output
printf('(A)Heat added per kg of air flow is %3.2f kJ/kg\n (B)Maximum possible heat transfer is %3.2f kJ/kg\n (C)Heat transfer required to get maximum static temperature is %3.1f kJ/kg',q,qmax,q_req)
```

Scilab code Exa 4.10 To find exit properties Maximum stagnation temperature percentage of pressure loss and initial mach number

```
clc
```

```
clear

//input data
T1=560 //Static Temperature at entry in K
P1=0.6 //Static Pressure at entry in bar
C1=75 //Air velocity into combustion chamber in m/s
mp=30 //air fuel ratio
CV=92000 //Calorific value of fuel in kJ/kg
Cp=1.005 //Specific heat of dry air in kJ/kg-K
k=1.4 //Adiabatic constant
R=287 //Gas constant in J/kg-K

//calculation
a1=sqrt(k*R*T1) //Sound velocity in m/s
M1=C1/a1 //Mach number at entry
t1=0.9949 //Temperature ratio at entry from gas
    tables (M1,k=1.4,isentropic)
To1=T1/t1 //Total stagnation temperature at inlet in
    K
p1=0.982 //Pressure ratio  at entry from gas tables
    (M1,k=1.4,isentropic)
Po1=P1/p1 //Stagnation Pressure at entry in bar
q=CV/(mp+1) //The heat transferred per unit mass
    flow in kJ/kg of gas, mp+1=total amount of fuel=
    mf+ma
p2=2.317 //Static Pressure ratio  at critical state
    from gas tables (Rayleigh,k=1.4,M1)
Pt=P1/p2 //Static critical pressure in bar
p3=1.246 //Stagnation Pressure ratio at critical
    state from gas tables (Rayleigh,k=1.4,M1)
Pot=Po1/p3 //Stagnation critical pressure in bar
t2=0.137 //Static temperature ratio at critical
    state from gas tables (Rayleigh,k=1.4,M1)
Tt=T1/t2 //Static critical temperature in K
t3=0.115 //Stagnation temperature ratio at critical
    state from gas tables (Rayleigh,k=1.4,M1)
Tot=To1/t3 //Stagnation critical temperature in K
To2=(q/Cp)+To1 //Stagnation exit temperation in K
```

```
t4=To2/Tot //Ratio of stagnation temperature at exit and critical state
M2=0.33 //Mach number at exit from gas tables (Rayleigh,t4,k=1.4)
p4=2.0825 //Static Pressure ratio  at exit from gas tables (Rayleigh,t4,k=1.4)
P2=p4*Pt //Static Pressure at exit in bar, miscalculation in textbook
p5=1.186 //Stagnation Pressure ratio at exit from gas tables (Rayleigh,t4,k=1.4)
Po2=Pot*p5 //Stagnation Pressure at exit in bar
t5=0.472 //Static temperature ratio  at exit from gas tables (Rayleigh,t4,k=1.4)
T2=t5*Tt //Static exit temperature in K
C2=M2*sqrt(k*R*T2) //exit velocity in m/s
SPL=((Po1-Po2)/Po1)*100 //Percentage of pressure loss in combustion chamber in %

//output
printf('(A)At exit:\n    Pressure is %3.5f bar \n    Temperature is %3i K \n    Velocity is %3.2f m/s \n    Mach number is %3.2f \n (B)Maximum stagnation temperature available is %3.2f K\n (C)Percentage of pressure loss in combustion chamber is %3.1f percent\n (D)Intial Mach number is %3.2f \n',P2,T2,C2,M2,Tot,SPL,M1)
```

Scilab code Exa 4.11 To find Mach number and percentage drop in pressure

```
clc
clear

//input data
To1=473 //Total stagnation temperature at inlet in K
```

```
To2=673 //Stagnation exit temperation in K
M1=0.5 //Mach number at entry

//calculation
t1=0.6914 //Stagnation temperature ratio at critical
    state from gas tables (Rayleigh,k=1.4,M1)
p1=1.7778 //Static pressure ratio at critical state
   from gas tables (Rayleigh,k=1.4,M1)
t2=(To2/To1)*t1 //Stagnation temperature ratio at
   exit
M2=0.867 //Mach number at exit from gas tables (
   Rayleigh,t2,k=1.4)
p2=1.16 //Static pressure ratio at exit from gas
   tables (Rayleigh,k=1.4,M2)
p=p2/p1 //ratio of static pressures at oulet and
   inlet
PL=(1-p)*100 //pressure loss in %

//output
printf('(A)Mach number is %3.3f\n (B)Percentage drop
    in pressure is %3.1f percent',M2,PL)
```

Scilab code Exa 4.12 To find inlet mach number and percentage loss in static pressure

```
clc
clear

//input data
t1=3 //Stagnation temperature ratio
M2=0.8 //Mach number at exit

//calculation
t2=0.964 //Ratio of stagnation temperature at exit
   and critical state (Rayleigh,M2,k=1.4)
```

```
p1=1.266 //Static Pressure ratio  at exit from gas
    tables (Rayleigh ,M2,k=1.4)
t3=t2/t1 //Stagnation temperature ratio at critical
    state
M1=0.29 //Mach number at entry from gas tables (
    Rayleigh ,t3 ,k=1.4)
p2=2.147 //Static pressure ratio at critical state
    from gas tables (Rayleigh ,k=1.4,M1)
p=p1/p2 //ratio of static pressures at exit and
    entry
PL=(1-p)*100 //Percentage loss in static pressure in
     %

//output
printf('(A)Mach number at entry is %3.2f\n (B)
    Percentage loss in static pressure is %3i percent
    ',M1,PL)
```

Scilab code Exa 4.13 To find inlet and exit mach number

```
clc
clear

//input data
To1=300 //Total stagnation temperature at inlet in K
To2=310 //Stagnation exit temperation in K
G=1300 //Mass velocity in kg/m^2-s
P1=105*10^3 //Static Pressure at entry in Pa
Cp=1.005 //Specific heat of dry air in kJ/kg-K
R=287 //Gas constant in J/kg-K

//calculation
T1=(((-2*P1^2*Cp)+sqrt(((-2*P1^2*Cp)^2)+(8*G^2*R^2*
    P1^2*Cp*To1)))/(2*G^2*R^2)) //Static temperature
    in K
```

```
t1=T1/To1 //Temperature ratio at entry
M1=1.4 //Mach number at entry from gas tables (
    isentropic ,t1 ,k=1.4)
t2=0.934 //Stagnation temperature ratio at critical
    state from gas tables (Rayleigh ,k=1.4 ,M1)
Tot=To1/t2 //Stagnation critical temperature in K
t3=To2/Tot //Stagnation temperature ratio at exit
    from gas tables (Rayleigh ,k=1.4 ,M1)
M2=1.26 //Mach number at exit from gas tables (
    Rayleigh ,t3 ,k=1.4)

//output
printf('(A)The inlet mach number is %3.2f \n (B)The
    exit mach number is %3.2f',M1,M2)
```

Scilab code Exa 4.14 To find properties at exit and sonic condition and heat required to accelerate gas from inlet to sonic condition

```
clc
clear

//input data
k=1.3 //Adiabatic constant
R=466 //Gas constant in J/kg-K
P1=0.345 //Static Pressure at entry in Pa
T1=312 //Static Temperature at entry in K
C1=65.5 //Entry velocity in m/s
q=4592 //The heat transferred per unit mass flow in
    kJ/kg

//calculation
a1=sqrt(k*R*T1) //Sound velocity in m/s
M1=C1/a1 //Mach number at entry
t1=0.9965 //Temperature ratio at entry from gas
    tables (M1,k=1.3,isentropic)
```

```
To1=T1/t1 //Total stagnation temperature at inlet in K
p1=2.235 //Static Pressure ratio  at critical state from gas tables (Rayleigh,k=1.3,M1)
Pt=P1/p1 //Static critical pressure in bar
c1=0.051 //Velocity ratio at critical state from gas tables (Rayleigh,k=1.3,M1)
Ct=C1/c1 //Critical velocity in m/s
t2=0.112 //Static temperature ratio at critical state from gas tables (Rayleigh,k=1.3,M1)
Tt=T1/t2 //Static critical temperature in K
t3=0.098 //Stagnation temperature ratio at critical state from gas tables (Rayleigh,k=1.3,M1)
Tot=To1/t3 //Stagnation critical temperature in K
Cp=(k*R)/(k-1) //Specific heat of dry air in kJ/kg-K
To2=(q/Cp)+To1 //Stagnation exit temperation in K
t4=(To2/Tot) //Stagnation Temperature ratio at exit
M2=0.60 //Mack number at exit from gas tables (Rayleigh,t4)
p2=1.567 //Static Pressure ratio  at exit from gas tables (Rayleigh,t4,k=1.4)
P2=p2*Pt //Static Pressure at exit in bar
t5=0.884 //Static temperature ratio  at exit from gas tables (Rayleigh,t4,k=1.4)
T2=t5*Tt //Static exit temperature in K
c2=0.564 //Velocity ratio at critical state from gas tables (Rayleigh,k=1.4,t4)
C2=Ct*c2 //exit velocity in m/s
qmax=Cp*(Tot-To1)/10^3 //Maximum possible heat transfer in kJ/kg

//output
printf('(A)Heat required to accelerate the gas from the inlet condition to sonic condition is %3.2f kJ/kg\n (B)The pressure and temperature at sonic condition are %3.3f bar and %3.2f K respectively\n (C)The properties at exit are:\n    Pressure is %3.3f bar\n    Temperature is %3.2f K\n
```

```
    Velocity is %3i m/s',qmax,Pt,Tt,P2,T2,C2)
```

Chapter 5

Normal and Oblique Shock

Scilab code Exa 5.1 To find Mach number before shock properties after shock density increase loss of stagnation pressure and entropy change of air in pipe

```
clc
clear

//Input data
Px=150 //Pressure before the shock in kPa
Tx=25+273 //Temperature before the shock in K
Py=350 //Pressure just after the shock in kPa
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculations
p1=Py/Px //Pressure ratio
Mx=1.4638 //Mach number before the shock
My=0.716 //Mach number after the shock from gas
    tables @Mx
t1=1.294 //Temperature ratio after and before the
    shock from gas tables @p1
Ty=t1*Tx //Temperature ratio after the shock in K
ax=sqrt(k*R*Tx) //Velocity of sound before the shock
```

```
in m/s
Cx=ax*Mx //Velocity of gas before the shock in m/s
ay=sqrt(k*R*Ty) //Velocity of sound after the shock in m/s
Cy=ay*My //Velocity of gas after the shock in m/s
p2=0.942 //Stagnation pressure ratio after and before the shock from gas tables @p1
ds=R*log(1/p2) //Change in entropy in J/kg-K
p3=3.265 //Stagnation pressure after shock to Static pressure before shock from gas tables @p1
Poy=p3*Px //Stagnation pressure after shock in kPa
Pox=Poy/p2 //Stagnation pressure before shock in kPa
pr_loss=Pox-Poy //Loss of stagnation pressure of air in kPa
dd=(1000/R)*((Py/Ty)-(Px/Tx)) //Increase in density of air in kg/m^3

//Output
printf('(A)Mach number before shock is %3.4f\n (B) After shock:\n     Mach number is %3.3f\n     Static temperature is %3.3f K\n     Velocity is %3.2f m/s\n (C)Increase in density of air is %3.2f kg/m^3\n (D)Loss of stagnation pressure of air is %3.2f kPa\n (E)Change in entropy is %3.3f J/kg-K',Mx,My,Ty,Cy,dd,pr_loss,ds)
```

Scilab code Exa 5.2 To find properties across normal shock and entropy change

```
clc
clear

//Input data
Tx=350 //Temperature before the shock in K
Px=137.8 //Pressure before the shock in kPa
```

```
Cx=750 //Velocity before the shock in m/s
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
ax=sqrt(k*R*Tx) //Velocity of sound before the shock in m/s
Mx=Cx/ax //Mach number before the shock
My=0.577 //Mach number after the shock from gas tables @Mx
p1=4.5 //Static pressure ratio after and before the shock from gas tables @My
Py=Px*p1 //Static pressure after shock in kPa
t1=1.687 //Temperature ratio after and before the shock from gas tables @My
Ty=Tx*t1 //Temperature ratio after the shock in K
p2=5.641 //Stagnation pressure after shock to Static pressure before shock from gas tables @My
Poy=Px*p2 //Stagnation pressure after shock in kPa
p3=0.721 //Stagnation pressure ratio after and before the shock from gas tables @My
Pox=Poy/p3 //Stagnation pressure before shock in kPa
ds=R*log(1/p3) //Change in entropy in J/kg-K
t2=0.555 //Static to Stagnation temperature ratio before shock from isentropic gas tables @Mx,k=1.4
Tox=Tx/t2  //Stagnation temperature before shock in K
p4=0.128 //Static to Stagnation pressure ratio from isentropic gas tables @Mx,k=1.4
Pox=Px/p4 //Stagnation pressure in kPa
t4=0.937 //Static to Stagnation temperature ratio before shock from normal shock gas tables @Mx,k=1.4 (Tox=Toy Checked)
Toy=Ty/t4 //Stagnation temperature after shock in K
ay=sqrt(k*R*Ty) //Velocity of sound after the shock in m/s
Cy=(My*ay) //Velocity of gas after the shock in m/s

```

```
//Output
printf('(A)At inlet to shock:\n    Stagnation pressure is %3.1f kPa\n    Stagnation temperature is %3.2f K\n    Mach number is %3.0f\n (B)After shock:\n    Stagnation pressure is %3.2f kPa\n    Stagnation temperature is %3.2f K\n    Static pressure is %3.1f kPa\n    Static temperature is %3.2f K\n    Mach number is %3.3f\n    Velocity is %3.2f m/s\n (C)Change in entropy across the shock is %3.2f J/kg-K',Pox,Tox,Mx,Poy,Toy,Py,Ty,My,Cy,ds)
```

Scilab code Exa 5.3 To find properties downstream of shock

```
clc
clear

//Input data
Tx=0+273 //Temperature before the shock in K
Px=60 //Pressure before the shock in kPa
Cx=497 //Air Velocity before the shock in m/s
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
ax=sqrt(k*R*Tx) //Velocity of sound before the shock in m/s
Mx=Cx/ax //Mach number before the shock
My=0.70109 //Mach number after the shock from gas tables @Mx
p1=2.45833 //Static pressure ratio after and before the shock from gas tables @My
Py= p1*Px //Static pressure after shock in kPa
t1=1.32022 //Temperature ratio after and before the shock from gas tables @My
```

```
Ty=Tx*t1 //Temperature ratio after the shock in K
p2=3.41327 //Stagnation pressure after shock to Static pressure before shock from gas tables @My
Poy=p2*Px //Stagnation pressure after shock in kPa
p3=0.92979 //Stagnation pressure ratio after and before the shock from gas tables @My
Pox=Poy/p3 //Stagnation pressure before shock in kPa
ay=sqrt(k*R*Ty) //Velocity of sound after the shock in m/s
Cy=ay*My //Velocity of air after the shock in m/s

//Output
printf('After shock:\n    (A)Mach number is %3.5f\n    (B)Velocity is %3.3f m/s\n    (C)Stagnation pressure is %3.3f kPa\n',My,Cy,Poy)
```

Scilab code Exa 5.4 To find velocities across shock and stagnation pressure change

```
clc
clear

//Input data
Px=30 //Pressure before the shock in kPa
Tx=-30+273 //Temperature before the shock in K
pr=2.6 //Pressure ratio across the shock wave
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
Mx=1.54 //Mach number before the shock from gas tables @pr
My=0.687 //Mach number after the shock from gas tables @Mx
t1=1.347 //Temperature ratio after and before the
```

```
shock from gas tables @My
Ty=t1*Tx //Temperature ratio after the shock in K
p1=3.567 //Stagnation pressure after shock to Static pressure before shock from gas tables @My
Poy=p1*Px //Stagnation pressure after shock in kPa
p2=0.917 //Stagnation pressure ratio after and before the shock from gas tables @My
Pox=Poy/p2 //Stagnation pressure before shock in kPa
dP=Pox-Poy //Change in stagnation pressure in kPa
ax=sqrt(k*R*Tx) //Velocity of sound before the shock in m/s
Cx=(Mx*ax) //Air Velocity before the shock in m/s
ay=sqrt(k*R*Ty) //Velocity of sound after the shock in m/s
Cy=(My*ay) //Velocity of air after the shock in m/s

//Output
printf('(A)Velocities upstream and downstream of shock wave are %3.2f m/s and %3.2f m/s respectively\n (B)Change in stagnation pressure is %3.3f kPa',Cx,Cy,dP)
```

Scilab code Exa 5.5 To find properties downstream of shock

```
clc
clear

//Input data
Mol=39.9 //Molar mass of a gas in kg/mol
k=1.67 //Specific heat ratio
Mx=2.5 //Mach number before the shock
Px=40 //Pressure before the shock in kPa
Tx=-20+273 //Temperature before the shock in K

//Calculation
```

```
My=0.554 //Mach number after the shock from gas
    tables @Mx
p1=7.567 //Static pressure ratio after and before
    the shock from gas tables @My
Py=p1*Px //Static pressure after shock in kPa
t1=2.805 //Temperature ratio after and before the
    shock from gas tables @My
Ty=Tx*t1 //Temperature ratio after the shock in K

//Output
printf('Downstream the normal shock:\n    Mach
    number is %3.3f\n    Pressure is %3.2f kPa\n
    Temperature is %3.3f K',My,Py,Ty)
```

Scilab code Exa 5.6 To find pressure acting on front of the body

```
clc
clear

//Input data
Mx=2 //Mach number before the shock
Px=50 //Pressure before the shock in kPa

//Calculation
p1=6.335 //Stagnation pressure after shock to Static
     pressure before shock from gas tables @Mx
Poy=p1*Px //Stagnation pressure after shock in kPa

//Output
printf('Pressure acting on the front of the body is
    %3.2f kPa',Poy)
```

Scilab code Exa 5.7 To find mass flow rate and properties at exit of CD nozzle

```
clc
clear

//Input data
Po=800 //Pressure in reservoir in kPa
To=40+273 //Temperature in reservoir in K
M2a=2.5 //Mach number at exit from diagram
At=25 //Throat Area in cm^2
Ax=40 //Area just before the shock in cm^2
Ay=40 //Area just after the shock in cm^2
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
t1=0.834 //Ratio of critical temperature and
    stagnation temperature from gas tables @M=1
Tt=To*t1 //Critical temperature in K
p1=0.528 //Ratio of critical pressure and stagnation
     pressure from gas tables @M=1
Pt=Po*p1 //Critical pressure in kPa
dt=Pt*10^3/(R*Tt) //Density in kg/m^3, Pt in Pa
at=sqrt(k*R*Tt) //Velocity of sound at throat in m/s
Ct=at //Air Velocity of sound at throat in m/s
m=dt*At*10^-4*Ct //Mass flow rate in kg/s
p2=0.0585 //Ratio of exit to stagnation pressure
    from isentropic gas tables @M2=2.5
a1=2.637 //Ratio of exit to critical area from
    isentropic gas tables @M2=2.5
A2=a1*At //Exit area in cm^2
a2=Ax/At //Area ratio
M=1.94 //Mach number upstream of shock from gas
    tables @a2
p3=0.140 //Ratio of upstram of shock to stagnation
    pressures from isentropic gas tables @M
Px=p3*Po //Pressure upstram of shock in kPa
```

```
t2=0.570 //Ratio of upstram of shock to stagnation temperature from isentropic gas tables @M
Tx=t2*To //Temperature upstram of shock in K
My=0.588 //Mach number downstream of shock from normal shock gas tables @M
p4=4.225 //Static pressure ratio after and before the shock from gas tables @My
Py=Px*p4 //Static pressure after shock in kPa
t3=1.639 //Temperature ratio after and before the shock from gas tables @My
Ty=Tx*t3 //Temperature ratio after the shock in K
p5=2.338 //Stagnation pressure after shock to Static pressure before shock from gas tables @My
Poy=p5*Px //Stagnation pressure after shock in kPa
p6=0.749 //Stagnation pressure ratio after and before the shock from gas tables @My
Pox=Poy/p6 //Stagnation pressure before shock in kPa
//Here At2=Aty, Po2=Poy, Toy=To2=To1=To
p7=0.79 //Static to stagnation pressure ratio after shock from isentropic gas tables @My
Po2=Py/p7 //Stagnation pressure at exit in kPa
t4=0.935 //Static to stagnation temperature ratio after shock from isentropic gas tables @My
To2=Ty/t4 //Stagnation temperature in K (checked)
a3=1.2 //Ratio of areas after shock i.e. (Ay/At2)
At2=Ay/a3 //Critical area after shock in cm^2
a4=A2/At2 //Ratio of areas
M2b=0.31 //Mach number at exit from gas tables @a4(as per section-b)
p8=0.936 //Static to stagnation pressure ratio at exit from isentropic gas tables @M2b
P2=Po2*p8 //Exit pressure in kPa
t5=0.981 //Static to stagnation temperature ratio after shock from isentropic gas tables @M2b
T2=To2*t5 //Exit temperature in K

//Output
printf('CASE-I:\n     (A)Mass flow rate is %3.2f kg/s
```

```
\n     (B) Exit area is %3.1f cm^2\n CASE-II:\n
(A) Temperature is %3.3f K\n     (B) Pressure is %3
.1f kPa',m,A2,T2,P2)
```

Scilab code Exa 5.8 To find properties upstream of wave front

```
clc
clear

//Input data
Px=1 //Pressure before the shock in bar
Tx=17+273 //Temperature before the shock in K
Cx=500 //Air Velocity before the shock in m/s
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
ax=sqrt(k*R*Tx) //Velocity of sound before the shock in m/s
Mx=Cx/ax //Mach number before the shock
My=0.715 //Mach number after the shock from gas tables @Mx
p1=2.335 //Static pressure ratio after and before the shock from gas tables @My
Py=p1*Px //Static pressure after shock in bar
t1=1.297 //Temperature ratio after and before the shock from gas tables @My
Ty=Tx*t1 //Temperature ratio after the shock in K
ay=sqrt(k*R*Ty) //Velocity of sound after the shock in m/s
Cy=ay*My //Velocity of air after the shock in m/s
C_y=Cx-Cy //Velocity of air in m/s
M_y=C_y/ay  //Mach number impared upstream of the wave front
t2=0.939 //Static to stagnation temperature ratio
```

```
    after shock from isentropic gas tables @M_y
T_oy=Ty/t2 //Stagnation temperature of air in K

//Output
printf('(A)Pressure is %3.3f bar\n (B)Temperature is
     %3.2f K\n (C)Velocity of air is %3.2f m/s\n (D)
    Stagnation temperature is %3.2f K\n (E)Mach
    number is %3.3f',Py,Ty,C_y,T_oy,M_y)
```

Scilab code Exa 5.9 To find properties downstream of shock total head pressure ratio entropy change strength of shock

```
clc
clear

//Input data
Mx=3 //Mach number before the shock
Tx=27+273 //Temperature before the shock in K
Px=1 //Pressure before the shock in bar
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
My=0.475 //Mach number after the shock from gas
    tables @Mx
p1=10.333 //Static pressure ratio after and before
    the shock from gas tables @My
Py=p1*Px //Static pressure after shock in bar
t1=2.679 //Temperature ratio after and before the
    shock from gas tables @My
Ty=Tx*t1 //Temperature ratio after the shock in K
p2=12.061 //Stagnation pressure after shock to
    Static pressure before shock from gas tables @My
Poy=p2*Px //Stagnation pressure after shock in bar
p3=0.328 //Stagnation pressure ratio after and
```

```
before the shock from gas tables @My
Pox=Poy/p3 //Stagnation pressure before shock in kPa
ay=sqrt(k*R*Ty) //Velocity of sound after the shock in m/s
Cy=ay*My //Velocity of air after the shock in m/s
ds=R*log(1/p3) //Change in entropy in J/kg-K
e=(Py-Px)/Px //Strength of shock

//Output
printf('(I)Downstream of the shock:\n    (A)Pressure is %3.3f bar\n    (B)Temperature is %3.1f K\n    (C)Gas velocity is %3.2f m/s\n    (D)Mach number is %3.3f\n (II)Total head pressure ratio is %3.3f\n (III)Entropy change across the shock is %3.3f J/kg-K\n (IV)Strength of the shock is %3.3f',Py,Ty,Cy,My,p3,ds,e)
```

Scilab code Exa 5.10 To determine Mach number across shock and area at shock

```
clc
clear

//Input data
a1=0.4 //Ratio of throat area to exit area
p1=0.8 //Ratio of static pressure to Stagnation pressure at inlet
At=1 //Throat area in m^2

//Calculation
a2=1/a1 //reciprocal of a1 to find in gas tables
//Pox=Po1=Po, Poy=Po2
a2p2=a2*p1 //Area pressure ratio i.e. (A2*P2)/(At2*Po2)
M2=0.28 //Exit mach number from gas tables @a2p2
```

```
a3=2.166 //Ratio of exit area to throat area after
    shock from gas tables @a2p2
p2=0.947 //Static to stagnation pressure ratio at
    exit from gas tables @a2p2
p3=a2/a3 //Stagnation pressure ratio after and
    before shock
Mx=1.675 //Mach number before the shock @p3
My=0.647 //Mach number after the shock from gas
    tables @Mx
a4=1.14 //Ratio of area after shock to throat area
    after shock from isentropic gas tables @My
a5=1.315 //Ratio of area before shock to throat area
     before shock from isentropic gas tables @My
Ax=a5*At //Area at shock in m^2

//Output
printf('(A)Mach number across the shock: Mx=%3.3f (
   My=%3.3f)\n (B)Area at shock is %3.3f m^2',Mx,My,
   Ax)
```

Scilab code Exa 5.11 To find Mach number across shock Static pressure and area at shock

```
clc
clear

//Input data
a1=1/3 //Ratio of throat area to exit area
p1=0.4 //Ratio of static pressure to Stagnation
    pressure at inlet

//Calculation
a2=1/a1 //reciprocal of a1 to find in gas tables
//we know Pox=Po1=Po, Poy=Po2, At=Atx and Aty=At2
a2p2=a2*p1 //Area pressure ratio i.e. (A2*P2)/(At2*
```

```
Po2)
M2=0.472 //Exit mach number from gas tables @a2p2
a3=1.397 //Ratio of exit area to throat area after shock from gas tables @a2p2
p2=0.858 //Static to stagnation pressure ratio at exit from gas tables @a2p2
p3=a3/a2 //Stagnation pressure ratio after and before shock
Mx=2.58 //Mach number before the shock @p3
My=0.506 //Mach number after the shock from gas tables @Mx
p4=9.145 //Stagnation pressure after shock to Static pressure before shock from gas tables @My
a4=2.842 //Ratio of area before shock to throat area
p5=0.051 //Ratio of Pressure before shock to Stagnation pressure at entry

//Output
printf('At section where shock occurs:\n    (A)Mach number Mx=%3.2f and My=%3.3f\n    (B)Static Pressure is %3.3f*Po1 (units depend on Po1)\n    (C)Area of cross section is %3.3f*At (units depend on At)',Mx,My,p5,a4)
```

Scilab code Exa 5.12 To find properties at various sections

```
clc
clear

//Input data
Po=300 //Pressure in reservoir in kPa
To=500 //Temperature in reservoir in K
At=1 //Throat area in m^2
Ax=2 //Area just before the shock in m^2
Ay=2 //Area just after the shock in m^2
```

```
A2=3 //Exit area in m^2

//Calculation
a1=Ax/At //Area ratio
Mx=2.2 //Mach number upstream of shock
p1=0.0935 //Ratio of pressure before shock to
    stagnation pressure before shock from gas tables
    @Mx
Px=p1*Po //pressure before shock in kPa
t1=0.50 //Ratio of temperature before shock to
    stagnation pressure before shock from gas tables
    @Mx
Tx=t1*To //temperature before shock in K
My=0.547 //Mach number downstream of shock
p2=5.480 //Static pressure ratio after and before
    the shock from gas tables @My
Py=Px*p2 //Static pressure after shock in kPa
t2=1.857 //Temperature ratio after and before the
    shock from gas tables @My
Ty=t2*Tx //Temperature ratio after the shock in K
p3=6.716 //Stagnation pressure after shock to Static
     pressure before shock from gas tables @My
Poy=Px*p3 //Stagnation pressure after shock in kPa
Po2=Poy //Exit stagnation pressure in kPa, Since
    total pressure remains same after shock
t3=0.943 //Static to stagnation pressure after shock
     from isentropic gas tables @My
Toy=Ty/t3 //Stagnation pressure after shock in K
To2=Toy //Exit stagnation temperature in K, Since
    temperature remains after shock
a2=1.255 //Ratio of area after shock to throat area
    after shock from isentropic gas tables @My
Aty=Ay/a2 //Throat area after shock in m^2
At2=Aty //Throat area at exit in m^2
a3=A2/At2 //Areas ratio
M2=0.33 //Exit mach number from gas tables @a3
p4=0.927 //Static to Stagnation pressure at exit
    from gas isentropic gas tables @a3
```

```
P2=Po2*p4 //Exit pressure in kPa
t4=0.978 //Static to Stagnation temperature at exit
    from gas isentropic gas tables @a3
T2=To2*t4 //Exit temperature in K

//Output
printf('(A)Pressure at section (x) Px=%3.2f kPa\n (B
    )Pressure at section (y) Px=%3.3f kPa\n (C)
    Stagnation pressure at section (y) Poy=%3.2f kPa\
    n (D)Throat area of cross section at section (y)
    Aty=%3.4f m^2\n (E)Stagnation pressure at exit
    Po2=%3.2f kPa\n (F)Throat area of cross section
    at exit At2=%3.4f m^2\n (G)Static Pressure at
    exit P2=%3.2f kPa\n (H)Stagantion temperature at
    exit To2=%3i K\n (I)Temperature at exit T2=%3i k'
    ,Px,Py,Poy,Aty,Po2,At2,P2,To2,T2)
```

Scilab code Exa 5.13 To find mass flow rate and properties at throat and exit at various sections of CD nozzle

```
clc
clear

//Input data
Po1=500 //Stagnation pressure in kPa
To1=600 //Stagnation temperature in K
C1=100 //inlet velocity in m/s
A1=0.01 //Inlet Area in m^2
A2=0.01 //Exit Area in m^2
Mx=1.2 //Mach number before the shock
Ax=37.6 //Area just before the shock in cm^2
Ay=37.6 //Area just after the shock in cm^2
Px=109.9 //Pressure before the shock in kPa
Poy=350 //Stagnation pressure after shock in kPa
k=1.4 //Adiabatic constant
```

```
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant volume in J/kg-K

//Calculation
T1=To1+(C1^2/(2*Cp)) //Inlet static temperature in K
ai_1=sqrt(k*R*T1) //Velocity of sound at inlet in m/s
M1=C1/ai_1 //Inlet Mach number
p1=0.973 //Static to Stagnation pressure ratio at entry from gas tables @M1
P1=Po1*p1 //Inlet static pressure in kPa
d1=P1*10^3/(R*T1) //Density at inlet in kg/m^3, P1 in Pa
m=d1*A1*C1 //Mass flow rate at inlet in kg/s
p2=0.528 //Ratio of critical pressure to stagnation pressure from gas tables @M=1
Pt=Po1*p2 //Critical pressure in kPa
t1=0.834 //Ratio of critical temperature to stagnation temperature from gas tables @M=1
Tt=t1*To1 //critical temperature in K
ai_t=sqrt(k*R*Tt) //Velocity of sound at critical state in m/s
Ct=ai_t //Velocity of air at critical state in m/s
a1=2.964 //Ratio of inlet area to critical area from gas tables @M=1
At=A1/a1 //critical area in m^2
dt=Pt/(R*Tt) //Density at critical state in kg/m^3
mt=dt*At*Ct //Mass flow rate at critical satate in kg/s
//Sub-division (a)
a2=1.030 //Ratio of area after shock to critical area from gas tables @Mx
Ay_a=At*a2 //Area after shock in cm^2
p3=0.412 //Ratio of upstram of shock to stagnation pressures from isentropic gas tables @Mx
Px_a=Po1*p3 //Pressure upstram of shock in kPa
t2=0.776 //Ratio of upstram of shock to stagnation
```

```
temperature from isentropic gas tables @Mx
Tx_a=To1*t2 //Temperature upstram of shock in K
My_a=0.84 //Mach number downstream of shock from normal shock gas tables @Mx
p4=1.497 //Static pressure ratio after and before the shock from gas tables @My
Py_a=Px_a*p4 //Static pressure after shock in kPa
t3=1.099 //Temperature ratio after and before the shock from gas tables @My
Ty_a=Tx_a*t3 //Temperature ratio after the shock in K
p5=2.407 //Stagnation pressure after shock to Static pressure before shock from gas tables @My
Poy_a=Px_a*p5 //Stagnation pressure after shock in kPa
a3=1.204 //Ratio of area after shock to throat area after shock from isentropic gas tables @My
At2_a=(Ay_a/a3)*10^4 //Throat area at exit in m^2, calculation mistake in textbook
a4=A2/At2_a //Ratio of areas to find gas tables
M2_a=0.2 //Exit mach number at section-A from gas tables @a4
p5=0.973 //ratio of exit pressure to stagnation pressure after shock from gas tables
P2_a=p5*Poy_a //exit pressure in kPa
//Sub-division (b)
a5=Ax/At //Ratio of area before shock to critical area
Mx_b=1.4 //Mach number at section-B from gas tables @a5
p6=0.314 //Ratio of upstram of shock to stagnation pressures from isentropic gas tables @Mx_b
Px_b=Po1*p6 //Pressure upstram of shock in kPa
t4=0.718 //Ratio of upstram of shock to stagnation temperature from isentropic gas tables @Mx_b
Tx_b=To1*t4 //Temperature upstram of shock in K
p20=3.049 //Stagnation pressure ratio after shock to Static pressure before shock from gas tables
```

```
Poy_b=Px_b*p20 //Stagnation pressure after shock in
    kPa
My_b=0.735 //Mach number downstream of shock from
    normal shock gas tables @Mx_b
p7=2.085 //Static pressure ratio after and before
    the shock from gas tables @My_b
Py_b=Px_b*p7 //Static pressure after shock in kPa
t5=1.260 //Temperature ratio after and before the
    shock from gas tables @My_b
Ty_b=Tx_b*t5 //Temperature after the shock in K
a6=1.071 //Ratio of area after shock to throat area
    after shock from isentropic gas tables My_b=0.735
At2_b=Ay/a6 //Throat area at exit in m^2
a7=A2/At2_b //Ratio of areas
M2_b=0.21 //Exit mach number at section-B from gas
    tables @a7
p8=0.9697 //ratio of exit pressure to stagnation
    pressure after shock from gas tables
P2_b=p8*Poy_b //exit pressure in kPa
//Sub-division (c)
p9=Px/Po1 //Ratio of upstram of shock to stagnation
    pressures
Mx_c=1.65 //Mach number at section-B from gas tables
     @p9
a8=1.292 //Ratio of area before shock to critical
    area from gas tables @p9
Ax_c=At*a8*10^4 //Area before shock in cm^2
t6=0.647 //Ratio of upstram of shock to stagnation
    temperature from isentropic gas tables @p9
Tx_c=To1*t6 //Temperature upstream of shock in K
My_c=0.654  //Mach number downstream of shock from
    normal shock gas tables @Mx_c
p10=3.0095 //Static pressure ratio after and before
    the shock from gas tables @My_c
Py_c=Px*p10 //Pressure downstram of shock in kPa
t7=1.423 //Temperature ratio after and before the
    shock from gas tables @My_c
Ty_c=Tx_c*t7 //Temperature after the shock in K
```

```
p12=4 //Stagnation pressure after shock to Static pressure before shock from gas tables @Mx_c
Poy_c=Px*p12 //Stagnation pressure after shock in kPa
a9=1.136 //Ratio of area after shock to throat area after shock from gas tables My_c=0.654
At2_c=Ax_c/a9 //Throat area at exit in m^2
a8=A2/At2_c //Ratio of areas
M2_c=0.23 //Exit mach number at section-B from gas tables @a8
p11=0.964 //ratio of exit pressure to stagnation pressure after shock from gas tables
P2_c=p11*Poy_c //exit pressure in kPa
//Sub-division (D)
p13=Poy/Po1 //Pressure ratio , Since Pox=Po1
Mx_d=2.04 //Mach number upstream of shock from gas tables @p13
My_d=0.571 //Mach number downstream of shock from gas tables @p13
p14=4.688 //Static pressure ratio after and before the shock from gas tables @My_d
t8=1.72 //Temperature ratio after and before the shock from gas tables @My_d
p15=5.847 //Stagnation pressure after shock to Static pressure before shock from gas tables @Mx_d
p16=0.120 //Ratio of upstram of shock to stagnation pressures from isentropic tables @Mx_d
Px_d=Po1*p16 //Pressure upstram of shock in kPa
t9=0.546 //Ratio of upstram of shock to stagnation temperature from isentropic gas tables @Mx_d
Tx_d=To1*t9 //Temperature upstram of shock in K
p21=4.688 //Static pressure ratio after and before the shock from gas tables
Py_d=Px_d*p21 //Pressure downstram of shock in kPa
t12=1.72 //Ratio of upstram of shock to stagnation temperature from isentropic gas tables
Ty_d=Tx_d*t12 //Temperature after the shock in K
```

```
a9=1.745 //Ratio of area before shock to throat area
    from isentropic gas tables
Ax_d=At*a9*10^4 //Area before shock in cm^2
a10=1.226 //Ratio of area after shock to throat area
    after shock from isentropic tables @My_d
At2_d=(Ax_d/a10) //Throat area at exit in cm^2
a11=A2/At2_d //Ratio of areas
M2_d=0.29 //Exit mach number at section-B from gas
   tables @a11
p17=0.943 //ratio of exit pressure to stagnation
   pressure after shock from gas tables
P2_d=p17*Poy //exit pressure in kPa
//Sub-division (e)
a12=Ax/At //Ratio of areas
Mx_e=2.62 //Mach number upstream of shock from gas
   tables @a12
t10=0.421 //Ratio of upstram of shock to stagnation
   temperature from isentropic gas tables
Tx_e=To1*t10 //Temperature upstram of shock in K
p18=0.0486 //Ratio of upstram of shock to stagnation
    pressures from isentropic tables @Mx_e
Px_e=p18*Po1 //Pressure upstram of shock in kPa
My_e=0.502 //Mach number downstream of shock from
   gas tables @Mx_e
p19=7.842 //Static pressure ratio after and before
   the shock from gas tables @My_e
Py_e=Px_e*p19 //Pressure downstram of shock in kPa
P2_e=Py_e //Exit pressure in kPa
t11=2.259 //Temperature ratio after and before the
   shock from gas tables @My_d
Ty_e=Tx_e*t11 //Temperaure downstram of shock in K
T2_e=Ty_e //Exit temperature in K

//Output
printf('At throat:\n    Mass flow rate is %3.2f kg/s
   \n    Area at throat is %3.5f m^2\n    Pressure
   is %3i kPa\n    Temperature is %3.1f K\n
   Velocity is %3.1f m/s\n (a)At section (A):\n
```

```
Pressure upstream is %3i kPa\n    Temperature
upstream is %3.1f K\n    Mack number downstream
is %3.2f\n    Pressure downstream is %3.3f kPa\n
    Temperature downstream is %3.3f K\n
Stagnation pressure downstream is %3.1f kPa\n
Area is %3.3f cm^2\n  At exit:\n    Mach number
is %3.1f\n    Pressure is %3.1f kPa\n (b)At
section (B):\n    Pressure upstream is %3i kPa\n
    Temperature upstream is %3.1f K\n    Mack
number upstream is %3.1f\n    Mack number
downstream is %3.3f\n    Pressure downstream is
%3.2f kPa\n    Temperature downstream is %3.2f K\
n    Stagnation pressure downstream is %3.1f kPa\
n    Area is %3.3f cm^2\n  At exit:\n    Mach
number is %3.2f\n    Pressure is %3.1f kPa\n (c)
At section (C):\n    Area upstream is %3.2f cm^2\
n    Temperature upstream is %3.1f K\n    Mack
number upstream is %3.2f\n    Mack number
downstream is %3.3f\n    Pressure downstream is
%3.2f kPa\n    Temperature downstream is %3.2f K\
n    Stagnation pressure downstream is %3i kPa\n
    Area is %3.4f cm^2\n  At exit:\n    Mach
number is %3.2f\n    Pressure is %3.1f kPa\n (d)
At section (D):\n    Pressure upstream is %3i kPa
\n    Temperature upstream is %3.1f K\n    Area
upstream is %3.3f cm^2\n    Mack number upstream
is %3.2f\n    Mack number downstream is %3.2f\n
    Pressure downstream is %3.2f kPa\n
Temperature downstream is %3.2f K\n    Area is %3
.3f cm^2\n  At exit:\n    Mach number is %3.2f\n
    Pressure is %3.2f kPa\n (e)At section (E):\n
    Pressure upstream is %3.1f kPa\n
Temperature upstream is %3.1f K\n    Mack number
upstream is %3.2f\n    Mack number downstream is
%3.3f\n    Pressure downstream is %3.1f kPa\n
Temperature downstream is %3.2f K\n  At exit:\n
    Temperature is %3.2f K\n    Pressure is %3.1f
kPa\n',m,At,Pt,Tt,Ct,Px_a,Tx_a,My_a,Py_a,Ty_a,
```

```
Poy_a,At2_a,M2_a,P2_a,Px_b,Tx_b,Mx_b,My_b,Py_b,
Ty_b,Poy_b,At2_b,M2_b,P2_b,Ax_c,Tx_c,Mx_c,My_c,
Py_c,Ty_c,Poy_c,At2_c,M2_c,P2_c,Px_d,Tx_d,Ax_d,
Mx_d,My_d,Py_d,Ty_d,At2_d,M2_d,P2_d,Px_e,Tx_e,
Mx_e,My_e,Py_e,Ty_e,T2_e,P2_e)
```

Scilab code Exa 5.14 To estimate the difference in mercury in limbs of U tube manometer at various velocities

```
clc
clear

//Input data
T=300 //Temperature in K
P=1.01325*10^5 //Absolute pressure in Pa
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K
C_1=60 //Velocity of air in m/s
C_2=200 //Velocity of air in m/s
C_3=500 //Velocity of air in m/s
d_hg=13600 //Density of mercury in kg/m^3
g=9.81 //Acceleration due to gravity in m/s^2

//Calculation
a=sqrt(k*R*T) //Sound velocity in m/s
M_1=C_1/a //Mach number
dP1=(P*C_1^2)/(2*R*T) //Difference in mercury levels in Pa
dP1_hg=(dP1/(d_hg*g))*1000 //Difference in mercury levels in mm of Hg
M_2=C_2/a //Mach number
p1=(1+((k-1)/2)*M_2^2)^(k/(k-1)) //Stagnation to static pressure ratio
Po=p1*P //Stagnation pressure in Pa
dP2=abs(Po-P) //Difference in mercury levels in Pa
```

```
dP2_hg=(dP2/(d_hg*g))*1000 //Difference in mercury levels in mm of Hg
M_3=C_3/a //Mach number & M_3=Mach number just before shock
My=0.723 //Mach number just after shock
p1=2.2530 //Ratio of pressure after shock to before shock from gas tables @My
Py=p1*P //Pressure after shock in Pa
p2=0.706 //Ratio of pressure after shock to Stagnation pressure from gas tables @My
Po=Py/p2 //Stagnation pressure in Pa
dP3=Po-Py //Difference in mercury levels in Pa
dP3_hg=(dP3/(d_hg*g))*1000 //Difference in mercury levels in mm of Hg

//Output
printf('Difference in mercury levels at velocity equal to:\n    (A)%2i m/s is %3.3f mm of Hg\n    (B)%3i m/s is %3.1f mm of Hg\n    (C)%3i m/s is %3i mm of Hg',C_1,dP1_hg,C_2,dP2_hg,C_3,dP3_hg)
```

Scilab code Exa 5.15 To estimate Mach number and properties across the normal shock of tube

```
clc
clear

//Input data
Px=16 //Pressure before the shock in kPa
Poy=70 //Stagnation pressure after shock in kPa
To=300+273 //Stagnation temperature in K
k=1.4 //Adiabatic constant

//Calculation
p1=Poy/Px //Pressure ratio
```

```
Mx=1.735 //Mach number upstream of shock
My=0.631 //Mach number downstream of shock
p2=0.84 //Ratio of stagnation pressures after and before shock from gas tables
t1=1.483 //Temperature ratio after and before shock from gas tables
Tx=To/(1+((k-1)/2)*Mx^2) //Temperature upstream of shock in K
Ty=Tx*t1 //Temperature downstream of shock in K
Pox=Poy/p2 //Stagnation pressure before shock in kPa

//Output
printf('(A)Mach number of the tunnal is Mx=%3.3f (My=%3.3f)\n (B)Upstream of the tube:\n     Static temperature is %3i K\n     Total pressure is %3.1f kPa\n (C)Downstream of the tube:\n     Static temperature is %3i K\n     Total pressure is %3i kPa',Mx,My,Tx,Pox,Ty,Poy)
```

Scilab code Exa 5.16 To find Mach number and velocity in pitot tube

```
clc
clear

//Input data
Py=455 //Pressure downstream of shock in kPa
Ty=65+273 //Temperature downstream of shock in K
dP=65 //Difference between dynamic and static pressure in kPa
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
Poy=dP+Py //Stagnation pressure after shock in kPa
p1=Py/Poy //Pressure ratio
```

```
My=0.44 //Mach number downstream of shock from
    isentropic gas tables @p1
Mx=3.8 //Mach number upstream of shock from normal
    shock gas tables @My
t1=3.743 //Temperature ratio after and before the
    shock from gas tables @My
Tx=Ty/t1 //Temperature before the shock in K
ax=sqrt(k*R*Tx) //Velocity of sound before the shock
     in m/s
Cx=Mx*ax //Air Velocity before the shock in m/s

//Output
printf('(A)Mach number is Mx=%3.1f (My=%3.2f)\n (B)
    Velocity is %3.2f m/s',Mx,My,Cx)
```

Scilab code Exa 5.17 To find shock speed and air velocity inside the shock

```
clc
clear

//Input data
k=1.4 //Adiabatic constant
Px=1.01325 //Pressure before the shock in bar
Tx=15+273 //Temperature before the shock in K
Py=13.789 //Pressure just after the shock in bar
R=287 //Specific gas constant in J/kg-K

//Calculation
p1=Py/Px //Pressure ratio
Mx=3.47 //Mach number upstream of shock from normal
    shock gas tables @p1
My=0.454 //Mach number downstream of shock from
    isentropic gas tables @p1
t1=3.213 //Temperature ratio after and before the
    shock from gas tables @Mx
```

```
Ty=Tx*t1 //Temperature downstream of shock in K
p2=15.574 //Stagnation pressure after shock to
    Static pressure before shock from gas tables @Mx
Poy=Px*p2 //Stagnation pressure after shock in bar
ax=sqrt(k*R*Tx) //Velocity of sound before the shock
     in m/s
Cx=Mx*ax  //Velocity of air before the shock in m/s
Csh=Cx //Since Csh=Cx, see dig.
ay=sqrt(k*R*Ty) //Velocity of sound after the shock
    in m/s
Cy=My*ay //Velocity of air after the shock in m/s
C_y=Cx-Cy //Air velocity just inside the shock in m/
    s
P_y=Py //Pressure of air in bar, Since a powerful
    explosion creates a brief but intense blast wind
    as it passes
a_y=sqrt(k*R*Ty) ////Velocity of sound after the
    shock in m/s
M_y=C_y/a_y //Mach number

//Output
printf('(A)Shock speed is %3.2f m/s\n (B)Air
    velocity just inside the shock is %3.2f m/s',Cx,
    C_y)
```

Scilab code Exa 5.18 To compute speed of wave pressure and temperature of air at rest

```
clc
clear

//Input data
T=300 //Temperature in K
P=1.5 //Pressure in bar
C_y=150 //Air velocity just inside the shock in m/s
```

```
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
ax=sqrt(k*R*T) //Velocity of sound before the shock
    in m/s
Mx=sqrt(((C_y*(k+1))/(2*ax))+1) //Mach number before
     the shock
My=0.79 ////Mach number after the shock from normal
    shock gas tables
Cx=Mx*ax //Velocity of gas before the shock in m/s
p1=1.775 //Stagnation pressure ratio after and
    before the shock from gas tables @My
Py=P*p1 //Pressure just after the shock in bar
t1=1.1845 //Temperature ratio after and before the
    shock from gas tables @My
Ty=T*t1 //Temperature ratio after the shock in K
ay=sqrt(k*R*Ty) //Velocity of sound after the shock
    in m/s
Csh=My*ay //Speed of the wave in m/s

//Output
printf('(A)Speed of the wave is %3.1f m/s\n (B)At
    rest condition:\n     Pressure is %3.4f bar\n
    Temperature is %3.2f K',Csh,Py,Ty)
```

Scilab code Exa 5.19 To find Mach number pressure temperature at exit and diffuser efficiency

```
clc
clear

//Input data
Mx=2 //Mach number before the shock
a1=3 //Diffuser area ratio
```

```
Pox=0.1 //Stagnation pressure before shock in bar
Tx=300 //Temperature before the shock in K
k=1.4 //Adiabatic constant

//Calculation
t1=0.555 //Static to stagnation temperature ratio before shock from isentropic gas tables @Mx,k=1.4
Tox=Tx/t1 //Stagnation temperature before shock in K
p1=0.128 //Static to stagnation pressure ratio before shock from isentropic gas tables @Mx,k=1.4
Px=Pox*p1 //Pressure before the shock in bar
My=0.577 //Mach number after the shock
p2=4.5 //Pressure ratio after and before the shock from gas tables @Mx
Py=Px*p2 //Pressure just after the shock in bar
t2=1.687 //Temperature ratio after and before the shock from gas tables @Mx
Ty=Tx*t2 //Temperature ratio after the shock in K
p3=0.721 //Stagnation pressure ratio after and before shock from gas tables @Mx
Poy=Pox*p3 //Stagnation pressure after shock in kPa
a2=1.2195 //Ratio of area after shock to throat area after shock from gas tables @My
a3=a2*a1 //Ratio of exit area to throat area at exit
M2=0.16 //Exit mach number from gas tables @a3
t3=0.9946 //Static to stagnation temperature ratio at exit from isentropic gas tables @Mx
T2=Tox*t3 //Exit Temperature in K, Since Tox=Toy=T02 in case of diffuser
p4=0.982 //Static to stagnation pressure ratio at exit from isentropic gas tables @Mx
P2=Poy*p4 //Exit pressure in bar, Calculation mistake in textbook
eff=((((Tox/Tx)*(Poy/Pox)^((k-1)/k))-1)/(((k-1)/2)*Mx^2))*100 //Diffuser efficiency including shock in percent

//Output
```

```
printf('(A)At the diffuser exit:\n    Mach number is %3.2f\n    Pressure is %3.3f bar\n    Temperature is %3.2f K\n (B)Diffuser efficiency including shock is %3.3f percent',M2,P2,T2,eff)
```

Scilab code Exa 5.20 To find length of duct across shock mass flow rate entropy change across and downstream of shock

```
clc
clear

//Input data
k=1.3 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K
P1=1 //Inlet pressure in bar
T1=400 //Inlet temperature in K
D=0.3 //Duct diameter in m
M1=2 //Mach number at entry
Mx=1.5 //Mach number upstream of shock
M2=1 //Mach number at outlet
f=0.003 //Friction factor

//Calculation
d1=P1*10^5/(R*T1) //Density at inlet in kg/m^3
a1=sqrt(k*R*T1) //Velocity of sound at inlet in m/s
C1=M1*a1 //Gas velocity at inlet in m/s
A1=%pi*D^2/4 //Inlet Area of the duct in m^2
m=d1*C1*A1 //Mass flow rate in kg/s
p1=0.131 //Static to Stagnation pressure ratio at entry from gas tables (M1,k=1.4,isentropic)
Po1=P1/p1 //Stagantion pressure at inlet in bar
t1=0.625 //Static to Stagnation temperature ratio at entry from gas tables (M1,k=1.4,isentropic)
To1=T1/t1 //Stagnation temperature at inlet in K
p2=0.424 //Static to Critical pressure ratio at
```

```
inlet from gas tables,fanno flow tables @M1,k=1.4
Pt1=P1/p2 //Critical pressure in bar
p3=1.773 //Stagnation pressure ratio at entry to critical state from gas tables,fanno flow tables @M1,k=1.4
Pto1=Po1/p3 //Stagnation pressure at critical state in bar
t2=0.719 //Static to Critical temperature ratio at inlet from gas tables,fanno flow tables @M1,k=1.4
Tt1=T1/t2 //Critical temperature in K
X1=0.357 //frictional constant fanno parameter from gas tables,fanno flow tables @M1,k=1.4
p4=0.618 //Ratio of Static pressure before shock to critical pressure at entry from gas tables (fanno flow,Mx,k=1.4)
Px=Pt1*p4 //pressure before shock in bar
t3=0.860 //Ratio of Static temperature before shock to critical temperature at entry from gas tables (fanno flow,Mx,k=1.4)
Tx=Tt1*t3 //Temperature before shock in K
p5=1.189 //Ratio of Stagnation pressure before shock to Stagnation pressure at critical state at entry from gas tables (fanno flow,Mx,k=1.4)
Pox=Pto1*p5 //Stagnation pressure at critical state in bar
Xx=0.156 //frictional constant fanno parameter from gas tables,fanno flow tables @Mx,k=1.4
X3=X1-Xx //Overall frictional constant fanno parameter upstream of duct
L1=(X3*D)/(4*f) //Length upstream of duct in m
My=0.7 //Mach number downstream of shock from gas tables @Mx
p6=2.413 //Static pressure ratio after and before the shock from gas tables @My
Py=Px*p6 //Pressure after shock in bar
t4=1.247 //Temperature ratio after and before the shock from gas tables @My
Ty=Tx*t4 //temperature after shock in K
```

```
p7=0.926 //Stagnation pressure ratio after and
    before the shock from gas tables @My
Poy=Pox*p7 //Stagnation pressure after shock in bar
p8=1.479 //Ratio of pressure after shock to pressure
     at critical state from gas tables @My
Pt=Py/p8 //Critical pressure in bar
p9=1.097 //Ratio of Stagnation pressure after shock
    to Stagnation pressure at critical state from gas
     tables @My
Pot=Poy/p9 //Stagnation pressure at critical state
    in bar
t5=1.071 //Ratio of temperature after shock to
    temperature at critical state from gas tables @My
Tt=Ty/t5 //Critical temperature in K
Xy=0.231 //frictional constant fanno parameter from
    gas tables ,fanno flow tables @My,k=1.4
X2=0 //frictional constant fanno parameter from gas
    tables ,fanno flow tables @M=1,k=1.4
X4=Xy-X2 //Overall frictional constant fanno
    parameter downstream of duct
L2=(X4*D)/(4*f) //Length downstream of duct in m
ds1=R*log(Po1/Pox) //Change of entropy upstream of
    the shock in J/kg-K
ds2=R*log(Pox/Poy) //Change of entropy across the
    shock in J/kg-K
ds3=R*log(Poy/Pot) //Change of entropy downstream of
     the shock in J/kg-K

//Output
printf('(A)Length of the duct upstream and
    downstream of the duct is %3.3f m and %3.3f m
    respectively\n (B)Mass flow rate of the gas is %3
    .3f kg/s\n (C)Change of entropy:\n    Upstream of
     the shock is %3.2f J/kg-K\n    Across the shock
    is %3.3f J/kg-K\n    Downstream of the shock is
    %3.4f J/kg-K',L1,L2,m,ds1,ds2,ds3)
```

Scilab code Exa 5.21 To find length across the shock properties of air at exit and mass flow rate through the duct

```
clc
clear

//Input data
P1=0.685 //Inlet pressure in bar
T1=310 //Inlet temperature in K
D=0.6 //Duct diameter in m
M1=3 //Mach number at entry
Mx=2.5 //Mach number upstream of shock
M2=0.8 //Mach number at outlet
f=0.005 //Friction factor
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
d1=P1*10^5/(R*T1) //Density at inlet in kg/m^3
a1=sqrt(k*R*T1) //Velocity of sound at inlet in m/s
C1=M1*a1 //Air velocity at inlet in m/s
A1=%pi*D^2/4 //Inlet Area of the duct in m^2
m=d1*C1*A1 //Mass flow rate in kg/s
p1=0.218 //Static to Critical pressure ratio at
    inlet from gas tables,fanno flow tables @M1,k=1.4
Pt1=P1/p1 //Critical pressure in bar
t1=0.428 //Static to Critical temperature ratio at
    inlet from gas tables,fanno flow tables @M1,k=1.4
Tt1=T1/t1 //Critical temperature in K
X1=0.522 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.4
p2=0.292 //Ratio of Static pressure before shock to
    critical pressure at entry from gas tables (fanno
     flow,Mx,k=1.4)
```

```
Px=Pt1*p2 //pressure before shock in bar
t2=0.533 //Ratio of Static temperature before shock to critical temperature at entry from gas tables (fanno flow ,Mx, k=1.4)
Tx=Tt1*t2 //Temperature before shock in K
Xx=0.432 //frictional constant fanno parameter from gas tables ,fanno flow tables @Mx, k=1.4
X3=X1-Xx //Overall frictional constant fanno parameter upstream of duct
L1=(X3*D)/(4*f) //Length upstream of duct in m
My=0.513 //Mach number downstream of shock from gas tables @Mx
p3=7.125 //Static pressure ratio after and before the shock from gas tables @My
Py=Px*p3 //Pressure after shock in bar
t3=2.138 //Temperature ratio after and before the shock from gas tables @My
Ty=Tx*t3 //temperature after shock in K
p4=2.138 //Ratio of pressure after shock to pressure at critical state from gas tables @My
Pt=Py/p4 //Critical pressure in bar
t4=1.143 //Ratio of temperature after shock to temperature at critical state from gas tables @My
Tt=Ty/t4 //Critical temperature in K
p5=1.289 //Ratio of pressure at exit to pressure at critical state from gas tables @M2
P2=Pt*p5 //Exit pressure in bar
t5=1.064 //Ratio of temperature at exit to temperature at critical state from gas tables @M2
T2=Tt*t5 //Exit temperature in K
Xy=1.069 //frictional constant fanno parameter from gas tables ,fanno flow tables @My, k=1.4
X2=0.073 //frictional constant fanno parameter from gas tables ,fanno flow tables @M2, k=1.4
X4=Xy-X2 //Overall frictional constant fanno parameter downstream of duct
L2=(X4*D)/(4*f) //Length downstream of duct in m

```

```
//Output
printf('(A)Length L1 and L2 are %3.1f m and %3.2f m
    respectively\n (B)State of air at exit:\n
    Pressure is %3.3f bar\n     Temperature is %3.1f K
    \n (C)Mass flow rate through the duct is %3.2f kg
    /s',L1,L2,P2,T2,m)
```

Scilab code Exa 5.22 To find properties after shock and exit and exit Mach number

```
clc
clear

//Input data
At=24 //Throat area in cm^2
A2=50 //Exit area in cm^2
Po=700 //Stagnation pressure in kPa
To=100+273 //Stagnation temperature in K
Ax=34 //Area before the shock in cm^2
Ay=34 //Area after the shock in cm^2

//Calculation
a1=Ax/At //Ratio of areas
Mx=1.78 //Mach number upstream of shock from gas
    tables @a1
t1=0.61212 //Ratio of temperature before shock to
    critical state from isentropic gas tables @Mx
Tx=To*t1  //temperature before shock in K
p1=0.179 //Ratio of pressure before shock to
    critical state from isentropic gas tables @Mx
Px=Po*p1 //pressure before shock in kPa
My=0.621 //Mach number downstream of shock from gas
    tables @Mx
p2=3.5298 //Static pressure ratio after and before
    the shock from gas tables @My
```

```
Py=Px*p2 //Pressure after shock in kPa
t2=1.51669 //Temperature ratio after and before the
    shock from gas tables @My
Ty=Tx*t2 //temperature after shock in K
p3=4.578 //Ratio of Stagnation pressure after the
    shock to static pressure before shock from gas
    tables @My
Po2=Px*p3 //Stagnation pressure at exit in bar
a2=1.16565 //Ratio of area after shock to critical
    area across shock from isentropic gas tables @My
At2=Ay/a2 //critical area at exit in cm^2
a3=A2/At2 //Ratio of areas
M2=0.36 //Exit mach number from gas tables (a3,k
    =1.4,isentropic)
p4=0.914 //Static to Stagnation pressure ratio at
    exit from gas tables (a3,k=1.4,isentropic)
P2=Po2*p4 //Stagnation pressure ratio at exit in kPa
t3=0.975 //Static to Stagnation temperature ratio at
     exit from gas tables (a3,k=1.4,isentropic)
T2=To*t3 //Stagnation temperature at exit in K

//Output
printf('(A)Properties of fluid just after shock:\n
       Mach number My=%3.3f\n     Temperature is %3.2f
     K\n     Pressure is %3.2f kPa\n (B)Exit mach
    number is %3.2f\n (C)Properties of fluid at exit
    :\n     Pressure is %3i kPa\n     Temperature is %3
    .3f K',My,Ty,Py,M2,P2,T2)
```

Scilab code Exa 5.23 To find length diameter of pipe and properties at pipe exit

```
clc
clear

```

```
//Input data
D=0.4 //Duct diameter in m
Po=12 //Stagnation pressure in kPa
To=600 //Stagnation temperature in K
f=0.0025 //Friction factor
M1=1.8 //Mach number at entry
M2=1 //Mach number at outlet
Mx=1.22 //Mach number upstream of shock

//Calculations
A2=%pi*D^2/4 //Exit area in cm^2
p1=0.174 //Static to Stagnation pressure ratio at
    entry from gas tables (M1,k=1.4,isentropic)
P1=Po*p1 //Inlet pressure in bar
t1=0.607 //Static to Stagnation temperature ratio at
     entry from gas tables (M1,k=1.4,isentropic)
T1=To*t1 //Inlet temperature in K
a1=1.094 //Ratio of area at exit to critical area
    across shock from isentropic gas tables @M1,k=1.4
Ax=A2/a1 //Area before the shock in cm^2
Dt=sqrt((Ax*4)/(%pi))*10^2 //Duct diameter at throat
     in cm
p2=0.474 //Static to Critical pressure ratio at
    inlet from gas tables,fanno flow tables @M1,k=1.4
Pt=P1/p2 //Critical pressure in bar
t2=0.728 //Static to Critical temperature ratio at
    inlet from gas tables,fanno flow tables @M1,k=1.4
Tt=T1/t2 //Critical temperature in K
X1=0.242 //frictional constant fanno parameter from
    gas tables,fanno flow tables @M1,k=1.4
p3=0.788 //Ratio of Static pressure before shock to
    critical pressure at entry from gas tables (fanno
     flow,Mx,k=1.4)
Px=Pt*p3 //pressure before shock in bar
t3=0.925 //Ratio of Static temperature before shock
    to critical temperature at entry from gas tables
    (fanno flow,Mx,k=1.4)
Tx=Tt*t3 //Temperature before shock in K
```

```
Xx=0.039 //frictional constant fanno parameter from
    gas tables,fanno flow tables @Mx,k=1.4
X3=X1-Xx //Overall frictional constant fanno
    parameter upstream of duct
L1=(X3*D)/(4*f) //Length upstream of duct in m
My=0.83 //Mach number downstream of shock from gas
    tables @Mx
p4=1.57 //Static pressure ratio after and before the
     shock from gas tables @My
Py=Px*p4 //Pressure after shock in bar
t4=1.141 //Temperature ratio after and before the
    shock from gas tables @My
Ty=Tx*t4 //temperature after shock in K
p5=1.2375 //Ratio of pressure after shock to
    pressure at critical state from gas tables @My
Pt=Py/p5 //Critical pressure in bar
t5=1.055 //Ratio of temperature after shock to
    temperature at critical state from gas tables @My
Tt=Ty/t5 //Critical temperature in K
Xy=0.049 //frictional constant fanno parameter from
    gas tables,fanno flow tables @My,k=1.4
X2=0 //frictional constant fanno parameter from gas
    tables,fanno flow tables @M=1,k=1.4
X4=Xy-X2 //Overall frictional constant fanno
    parameter downstream of duct
L2=(X4*D)/(4*f) //Length downstream of duct in m
L=L1+L2 //Length of duct in m

//Output
printf('(A)Length of the pipe is %3.2f m\n (B)
    Diameter of the nozzle throat is %3.3f cm\n (C)At
     the pipe exit:\n     Pressure is %3.3f bar\n
    Temperature is %3.2f K',L,Dt,Pt,Tt)
```

Scilab code Exa 5.24 To estimate amount of heat added in two pipe section and properties

```
clc
clear

//Input data
Po=700 //Stagnation pressure in kPa
To=500+273 //Stagnation temperature in K
a1=3.5 //Ratio of exit area to throat area
m=5.5 //Mass flow rate in kg/s
Cp=1.005 //Specific heat capacity at constant
    pressure in kJ/kg-K
k=1.4 //Adiabatic constant

//Calculation
My=1/sqrt(k) //Mach number downstream of shock
M2=2.8 //Mach number at outlet from gas tables @a1
t1=0.389 //Static to Stagnation temperature ratio at
     exit from gas tables (M1,k=1.4,isentropic)
T2=To*t1 //Exit temperature in K
p1=0.0369 //Static to Stagnation pressure ratio at
    exit from gas tables (M1,k=1.4,isentropic)
P2=Po*p1 //exit pressure in kPa
p2=0.2  //Ratio of pressure at exit to pressure at
    critical state at exit from Rayleigh flow gas
    tables @M2
Pt2=P2/p2 //Exit pressure at critical state in kPa
t2=0.315 //Ratio of temperature at exit to
    temperature at critical state at exit from
    Rayleigh flow gas tables @M2
Tt2=T2/t2 //Exit temperature at critical state in K
t3=0.674 //Ratio of Stagnation temperature at exit
    to stagnation temperature at critical state at
    exit from Rayleigh flow gas tables @M2
Tto2=To/t3 //Exit stagnation temperature at critical
     state in K
Mx=1.2 //Mach number upstream of shock from gas
```

```
tables @My
p3=0.796 //Ratio of Static pressure before shock to critical pressure at exit from gas tables (Rayleigh flow ,Mx, k=1.4)
Px=Pt2*p3 //Static pressure before shock in kPa
t4=0.912 //Ratio of Static temperature before shock to critical temperature at exit from gas tables (Rayleigh flow ,Mx, k=1.4)
Tx=Tt2*t4 //Static temperature before shock in K
t5=0.978 //Ratio of Stagnation temperature before shock to critical Stagnation temperature at exit from gas tables (Rayleigh flow ,Mx, k=1.4)
Tox=Tto2*t5 //Stagnation temperature before shock in K
p4=1.513 //Static pressure ratio after and before the shock from gas tables @Mx
Py=Px*p4 //Pressure after shock in kPa
t6=1.128 //Temperature ratio after and before the shock from gas tables @Mx
Ty=Tx*t6 //temperature after shock in K
t7=0.875 //Ratio of Temperature after the shock to Stagnation temperature after shock from gas tables @Mx
Toy=Ty/t7 //Stagnation temperature after shock in K,
p5=1.207 //Ratio of pressure after shock to pressure at critical state from gas tables @My
Pt=Py/p5 //Critical pressure in kPa
t8=1.028 //Ratio of temperature after shock to temperature at critical state from gas tables @My
Tt=Ty/t8 //Critical temperature in K
t9=0.978 //Ratio of Stagnation temperature after shock to Stagnation temperature at critical state from gas tables @My
Tot=Toy/t9 //Stagnation temperature at critical state in K, calculation mistake in textbbok
q1=Cp*(Tox-To) //Amount of heat added in upstream of shock in kJ/s
q2=Cp*(Tot-Toy) //Amount of heat added in downstream
```

```
of shock in kJ/s
Q=m*(q1+q2) //Amount of heat added in two pipe section in kJ/s

//Output
printf('(A)Amount of heat added in two pipe section is %3.2f kJ/s\n (B)Properties:\n Upstream of shock:\n     Pressure is %3.1f kPa\n     Temperature is %3.3f K\n     Stagnation temperature is %3.2f K\n     Mach number is %3.1f\n Downstream of shock:\n     Pressure is %3.3f kPa\n     Temperature is %3.3f K\n     Stagnation temperature is %3.1f K\n     Mach number is %3.3f\n At the throat:\n     Pressure is %3.2f kPa\n     Temperature is %3.3f K\n     Stagnation temperature is %3.2f K\n At the exit:\n     Pressure is %3.2f kPa\n     Temperature is %3.2f K\n     Mach number is %3.2f',Q,Px,Tx,Tox,Mx,Py,Ty,Toy,My,Pt,Tt,Tot,P2,T2,M2)
```

Scilab code Exa 5.25 To find deflection angle Downstream Mach number Static pressure and total pressure loss through the shock

```
clc
clear

//Input data
M1=2.8 //Inlet mach number
sig=42 //Shock wave angle in degree
Px=1 //Pressure upstream of shock in bar(Assuming)
k=1.4 //Adiabatic constant

//Calculations
Mx=M1*sind(sig) //Mach number before the shock
My=0.601 //Mach number after the shock from gas
```

```
    tables @Mx
p1=3.98 //Static pressure ratio after and before the
     shock from gas tables @Mx
Py=Px*p1 //Pressure after shock in bar
p2=4.994 //Stagnation pressure after shock to Static
     pressure before shock from gas tables @Mx
Poy=Px*p2 //Stagnation pressure after shock in bar
p3=0.788 //Stagnation pressure ratio after and
    before the shock from gas tables @Mx
Pox=Poy/p3 //Stagnation pressure before shock in kPa
dPl=Pox-Poy //Total pressure loss in bar
def=atand(((M1^2*sind(2*sig))-(2/tand(sig)))/(2+(M1
    ^2*(k+cosd(2*sig))))) //Deflection angle in
    degree
M2=My/(sind(sig-def)) //Downstream mach number

//Output
printf('(A)Deflection angle is %3i degree\n (B)
    Downstream mach number is %3.3f\n (C)Static
    pressure is %3.3f bar\n (D)Total pressure loss is
     %3.3f bar',def,M2,Py,dPl)
```

Scilab code Exa 5.26 To determine static pressure temperature behind wave Mach number and Wedge angle

```
clc
clear

//Input data
M1=2 //Inlet mach number
sig=40 //Shock wave angle in degree
Px=0.5 //Pressure upstream of shock in bar
Tx=273 //Temperature upstream of shock in K
k=1.4 //Adiabatic constant

```

```
//Calculation
Mx=M1*sind(sig) //Mach number before the shock
My=0.796 //Mach number after the shock from gas tables @Mx
p1=1.745 //Static pressure ratio after and before the shock from gas tables @Mx
Py=p1*Px //Pressure after shock in bar
t1=1.178 //Static temperature ratio after and before the shock from gas tables @Mx
Ty=Tx*t1 //Temperature after shock in K
Ws=atand(((M1^2*sind(2*sig))-(2/tand(sig)))/(2+(M1^2*(k+cosd(2*sig))))) //Wedge semi angle in degree
W=2*Ws //Wedge angle in degree

//Output
printf('(A)Static pressure is %3.4f bar\n (B) Temperature behind the wave is %3.2f K\n (C)Mach number of flow passing over wedge is %3.3f\n (D) Wedge angle is %3.2f degree',Py,Ty,Mx,W)
```

Scilab code Exa 5.27 To find property ratios at strong and weak shock at wedge

```
clc
clear

//Input data
def=15
M1=2
k=1.4

//Calculation
//Using relation def=atand(((M1^2*sind(2*sig))-(2/tand(sig)))/(2+(M1^2*(k+cosd(2*sig))))) and
```

```
converting into 6th degree polynomial of sind(sig)=x
C=((2*tand(def))+((M1^2)*k*tand(def))+((M1^2)*tand(def))) //Constant value for convenience
D=(2*M1^2*tand(def)) //Constant value for convenience
a=4 //Value of constant in polynomial
b=0 //Coefficient of power 1 i.e. x^1
c=(4+C^2+(8*M1^2)) //Coefficient of power 2 i.e. x^2
d=0 //Coefficient of power 3 i.e. x^3
e=(4*(M1^4))+(2*C*D)+(8*M1^2) //Coefficient of power 4 i.e. x^4
f=0 //Coefficient of power 5 i.e. x^5
g=(4*M1^4)+D^2 //Coefficient of power 6 i.e. x^6
p4=poly([a b -c -d e f -g],'x','c') //Expression for solving 6th degree polynomial
disp('Values for sine of wave angle are:\n')
disp(roots(p4))
sig1=asind(0.9842) //Strong shock wave angle in degree, nearer to 90 degree
sig2=asind(0.7113) //Weak shock wave angle in degree, nearer to 45 degree
//(a)Strong Shock Wave
Mx_1=M1*sind(sig1) //Mach number before the shock of stong shock wave
My_1=0.584 //Mach number after the shock from gas tables @Mx_1
p1=4.315 //Static pressure ratio after and before the shock from gas tables @Mx_1
t1=1.656 //Static temperature ratio after and before the shock from gas tables @Mx_1
d1=p1/t1 //Density ratio after and before the shock of stong shock wave
M2_1=My_1/(sind(sig1-def)) //Exit mach number of stong shock wave
Mx_2=M1*sind(sig2) //Mach number before the shock of weak shock wave
My_2=0.731 //Mach number after the shock from gas
```

```
tables @Mx_2
p2=2.186 //Static pressure ratio after and before the shock from gas tables @Mx_2
t2=1.267 //Static temperature ratio after and before the shock from gas tables @Mx_2
d2=p2/t2 //Density ratio after and before the shock of weak shock wave
M2_2=My_2/(sind(sig2-def)) //Exit mach number of weak shock wave

//Output
printf('\nStrong Shock Wave:\n    (A)Wave angle is %3.1f degree\n    (B)Pressure ratio is %3.3f\n    (C)Density ratio is %3.3f\n    (D)Temperature ratio is %3.3f\n    (E)Downstream Mach number is %3.3f\n Weak Shock Wave:\n    (A)Wave angle is %3.1f degree\n    (B)Pressure ratio is %3.3f\n    (C)Density ratio is %3.3f\n    (D)Temperature ratio is %3.3f\n    (E)Downstream Mach number is %3.3f',sig1,p1,d1,t1,M2_1,sig2,p2,d2,t2,M2_2)
```

Scilab code Exa 5.28 To find deflection angle final Mach number and temperature of gas

```
clc
clear

//Input data
k=1.3 //Adiabatic constant
P1=0.345 //Inlet pressure in bar
T1=350 //Inlet temperature in K
M1=1.5 //Inlet mach number
P2=0.138 //Exit pressure in bar

//Calculation
```

```
p1=0.284 //Pressure ratio at entry from gas tables @M1,k=1.3
Po=P1/p1 //Stagnation Pressure in bar
t1=0.748 //Temperature ratio at entry from gas tables @M1,k=1.3
To=T1/t1 //Stagnation temperature in K
p2=P2/Po //Pressure ratio
M2=2.08 //Final Mach number from isentropic gas tables @p2
t2=0.606 //Temperature ratio at exit from gas tables @M2,k=1.3
T2=To*t2 //The temperature of the gas in K
w1=12.693 //Prandtl Merger function at M1
w2=31.12 //Prandtl Merger function at M2
def=w2-w1 //Deflection Angle in degree

//Output
printf('(A)Deflection Angle is %3.3f degree\n (B)Final Mach number is %3.2f\n (C)The temperature of the gas is %3.3f K',def,M2,T2)
```

Chapter 6

Aircraft Propulsion

Scilab code Exa 6.1 To calculate thrust and specific thrust of jet propulsion

```
clc
clear

//Input data
eff_com=0.8 //Compressor efficiency
eff_t=0.85 //Turbine efficiency
pr=4 //Pressure ratio including combustion pressure
    loss(Po2s/Po1)
eff_c=0.98 //Combustion efficiency
eff_m=0.99 //Mechanical transmission efficiency
eff_n=0.9 //Nozzle efficiency
Tmax=1000 //Maximum cycle temperature in K
To3=Tmax //Stagnation temperature before turbine
    inlet in K
w=220 //mass flow rate in N/s
Cp_air=1005 //Specific heat capacity at constant
    pressure in J/kg-K
k=1.4 //Adiabatic constant for air
Cp_gas=1153 //Specific heat capacity at constant
    pressure in J/kg-K
```

```
k_gas=1.3 //Adiabatic constant
To1=15+273 //Inlet Stagnation temperature of
   compressor in K
Po1=1 //Inlet Stagnation pressure in bar
Poe=Po1 //Exit stagnation pressure in bar, Since
   exit at ambient conditions
g=9.81 //Acceleration due to gravity in m/s^2

//Calculation
To2s=To1*(pr)^((k-1)/k) //Exit Stagnation
   temperature of compressor at isentropic process
   in K
To2=((To2s-To1)/eff_com)+To1 //Exit Stagnation
   temperature of compressor in K
Wc=(Cp_air*(To2-To1)) //Work given to compressor in
   J/kg, Cp in J/kg-K
To4=To3-(Wc/Cp_gas*eff_m) //Exit Stagnation
   temperature of turbine in K
To4s=To3-((To3-To4)/eff_t) //Exit Stagnation
   temperature of turbine at isentropic process in K
Po2=Po1*pr //Exit Stagnation pressure of compressor
   in bar
Po3=Po2 //Exit Stagnation pressure of combustion
   chamber in bar, Since the process takes place at
   constant pressure process
p1=(To3/To4s)^(k_gas/(k_gas-1)) //Stagnation
   Pressure ratio of inlet and outlet of turbine
Po4s=Po3/p1 //Stagnation Pressure at outlet of
   turbine at isentropic process in bar
pr_n=Po4s/Poe //Pressure ratio of nozzle
Toes=To4/((pr_n)^((k_gas-1)/k_gas)) //Exit
   Stagnation temperature of nozzle at isentropic
   process in K
Toe=To4-((To4-Toes)*eff_n) //Exit Stagnation
   temperature of nozzle in K
Cj=sqrt(2*Cp_gas*(To4-Toe)) //Jet velocity in m/s
m=w/g //Mass flow rate of air in kg/s
F=m*Cj*10^-3 //Thrust in kN
```

```
Fs=(F*10^3)/m  //Specific thrust in Ns/kg, F in N
Is=F/w //Specific impulse in sec

//Output
printf('(A)Thrust is %3.3f kN\n (B)Specific thrust is %3.2f Ns/kg',F,Fs)
```

Scilab code Exa 6.2 To find thrust developed thrust power and propulsive efficiency

```
clc
clear

//Input data
u=800*(5/18) //Flight velocity in m/s
Pe=60 //Ambient pressure in kPa
Pn=300 //Pressure entering nozzle in kPa
Tn=200+273 //Temperature entering nozzle in K
m=20 //Mass flow rate of air in kg/s
Cp=1005 //Specific heat capacity at constant pressure in J/kg-K
k=1.4 //Adiabatic constant for air

//Calculation
Te=Tn*(Pe/Pn)^((k-1)/k) //Exit temperature of nozzle in K
Cj=sqrt(2*Cp*(Tn-Te)) //Jet velocity in m/s
F=m*(Cj-u) //Thrust in N
P=F*u*10^-3 //Thrust power in kW
eff=((2*u)/(Cj+u))*100 //Propulsive efficiency in percent


//Output
printf('(A)Thrust developed is %3.1f N\n (B)Thrust
```

```
    developed is %3.2f kW\n (C)Propulsive efficiency
    is %3.3f percent',F,P,eff)
```

Scilab code Exa 6.3 To determine specific thrust and thrust specific fuel consumption for turbojet engine

```
clc
clear

//Input data
Mi=0.8 //Inlet mach number
h=10000 //Altitude in m
pr_c=8 //Pressure ratio of compressor
To3=1200 //Stagnation temperature at turbine inlet
    in K
eff_c=0.87 //Compressor efficiency
eff_t=0.9 //Turbine efficiency
eff_d=0.93 //Diffuser efficiency
eff_n=0.95  //Nozzle efficiency
eff_m=0.99 //Mechanical transmission efficiency
eff_cc=0.98 //Combustion efficiency
pl=0.04 //Ratio of combustion pressure loss to
    compressor delivery pressure
k=1.4 //Adiabatic constant of air
R=287 //Specific gas constant in J/kg-K
k_g=1.33 //Adiabatic constant of gas
Cp_a=1005 //Specific heat capacity at constant
    pressure of air in J/kg-K
Cp_g=1100 //Specific heat capacity at constant
    pressure of gas in J/kg-K
CV=43000000 //Calorific value in J/kg (Assume)

//Calculation
Ti=223.15 //Inlet temperature in K from gas tables
Pi=26.4 //Inlet pressure in kPa from gas tables
```

```
ai=sqrt(k*R*Ti) //Sound velocity in m/s
Ci=ai*Mi //Velocity of air in m/s,
u=Ci //Flight velocity in m/s, Since it is reaction force of Ci
t1=0.886 //Ratio of static to stagnation temperature a entry from gas tables at M=0.8
To1s=Ti/t1 //Stagnation temperature at inlet of compressor at isentropic process in K
To1=((To1s-Ti)/eff_d)+Ti //Stagnation temperature at inlet of compressor in K
p1=(To1s/Ti)^(k/(k-1)) //Pressure ratio i.e. (Po1s/Pi)
Po1s=Pi*p1 //inlet Stagnation pressure of compressor at isentropic process in kPa
Po1=Po1s //Inlet Stagnation pressure of compressor in kPa
Po2=pr_c*Po1 //Exit Stagnation pressure of compressor in kPa
To2s=To1s*(Po2/Po1)^((k-1)/k) //Exit Stagnation temperature of compressor at isentropic process in K
To2=((To2s-To1)/eff_c)+To1 //Exit Stagnation temperature of compressor in K
P_los=pl*Po2 //combustion pressure loss in kPa
Po3=Po2-P_los //Exit Stagnation pressure of combustion chamber in kPa
To4=To3-((Cp_a*(To2-To1))/(eff_m*Cp_g)) //Exit Stagnation temperature of turbine in K
To4s=To3-((To3-To4)/eff_t) //Exit Stagnation temperature of turbine at isentropic process in K
p1=(To3/To4s)^(k_g/(k_g-1)) //Pressure ratio i.e. (Po3/Po4s)
Po4s=Po3/p1 //Stagnation Pressure at outlet of turbine at isentropic process in kPa
Poe=Pi //Exit stagnation pressure in kPa, Since exit is at ambient conditions
pr_n=Po4s/Poe //Pressure ratio of nozzle
Toes=To4/((pr_n)^((k_g-1)/k_g)) //Exit Stagnation
```

```
temperature of nozzle at isentropic process in K
Toe=To4-((To4-Toes)*eff_n) //Exit Stagnation temperature of nozzle in K
Cj=sqrt(2*Cp_g*(To4-Toe)) //Jet velocity in m/s
Fs=Cj-u //Specific thrust in Ns/kg
f=((Cp_g*To3)-(Cp_a*To2))/((eff_cc*CV)-(Cp_g*To3)) //Fuel-air ratio
TSFC=(f/Fs)*10^5 //Thrust specific fuel consumption in kg/s-N x10^-5

//Output
printf('(A)Specific thrust is %3.2f Ns/kg\n (B) Thrust specific fuel consumption is %3.3fx10^-5 kg/s-N',Fs,TSFC)
```

Scilab code Exa 6.4 To estimate properties at exit and propulsive efficiency of a turbojet aircraft

```
clc
clear

//Input data
u=300 //Flight velocity in m/s
Pi=35 //Inlet pressure in kPa
Ti=-40+273 //Inlet temperature in K
pr_c=10 //Pressure ratio of compressor
T3=1100+273 //Inlet turbine temperature in K
m=50 //Mass flow rate of air in kg/s
k=1.4 //Adiabatic constant of air
Cp=1005 //Specific heat capacity at constant pressure of air in J/kg-K
R=287 //Specific gas constant in J/kg-K

//Calculation
ai=sqrt(k*R*Ti) //Sound velocity at diffuser in m/s
```

```
C1=u //Velocity of air in m/s, Since it is reaction force of u
T1=Ti+(C1^2/(2*Cp)) //Temperature at inlet of compressor in K
P1=Pi*((T1/Ti)^(k/(k-1))) //Inlet pressure of compressor in kPa
P2=pr_c*P1 //Exit pressure of compressor in kPa
P3=P2 //Exit pressure of combustion chamber in kPa, Since the process takes place at constant pressure process
T2=T1*(P2/P1)^((k-1)/k) //Exit temperature of compressor in K
T4=T3-(T2-T1) //Exit temperature of turbine in K
P4=P3/((T3/T4)^(k/(k-1))) //Pressure at outlet of turbine in kPa
Pe=Pi //Exit pressure in kPa, Since exit is at ambient conditions
pr_n=P4/Pe //Pressure ratio of nozzle
Te=T4/((pr_n)^((k-1)/k)) //Exit temperature of nozzle in K
Cj=sqrt(2*Cp*(T4-Te)) //Jet velocity in m/s
sig=u/Cj //Jet speed ratio
eff_prop=((2*sig)/(1+sig))*100 //Propulsive efficiency of the cycle in %

//Output
printf('(A)Temperature and pressure of gases at turbine exit is %3.2f K and %3i kPa\n (B)Velocity of gases is %3.2f m/s\n (C)Propulsive efficiency of the cycle is %3.2f percent',T4,P4,Cj,eff_prop)
```

Scilab code Exa 6.5 To calculate absolute velocity drag overall and turbine efficiency of jet

```
clc
clear

//Input data
n=2 //Number of jets
D=0.25 //Diameter of turbojet in m
P=3000 //Net power at turbojet in W
mf_kWh=0.42 //Fuel consumption in kg/kWh
CV=49000 //Calorific value in kJ/kg
u=300 //Flight velocity in m/s
d=0.168 //Density in kg/m^3
AFR=53 //Air fuel ratio

//Calculatioon
mf=mf_kWh*P/3600 //Mass flow rate of fuel in kg/s
ma=AFR*mf //Mass flow rate of air in kg/s
m=ma+mf //Mass flow rate of gas in kg/s
Q=m/d //Volume flow rate in m^3/s
Cj=(Q*4)/(2*%pi*D^2) //Jet velocity in m/s
Ca=Cj-u //Absolute Jet velocity in m/s
F=((m*Cj)-(ma*u))*10^-3 //Thrust in kN
eff=((F*u)/(mf*CV))*100 //Overall efficiency in %
eff_prop=((2*u)/(Cj+u))*100 //Propulsive efficiency of the cycle in %
eff_ther=(eff/eff_prop)*100 //Efficiency of turbine in %

//Output
printf('(A)Absolute velocity of jet is %3.3f m/s\n (B)Resistance of the plane is %3.4f kN\n (C)Overall efficiency is %3.2f percent\n (D)Efficiency of turbine is %3.3f percent',Ca,F,eff,eff_ther)
```

Scilab code Exa 6.6 To Calculate propulsive and thrust power total fuel consumption and propulsive thermal and overall efficiency

```
clc
clear

//Input data
u=900*(5/18) //Flight velocity in m/s
ma=3000/60 //Mass flow rate of air in kg/s
dh=200 //Enthalpy drop of nozzle in kJ/kg
eff_n=0.9 //Nozzle efficiency
AFR=85 //Air fuel ratio
eff_cc=0.95 //Combustion efficiency
CV=42000 //Calorific value in kJ/kg

//Calculation
mf=ma/AFR //Mass flow rate of fuel in kg/s
m=ma+mf //Mass flow rate of gas in kg/s
Cj=sqrt(2*eff_n*dh*10^3) //Jet velocity in m/s
sig=u/Cj //Jet speed ratio
F=((m*Cj)-(ma*u))*10^-3 //Thrust in kN
Pt=F*u //Thrust power in kW
Pp=0.5*((m*Cj^2)-(ma*u^2))*10^-3 //Propulsive power
   in kW
HS=eff_cc*mf*CV //Heat supplied in kW
eff_ther=(Pp/HS)*100 //Efficiency of turbine in %
eff_prop=(Pt/Pp)*100 //Propulsive efficiency of the
   cycle in %
eff=(Pt/HS)*100 //Overall efficiency in %

//Output
printf('(A)Propulsive power is %3.2f kW\n (B)Thrust
   power is %3.1f kW\n (C)Propulsive efficiency is
   %3.3f percent\n (D)Thermal efficiency is %3.2f
   percent\n (E)Total fuel consumption is %3.3f kg/s
   \n (F)Overall efficiency is %3.3f percent',Pp,Pt,
   eff_prop,eff_ther,mf,eff)
```

Scilab code Exa 6.7 To find specific thrust jet velocity TSFC and propulsive thermal and overall efficiency

```
clc
clear

//Input data
M=0.8 //Mach number
CV=42800 //Calorific value in kJ/kg
h=10 //Altitude in km
F=50 //Thrust in kN
ma=45 //Mass flow rate of air in kg/s
mf=2.65 //Mass flow rate of fuel in kg/s

//Calculation
m=ma+mf //Mass flow rate of gas in kg/s
a=299.6 //Sound velocity in m/s, from gas tables
T=233.15 //Inlet temperature in K
u=a*M //Flight velocity in m/s
Cj=((F*10^3)+(ma*u))/m //Jet velocity in m/s
sig=u/Cj //Jet speed ratio
Fs=F*10^3/m //Specific thrust in Ns/kg, F in N
TSFC=mf*3600/(F*10^3) //Thrust specific fuel consumption in kg/N-hr, F in N
Pt=F*u //Thrust power in kW
Pp=0.5*((m*Cj^2)-(ma*u^2))*10^-3 //Propulsive power in kW
HS=mf*CV //Heat supplied in kW
eff_ther=(Pp/HS)*100 //Efficiency of turbine in %
eff_prop=(Pt/Pp)*100 //Propulsive efficiency of the cycle in %
eff=(Pt/HS)*100 //Overall efficiency in %

//Output
```

```
printf('(A)Specific thrust is %3.2f N/kg\n (B)Thrust
    specific fuel consumption is %3.4f kg/N-hr\n (C)
   Jet velocity is %3.3f m/s\n (D)Thermal efficiency
    is %3.2f percent\n (E)Propulsive efficiency is
   %3.3f percent\n (F)Overall efficiency is %3.2f
   percent',Fs,TSFC,Cj,eff_ther,eff_prop,eff)
```

Scilab code Exa 6.8 To calculate fuel air and pressure ratios and Mach number of jet

```
clc
clear

//Input data
Mi=0.8 //Inlet mach number
h=10 //Altitude in km
To3=1200 //Stagnation temperature before turbine
   inlet in K
dTc=175 //Stagnation temperature rise through the
   compressor in K
CV=43000 //Calorific value in kJ/kg
eff_c=0.75 //Compressor efficiency
eff_cc=0.75 //Combustion efficiency
eff_t=0.81 //Turbine efficiency
eff_m=0.98 //Mechanical transmission efficiency
eff_n=0.97 //Nozzle efficiency
Is=25 //Specific impulse in sec
k=1.4 //Adiabatic constant of air
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constant
   pressure of air in J/kg-K
g=9.81 //Acceleration due to gravity in m/s^2

//Calculation
Ti=223.15 //Inlet temperature in K from gas tables
```

```
ai=sqrt(k*R*Ti) //Sound velocity in m/s
Toi=(1+((0.5*(k-1)*Mi^2)))*Ti //Stagnation
    temperature at diffuser inlet in K
To1=Toi //Inlet Stagnation temperature of compressor
     in K, since hoi=ho1
To2=dTc+To1 //Exit Stagnation temperature of
    compressor in K
pr_c=(1+(eff_c*((To2-To1)/To1)))^(k/(k-1)) //
    Compressor pressure ratio
f=((Cp*To3)-(Cp*To2))/((eff_cc*CV*10^3)-(Cp*To3)) //
    Fuel-air ratio, calculation mistake in textbook
dTt=dTc/(eff_m*(1+f)) //Temperature difference
    across turbine
pr_t=1/((1-(dTt/(To3*eff_t)))^(k/(k-1))) //Turbine
    pressure ratio
To4=To3-dTc //Exit Stagnation temperature of turbine
     in K
u=ai*Mi //Flight velocity in m/s
sig=1/(((Is*g)/u)+1) //Jet speed ratio
Ce=u/sig //Exit velocity in m/s
Cj=Ce //Jet velocity in m/s, Since Cj is due to exit
     velociy
Te=To4-(Ce^2/(2*Cp)) //Exit temperature in K
Tes=To4-((To4-Te)*eff_n) //Exit temperature in K, (
    At isentropic process)
pr_n=(To4/Te)^(k/(k-1)) //Nozzle pressure ratio
ae=sqrt(k*R*Te) //Exit Sound velocity in m/s
Me=Ce/ae //Exit mach number

printf('(A)Fuel-air ratio is %3.5f \n (B)Compressor,
     turbine, nozzle pressure ratio are %3.3f, %3.3f,
     %3.2f respectively\n (C)Mach number at exhaust
    jet is %3.3f',f,pr_c,pr_t,pr_n,Me)
```

Scilab code Exa 6.9 To determine air flow rate thrust power thrust produced specific thrust and specific impulse

```
clc
clear

//Input data
D=2.5 //Diameter in m
u=500*(5/18) //Flight velocity in m/s
h=8000 //Altitude in m
sig=0.75 //Jet speed ratio
g=9.81 //Acceleration due to gravity in m/s^2

//Calculation
d=0.525 //from gas tables
A=%pi*D^2*0.25 //Area of flow in m^2
Cj=u/sig //Jet velocity in m/s
Vf=(u+Cj)/2 //Velocity of flow in m/s
ma=d*A*Vf //Mass flow rate of air in kg/s
F=ma*(Cj-u)*10^-3 //Thrust in kN
P=F*u //Thrust power in kW
Fs=F*10^3/ma //Specific thrust in Ns/kg
Is=Fs/g //Specific impulse in sec

//Output
printf('(A)Flow rate of air through the propeller is %3.3f m/s\n (B)Thrust produced is %3.3f kN\n (C) Specific thrust is %3.2f N-s/kg\n (D)Specific impulse is %3.3f sec\n (E)Thrust power is %3.1f kW',ma,F,Fs,Is,P)
```

Scilab code Exa 6.10 To calculate pressure rise pressured developed by compressor and air standard efficiency of the engine

```
clc
```

```
clear

//Input data
h=3000 //Altitude in m
Pi=0.701 //Inlet pressure in bar
Ti=268.65 //Inlet temperature in K
u=525*(5/18) //Flight velocity in m/s
eff_d=0.875 //Diffuser efficiency
eff_c=0.79 //Compressor efficiency
C1=90 //Velocity of air at compressor in m/s
dTc=230 //Temperature rise through compressor
k=1.4 //Adiabatic constant of air
Cp=1005 //Specific heat capacity at constant pressure of air in J/kg-K
R=287 //Specific gas constant in J/kg-K

//Calculation
ai=sqrt(k*R*Ti) //Sound velocity in m/s
Mi=u/ai //Inlet mach number
Toi=(1+((0.5*(k-1)*Mi^2)))*Ti //Stagnation temperature at diffuser inlet in K
To1=Toi //Inlet Stagnation temperature of compressor in K, since hoi=ho1
T1=To1-(C1^2/(2*Cp)) //Temperature at inlet of compressor in K
P1=Pi*((1+(eff_d*((T1/Ti)-1)))^(k/(k-1))) //Inlet pressure of compressor in bar
dPc=P1-Pi //Pressure rise through inlet diffuser in bar
pr_c=(((eff_c*dTc)/To1)+1)^(k/(k-1)) //Pressure ratio of compressor
P=Cp*(dTc) //Power required by the compressor in kW/(kg/s)
eff=1-(1/pr_c^((k-1)/k)) //Air standard efficiency

//Output
printf('(A)Pressure rise through diffuser is %3.4f bar\n (B)Pressure developed by compressure is %3
```

```
.4f bar\n (C)Air standard efficiency of the
engine is %3.4f',dPc,P1,eff)
```

Scilab code Exa 6.11 To estimate diameter power output AFR and absolute velocity of the jet

```
clc
clear

//Input data
h=9500 //Altitude in m
u=800*(5/18) //Flight velocity in m/s
eff_prop=0.55 //Propulsive efficiency of the cycle
eff_o=0.17 //Overall efficiency
F=6100 //Thrust in N
d=0.17 //Density in kg/m^3
CV=46000 //Calorific value in kJ/kg

//Calculation
mf=(F*u)/(eff_o*CV*10^3) //Mass flow rate of fuel in
    kg/s
Cj=((2*u)/(eff_prop))-u //Jet velocity in m/s, wrong
    calculation in textbook
Ca=Cj-u //Absolute Jet velocity in m/s
ma=(F-(mf*Cj))/(Ca) //Mass flow rate of air in kg/s
m=ma+mf //Mass flow rate of gas in kg/s
f=ma/mf //Air fuel ratio
Q=m/d //Volume flow rate in m^3/s
Dj=sqrt((4*Q)/(%pi*Cj))*10^3 //Diameter of jet in mm
    , Cj value wrong in textbook
P=((F*u)/eff_prop)*10^-3 //Power output of engine in
    kW

//Output
printf('(A)Diamter of the jet is %3.1f mm\n (B)Power
```

```
output is %3.1f kW\n (C)Air-fuel ratio is %3.3f\n (D)Absolute velocity of the jet is %3i m/s\n',Dj,P,f,Ca)
```

Scilab code Exa 6.12 To determine jet velocity thrust specific thrust TSFC thrust power and efficiencies

```
clc
clear

//Input data
u=960*(5/18) //Flight velocity in m/s
ma=40 //Mass flow rate of air in kg/s
AFR=50 //Air fuel ratio
sig=0.5 //Jet speed ratio, for maximum thrust power
CV=43000 //Calorific value in kJ/kg

//Calculation
mf=ma/AFR //Mass flow rate of fuel in kg/s
m=ma+mf //Mass flow rate of gas in kg/s
Cj=u/sig //Jet velocity in m/s
F=((m*Cj)-(ma*u))*10^-3 //Thrust in kN
Fs=F*10^3/m //Specific thrust in Ns/kg, F in N
Pt=F*u //Thrust power in kW
eff_prop=((2*sig)/(1+sig))*100 //Propulsive efficiency of the cycle in %
eff_ther=((0.5*m*(Cj^2-u^2))/(mf*CV*10^3))*100 //Efficiency of turbine in %
eff=(eff_prop/100)*(eff_ther/100)*100 //Overall efficiency in %
TSFC=mf*3600/(F*10^3) //Thrust specific fuel consumption in kg/Nhr

//Output
printf('(A)Jet velocity is %3.1f m/s\n (B)Thrust is
```

```
%3.3f kN\n (C)Specific thrust is %3.2f N-s/kg\n (
D)Thrust power is %3.2f kW\n (E)propulsive ,
thermal and overall efficiency is %3.2f, %3.2f
and %3.3f respectively\n (F)Thrust specific fuel
consumption is %3.4f kg/Nhr',Cj,F,Fs,Pt,eff_prop,
eff_ther,eff,TSFC)
```

Scilab code Exa 6.13 To jet velocity fuel rate TSFC propulsive power and efficiencies

```
clc
clear

//Input data
u=960*(5/18) //Flight velocity in m/s
ma=54.5 //Mass flow rate of air in kg/s
dh=200 //Change of enthalpy for nozzle in kJ/kg
Cv=0.97 //Velocity coefficient
AFR=75 //Air fuel ratio
eff_cc=0.93 //Combustion efficiency
CV=45000 //Calorific value in kJ/kg

//Calculation
mf=ma/AFR //Mass flow rate of fuel in kg/s
Cj=Cv*sqrt(2*dh*10^3) //Jet velocity in m/s
F=ma*(Cj-u) //Thrust in kN
TSFC=mf*3600/(F) //Thrust specific fuel consumption
   in kg/Nhr
HS=mf*eff_cc*CV //Heat supplied in kJ/s
Pp=0.5*ma*(Cj^2-u^2)*10^-3 //Propulsive power in kW
Pt=F*u //Thrust power in kW
eff_p=Pt/(Pp*10^3) //Propulsive efficiency of the
   cycle
eff_t=Pp/HS //Efficiency of turbine
eff_o=Pt*10^-3/HS  //Overall efficiency
```

```

//Output
printf('(A)Exit velocity of the jet is %3.2f m/s\n (B)Fuel rate is %3.4f kg/s\n (C)Thrust specific fuel consumption is %3.5f kg/Nhr\n (D)Thermal efficiency is %3.3f\n (E)Propulsive power is %3.2f kW\n (F)Propulsive efficiency is %3.4f\n (G)Overall efficiency is %3.5f',Cj,mf,TSFC,eff_t,Pp,eff_p,eff_o)
```

Scilab code Exa 6.14 To find absolute jet velocity volume of air compressed diameter power output and air fuel ratio of the jet

```
clc
clear

//Input data
u=750*(5/18) //Flight velocity in m/s
h=10000 //Altitude in m
eff_p=0.5 //Propulsive efficiency of the cycle
eff_o=0.16 //Overall efficiency
d=0.173 //Density in kg/m^3
F=6250 //Thrust in N
CV=45000 //Calorific value in kJ/kg

//Calculation
sig=eff_p/(2-eff_p) //Jet speed ratio
Cj=u/sig //Jet velocity in m/s
Ca=Cj-u //Absolute Jet velocity in m/s
ma=F/Ca //Mass flow rate of air in kg/s
Q=ma*60/d //Volume flow rate in m^3/min
A=Q/(Cj*60) //Area of flow in m^2
D=sqrt((4*A)/(%pi))*10^3 //Diameter in mm
Pt=F*u //Thrust power in W
Pp=(Pt/eff_p)*10^-3  //Propulsive power in kW
```

```
eff_t=eff_o/eff_p //Efficiency of turbine
HS=Pp/eff_t //Heat supplied in kJ/s
mf=HS/CV //Mass flow rate of fuel in kg/s
AFR=ma/mf //Air fuel ratio

//Output
printf('(A)Absolute velocity of the jet is %3.2f m/s
    \n (B)Volume of air compressed per minute is %3.2
    f m^3/min\n (C)Diameter of the jet is %3i mm\n (D
    )Power unit of the unit is %3.3f kW\n (E)Air fuel
     ratio is %3.1f',Ca,Q,D,Pp,AFR)
```

Scilab code Exa 6.15 To estimate AFR nozzle thrust propeller thrust and mass flow rate

```
clc
clear

//Input data
P1=0.56 //Inlet pressure of compressor in bar
T1=260 //Temperature at inlet of compressor in K
pr_c=6 //Pressure ratio of compressor
eff_c=0.85 //Compressor efficiency
u=360*(5/18) //Flight velocity in m/s
D=3 //Propeller diameter in m
eff_p=0.8 //Efficiency of propeller
eff_g=0.95 //Gear reduction efficiency
pr_t=5 //Expansion ratio
eff_t=0.88 //Turbine efficiency
T3=1100 //temperature at turbine inlet in K
eff_n=0.9 //Nozzle efficiency
Cp=1005 //Specific heat capacity at constant
    pressure of air in J/kg-K
CV=40000 //Calorific value in kJ/kg
k=1.4 //Adiabatic constant of air
```

```
R=287 //Specific gas constant in J/kg-K

//Calculation
P2=pr_c*P1 //Exit pressure of compressor in bar
T2s=T1*(pr_c)^((k-1)/k) //Exit temperature of compressor at isentropic proces in K
T2=T1+((T2s-T1)/eff_c) //Exit temperature of compressor in K
Wc=Cp*(T2-T1)*10^-3 //Power input to compressor in kJ/kg of air
C1=u //Air velocity in m/s, since C1 is resultant of u
C=C1/eff_p //Average velocity in m/s
C2=(2*C)-C1 //Exit velocity from compressor in m/s
Ap=0.25*%pi*D^2 //Area of propeller passage in m^2
Q=Ap*C //Quantity of air inducted in m^3/s
mf=((T3-T2)*Cp)/((CV*10^3)-(Cp*T3)) //Mass flow rate of fuel in kg/s
f=mf //Fuel consumption in kg/kg of air
AFR=1/mf //Air fuel ratio
P3=P2 //Exit pressure of combustion chamber in bar, Since process is at constant pressure
P4=P3/pr_t //Exit pressure of turbine in bar
T4s=T3/((pr_t)^((k-1)/k)) //Exit temperature of turbine at isentropic proces in K, wrong calculation
T4=T3-(eff_t*(T3-T4s)) //Exit temperature of turbine in K
Po=(1+f)*Cp*(T3-T4)*10^-3 //Power output per kg of air in kJ/kg of air
Pa=Po-Wc //Power available for propeller in kJ/kg of air
Pe=P1 //Exit pressure in bar, Since exit is at ambient conditions
Tes=T4/((P4/Pe)^((k-1)/k)) //Exit temperature of nozzle at isentropic proces in K
Cj=sqrt(2*Cp*eff_n*(T4-Tes)) //Jet velocity in m/s
Fs=((1+f)*Cj)-u //Specific thrust in Ns/kg, F in N
```

```
Pp=((0.5*P1*10^5*Q*(C2^2-C1^2))/(R*T1))*10^-3 //
    Propulsive power by propeller in kJ/s
Ps=Pp/eff_g //Power supplied by the turbine in kW
ma=Ps/Pa //Air flow rate in kg/s
Fj=ma*Cj*10^-3 //Jet thrust in kN, calculation
    mistake
Fp=(Pp*eff_p)/u //Thrust produced by propeller in kN

//Output
printf('(A)Air fuel ratio is %3.2f\n (B)Thrust
    produced by the nozzle is %3.3f kN\n (C)Thrust by
     the propeller is %3.3f kN\n (D)mass flow rate
    through the compressor is %3.2f kg/s',AFR,Fj,Fp,
    ma)
```

Scilab code Exa 6.16 To find various parameters of ramjet engine through out its operation

```
clc
clear

//Input data
M1=1.5 //Mach number
h=6500 //Altitude in m
D=0.5 //Diameter in m
To4=1600 //Stagnation temperature at nozzle inlet in
     K
CV=40000 //Calorific value in kJ/kg
k=1.4 //Adiabatic constant of air
R=287 //Specific gas constant in J/kg-K
eff_d=0.9 //Diffuser efficiency
eff_cc=0.98 //Combustion efficiency
eff_n=0.96 //Nozzle efficiency
pr_l=0.02 //Pressure ratio i.e. Stagnation pressure
    loss to Exit presure of compressor
```

```
Cp=1005 //Specific heat capacity at constant pressure of air in J/kg-K

//Calculation
P1=0.44 //Inlet pressure of compressor in bar
T1=245.9  //Temperature at inlet of compressor in K
a1=314.5 //Sound velocity at compressor in m/s
d1=0.624 //Density at compressor in kg/m^3
A1=0.25*%pi*D^2 //Area at diffuser inlet in m^2
u1=M1*a1 //Flight velocity in m/s
ma=d1*A1*u1 //Mass flow rate of air in kg/s
To2=T1*(1+(((k-1)/2)*M1^2)) //Stagnation temperature at commpressor inlet in K
To1=To2 //Stagnation temperature at commpressor outlet in K, (It is in case of diffuser)
pr_d=((eff_d*(((k-1)/2)*M1^2))+1)^(k/(k-1)) //Pressure ratio of diffuser
P2=pr_d*P1 //Exit pressure of compressor in bar
Po2=P2 //Stagnation pressure at exit of compressor in bar
Po3=(Po2-(pr_l*Po2)) //Stagnation pressure at exit of combustion chamber in bar
Poe=P1 //Exit stagnation pressure in kPa, Since exit is at ambient conditions
pr_n=Po3/Poe //Pressure ratio of nozzle
p1=1/pr_n //Inverse of pr_n to find in gas tables
M4s=1.41 //Mach number at turbine exit  from gas tables
T4s=To4/(1+((0.5*(k-1)*M4s^2))) //Exit temperature of turbine at isentropic process in K
To3=To4 //Stagnation temperature at inlet turbine in K,
T4=To3-(eff_n*(To3-T4s)) //Exit temperature of turbine in K
C4=sqrt(2*Cp*(To4-T4)) //Flight velocity of air in m/s
a4=sqrt(k*R*T4) //Sound velocity in m/s
Me=C4/a4 //Nozzle jet mach number
```

```
f=(Cp*(To3-To2))/(eff_cc*CV*10^3) //Fuel air ratio
mf=ma*f //Mass flow rate of fuel in kg/s
m=ma+mf //Mass flow rate of gas in kg/s
eff_i=(1/(1+((2/(k-1))*(1/M1^2))))*100 //Efficiency of the ideal cycle in %
sig=u1/C4 //Jet speed ratio
eff_p=((2*sig)/(1+sig)) //Propulsive efficiency in %
F=((m*C4)-(ma*u1))*10^-3 //Thrust in kN

//Output
printf('(A)Efficiency of the ideal cycle is %3i percent\n (B)Flight speed is %3.3f m/s\n (C)Air flow rate is %3.3f kg/s\n (D)Diffuser pressure ratio is %3.4f\n (E)Fuel air ratio is %3.5f\n (F)Nozzle pressure ratio is %3.2f\n (G)Nozzle jet mach number is %3.3f\n (H)Propulsive efficiency is %3.4f percent\n (I)Thrust is %3.3f kN',eff_i,C4,ma,pr_d,f,pr_n,Me,eff_p,F)
```

Scilab code Exa 6.17 To find power input power output Fuel air ratio Exit Mach number thrust and thrust power developed in the jet

```
clc
clear

//Input data
ma=18 //Mass flow rate of air in kg/s
Mi=0.6 //Inlet mach number
h=4600 //Altitude in m
Pi=55 //Inlet pressure in
Ti=-20+273 //Inlet temperature in K
eff_d=0.9 //Diffuser efficiency
pr_d=5 //Diffuser pressure ratio
T3=1000+273 //Inlet turbine temperature in K
Pe=60 //Exit pressure in kPa
```

```
eff_c=0.81 //Compressor efficiency
eff_t=0.85 //Turbine efficiency
eff_n=0.915 //Nozzle efficiency
CV=46520 //Calorific value in kJ/kg
Cp=1005 //Specific heat capacity at constant pressure of air in J/kg-K
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
Ci=Mi*sqrt(k*R*Ti) //Velocity of air in m/s,
u=Ci //Flight velocity in m/s, Since it is reaction force of Ci
T1=Ti+(Ci^2/(2*Cp)) //Temperature at inlet of compressor in K
P1s=Pi*(T1/Ti)^(k/(k-1)) //Inlet pressure of compressor at isentropic process in kPa
P1=Pi+(eff_d*(P1s-Pi)) //Inlet pressure of compressor in kPa
P2=P1*pr_d //Outlet pressure of compressor in kPa
T2s=T1*(pr_d)^((k-1)/k) //Outlet temperature of compressor at isentropic process in K
T2=T1+((T2s-T1)/eff_c) //Exit temperature of compressor in K
Wc=Cp*(T2-T1)*10^-3 //Workdone on compressor in kJ/kg of air
Pc=ma*Wc //Power input in kW
Pt=Pc //Power out put of turbine for isentropic process in kW
f=(T3-T2)/((CV*10^3/Cp)-T3) //Fuel air ratio
Wt=Wc //Workdone by the turbine in kJ/kg of air
T4=T3-(Wt*10^3/Cp) //Exit temperature of turbine in K
T4s=T3-((T3-T4)/eff_t) //Exit temperature of turbine at isentropic process in K
P3=P2 //Exit pressure of combustion chamber in kPa, Since the process takes place at constant pressure process
```

```
P4=P3*(T4s/T3)^(k/(k-1)) //Pressure at outlet of
    turbine in kPa
pr_n=P4/Pe //Pressure ratio of nozzle
Tes=T4/(pr_n)^((k-1)/k) //Exit temperature of nozzle
     at isentropic process in K
Te=T4-(eff_n*(T4-Tes)) //Exit temperature of nozzle
    in K
Cj=sqrt(2*Cp*(T4-Te)) //Jet velocity in m/s
Ce=Cj //Flight velocity in m/s
ae=sqrt(k*R*Te) //Sound velocity at nozzle in m/s
Me=Ce/ae //Nozzle jet mach number
F=ma*(((1+f)*Cj)-u) //Thrust in N
P=F*u*10^-3 //Thrust power in kW

//Output
printf('(A)Power input of compressor is %3.2f kW\n (
    B)Power output of turbine is %3.2f kW\n (C)F/A
    ratio on mass basis is %3.4f\n (D)Exit mach
    number is %3.3f\n (E)Thrust is %3.2f N\n (F)
    Thrust power is %3.1f kW',Pc,Pt,f,Me,F,P)
```

Chapter 7

Rocket Propulsion

Scilab code Exa 7.1 To find thrust of the motor of a rocket

```
clc
clear

//input data
mp=12 //flow rate in kg/s
Ae=335*10^-4 //exit area in m^2
Ce=2000 //exhaust velocity in m/s
h=10 //altitude in km
Pe=1*10^5 //exhaust pressure in Pa
P0=1*10^5 //p0=atomspheric pressure in Pa at h=0.
P10=0.25*10^5 //atmospheric pressure in Pa using gas tables

//calculations
Fs=mp*Ce*10^-3 //thrust of motor at sea level since pe=p0 in kN
F10=((mp*Ce) + Ae*(Pe-P10))*10^-3 //thrust of motor at altitude of 10km in kN

//output
printf('(A)thrust of motor at sea level is %3i kN (
```

```
upwards) \n (B)thrust of motor at an altitude 10 km is %3.4f kN',Fs,F10)
```

Scilab code Exa 7.2 To calculate area ratio thrust characteristic velocity thrust coefficient exit velocity and possible maximum velocity

```
clc
clear

//input data
P0=38*10^5 //combustion chamber pressure in Pa
T0=3500 //combustion chamber temperature in K
ma=41.67 //oxidizer flow rate in kg/s
MR=5 //mixture ratio
k=1.3 //adiabatic constant
R=287 //gas constant in J/kg-K
Pamb=0.0582*10^5 //ambient pressure in Pa
Pe=Pamb //exhaust pressure at sea level in Pa

//calculation
mf=ma/MR //mass flow of fuel in kg/s
mp=mf+ma //propellant mass flow in kg/s
Cp=(k*R)/(k-1) //specific heat at constant pressure in J/kg-k
p=P0/Pe //ratio of pressures at combustion chamber and exhaust
Me=((((p^((k-1)/k))-1)*2)/(k-1))^0.5 //Mach number
t=1/(1+(((k-1)/2)*Me^2)) //ratio of exhaust temperature to combustion temperature
Te=t*T0 //exhaust temperature in Kelvin
a=(1/Me)*(((2/(k+1))+(((k-1)/(k+1))*Me^2))^((k+1)/(2*(k-1)))) //ratio of areas at exit section and throat section of the nozzle
Ce=(k*R*Te)^0.5*Me //exit velocity in the exhaust in m/s
```

```
Cj=Ce //average effective jet velocity in m/s, since
    Pe=Pamb
P1=P0*(2/(k+1))^(k/(k-1)) //pressure at throat
   section in Pa
T1=T0*(2/(k+1)) //temperature at throat section in K
d1=P1/(R*T1) //density of fuel at throat section in
   kg/m^3
C1=(k*R*T1)^0.5 //velocity at throat section in m/s
A1=(mp/(d1*C1))*10^4 //nozzle throat area in cm^2
Ae=a*A1 //exit area in cm^2
F=(mp*Ce)*10^-3 //thrust in kN
Cmax1=(2*Cp*T0)^0.5 //maximum possible velocity in m
   /s
Cf=(F*10^3)/(P0*A1*10^-4) //thrust coefficient , F in
    kN and A1 in m^2
Cch1=Cj/Cf //characteristic velocity in m/s

//output
printf('(A)nozzle throat area is %3.2f cm^2 \n (B)
   thrust is %3.1f kN \n (C)thrust coefficient is %3
   .2f \n (D)characteristic velocity is %3i m/s \n (
   E)exit velocity in exhaust is %3i m/s\n (F)
   maximum possible exhaust velocity is %3i m/s\n',
   A1,F,Cf,Cch1,Ce,Cmax1)
```

Scilab code Exa 7.3 To estimate thrust per unit area and specific impulse

```
clc
clear

//input data
a=3 //exit area to throat area ratio
T0=2973 //combustion chamber temperature in K
P0=20*10^5 //combustion chamber pressure in Pa
k=1.3 //adiabatic constant
```

```
R=248 //gas constant in J/kg-K
Pamb=1*10^5 //ambient pressure in Pa
Me=2.52 //mach number for k=1.3 and a=3 using gas
    tables
g=9.81 //acceleration due to gravity in m/s^2

//calculation
p=1/((1+(((k-1)/2)*Me^2))^(k/(k-1))) //ratio of
    pressures at exhaust and combustion chamber
Pe=p*P0 //exhaust pressure in Pa
t=1/(1+(((k-1)/2)*Me^2)) //ratio of exhaust
    temperature to combustion temperature
Te=t*T0 //exhaust temperature in Kelvin
Ce=(k*R*Te)^0.5*Me //exit velocity in the exhaust in
     m/s
M=(Pe*Ce)/(R*Te) //propellant mass flow per unit
    area of exit in kg/m^2-s
Fa=((M*Ce)+(Pe-Pamb))*10^-3 //thrust per unit area
    of exit in N/m^2
Is=(Fa*10^3)/(M*g) //specific impulse in sec

//output
printf('(A)thrust per unit area of exit is %3.2f kN/
   m^2 \n (B)specific impulse is %3.2f sec',Fa,Is)
```

Scilab code Exa 7.4 To find specific impulse specific propellant consumption effective and absolute jet velocity of rocket

```
clc
clear

//input data
mp=5 //propellent flow rate in kg/s (missing data)
de=0.10 //nozzle exit diameter in m
Pe=1.02*10^5 //nozzle exit pressure in Pa
```

```
Pamb=1.013*10^5 //ambient pressure in Pa
P0=20 //thrust chamber pressure in Pa
F=7000 //thrust in N
u=1000 //rocket speed in m/s
g=9.81 //acceleration due to gravity in m/s^2

//calculation
Cj=F/mp //effective jet velocity in m/s
Ca=Cj-u //absolute jet velocity in m/s
wp=mp*g //weight flow rate of propellent in N/s
Is=F/(wp) //specific impulse in sec
SPC=1/Is //specific propellent consumption in sec^-1

//output
printf('(A)effective jet velocity is %3i m/s \n (B)specific impulse is %3.2f sec \n (C)specific propellent consumption is %3.3f s^-1 \n (D)absolute jet velocity is %3i m/s',Cj,Is,SPC,Ca)
```

Scilab code Exa 7.5 To find propulsive efficiency thrust and thrust power of rocket

```
clc
clear

//input data
Cj=2700 //average effective jet velocity in m/s
u=1350 //forward flight velocity in m/s
mp=78.6 //propellant mass flow in kg/s

//calculation
s=u/Cj //effective jet speed ratio
np=(2*s)/(1+s^2) //propulsive efficiency
F=Cj*mp*10^-3 //thrust in kN
Pt=F*u*10^-3 //Thrust power in MW, F in N
```

```
printf('(A)thrust is %3.2f kN \n (B)Thrust power is %3.3f MW \n (C)propulsive efficiency is %3.1f',F,Pt,np)
```

Scilab code Exa 7.6 To find velocity and maximum height that rocket will reach

```
clc
clear

//input data
mi=15000 //mass of the rocket in kg
mp=125 //propellant mass flow in kg/s
Cj=2000 //velocity of gases coming out in m/s
t=70 //time interval in sec
t0=0 //lower limit in integration in sec
t1=70 //upper limit in integration in sec
g=9.81 //acceleration due to gravity in m/s^2

//calculation
u=(-Cj*(log(1-((mp*t)/mi))))-(g*t) //velocity attained in 70 sec in m/s
h1=(integrate('((-2000*(log(1-((125*t)/15000))))-(g*t))','t',t0,t1))*10^-3 //distance travelled through 70 sec obtained by integrating u w.r.t time with intervals 0 to 70 in km
h2=(u^2/(2*g))*10^-3 //distance reached after fuel last i.e. after 70 sec due to kinetic energy by using KE=PE in km
h=h1+h2 //maximum height the rocket will reach in km

//output
printf('(A)velocity attained in %i sec is %3.2f m/s\
```

```
n (B)maximum height the rocket will reach is %3.3f km',t,u,h)
```

Scilab code Exa 7.7 To determine thrust coefficient propellant weight flow coefficient SPC and characteristic velocity of rocket

```
clc
clear

//input data
A1=18*10^-4 //throat area in m^2
P0=25*10^5 //combustion chamber pressure in Pa
Is=127.42 //specific impulse in sec
wp=44.145 //weight flow rate of propellent in N/s
g=9.81 //acceleration due to kravity in m/s^2

//calculation
F=Is*wp //thrust in N
mp=wp/g //propellant mass flow in kg/s
Cj=F/mp //average effective jet velocity in m/s
Cf=F/(P0*A1) //thrust coefficient
Cw=wp/(P0*A1)/10^-3 //propellent weight flow coefficent *10^-3
SPC=(wp/F)/10^-3 //specific propellent consumption in sec^-1 *10^-3
Cch1=Cj/Cf //characteristic velocity in m/s

//output
printf('(A)thrust coefficient is %3.2f \n (B)propellent weight flow coefficent is %3.2f*10^-3 \n (C)specific propellent consumption is %3.2f*10^-3 s^-1 \n (D)characteristic velocity is %3.0f m/s',Cf,Cw,SPC,Cch1)
```

Scilab code Exa 7.8 To find various parameters of rocket projectile during its operation

```
clc
clear

//input data
m1=200 //internal mass in kg
m2=130 //mass after rocket operation in kg
m3=110 //payload,non-propulsive structure, etc in kg
tp=3 //rocket operation duration in sec
Is=240 //specific impulse in sec
g=9.81 //acceleration due to kravity in m/s^2

//calculation
MR=m2/m1 //mass ratio
Mp=m1-m2 //mass of propellant in kg
mp=Mp/tp //propellent flow rate in kg/s
wp=mp*g //weight flow rate of propellent in N/s
IMF=(m2-m3)/(m1-m3) //initial mass fraction
PMF=1-IMF //propellant mass fraction
F=Is*wp //thrust in N
TWRi=F/(m1*g) //initial thrust to weight ratio
TWRf=F/(m2*g) //final thrust to weight ratio
av=F/m2 //Maximum accelaration of the vechicle in m/
    s^2
Cj=Is*g //effective exhaust velocity in m/s
It=Is*Mp*g*10^-3 //total impulse in kN-s, units of
    the answer given in the book is wrong
IWR=(It*10^3)/((m1-m3)*g) //impulse to weighr ratio,
     It in N-s

//output
printf('(A)mass ratio is %3.2f \n (B)propellent mass
```

```
fraction is %3.3f \n (C)propellent flow rate is %3.1f kg/s\n (D)thrust is %3.1f N\n (E)thrust to weight ratio is %3.2f (intial) and %3.2f (final)\n (F)accelaration of the vechicle is %3.2f m/s^2\n (G)effective exhaust velocity is %3.1f m/s\n (H)total impulse is %3.3f kN-s\n (I)impulse to weighr ratio is %3.2f',MR,PMF,mp,F,TWRi,TWRf,av,Cj,It,IWR)
```

Scilab code Exa 7.9 To propulsive power engine output and efficiencies

```
clc
clear

//input data
u=2800 //rocket speed in m/s
Cj=1400 //effective exhaust velocity in m/s
mp=5 //propellent flow rate in kg/s
q=6500 //heat of propellent per kg of propellant mixture in kJ/kg

//calculation
s=u/Cj //effective jet speed ratio
np=(2*s)/(1+s^2) //propulsive efficiency
F=Cj*mp*10^-3 //thrust in kN
Pt=F*10^3*u*10^-6 //Thrust power in MW, F in N
Pe=Pt/np //engine outputin MW
nth=Pe*10^3/(mp*q) //thermal efficiency , Pe in kW
no=np*nth //overall efficiency

//output
printf('(A)propulsive efficiency is %3.1f \n (B)propulsive power is %3.1f MW\n (C)engine outut is %3.1f MW\n (D)thermal efficiency is %3.4f \n (E)overall efficiency is %3.3f',np,Pt,Pe,nth,no)
```

Scilab code Exa 7.10 To find thrust specific impulse and efficiencies

```
clc
clear

//input data
Cj=1250 //effective exhaust velocity in m/s
s=0.8 //effective jet speed ratio i.e. flight to jet
    speed ratio
ma=3.5 //oxidizer flow rate in kg/s
mf=1 //fuel flow rate in kg/s
g=9.81 //acceleration due to gravity in m/s^2
q=2500*10^3 //heat of propellent per kg of
   propellant mixture in J/kg

//calculation
u=s*Cj //flight velocity in m/s
mp=ma+mf //propellant mass flow in kg/s
F=Cj*mp*10^-3 //thrust in kN
wp=mp*g //weight flow rate of propellent in N/s
Is=(F*10^3)/(wp) //specific impulse in sec,F in N
np=(2*s)/(1+s^2) //propulsive efficiency
nth=0.5*mp*((Cj^2+u^2)/(mp*q)) //thermal efficiency
no=np*nth //overall efficiency

//output
printf('(A)thrust is %3.3f kN\n (B)specific impulse
   is %3.2f sec\n (C)propulsive efficiency is %3.4f
   \n (D)thermal efficiency is %3.4f \n (E)overall
   efficiency is %3.1f',F,Is,np,nth,no)
```

Scilab code Exa 7.11 To find specific impulse SPC effective and actual jet velocity and efficiencies

```
clc
clear

//input data
mp=193 //propellent flow rate in kg/s
P1=27*10^5 //pressure at throat section in Pa
T1=3000 //temperature at throat section in K
de=0.6 //nozzle exit diameter in m
Pe=1.1*10^5 //exhaust pressure in Pa
Pamb=1.013*10^5 //ambient pressure in Pa
F=380*10^3 //thrust of motor in N
u=694.44 //flight velocity in m/s
g=9.81 //acceleration due to gravity in m/s^2
q=6500*10^3 //heat of propellent per kg of
    propellant mixture in J/kg

//calculation
Ae=(%pi*0.6^2)/4 //exit area in m^2
Cj=F/mp //average effective jet velocity in m/s
Ce=(F-((Pe-Pamb)*Ae))/mp //exhaust velocity in m/s,
    wrong answer in textbook
wp=mp*g //weight flow rate of propellent in N/s
Is=(F)/(wp) //specific impulse in sec
SPC=(wp/F)/10^-3 //specific propellent consumption
    in sec^-1 *10^-3
Pt=F*u*10^-6 //Thrust power in MW
Pl=(0.5*mp*((Cj-u)^2))*10^-6 //Power loss in exhaust
     in MW
Pe=Pt+Pl //engine output in MW
np=Pt/Pe //propulsive efficiency
nth=Pe*10^3/(mp*q*10^-3) //thermal efficiency and Pe
    ,q in kW
no=np*nth //overall efficiency

//output
```

```
printf('(A)effective jet velocity is %3.4f m/s\n (B)
   Actual jet velocity is %3.4f m/s\n (C)specific
   impulse is %3.1f sec\n (D)specific propellent
   consumption is %3.4f*10^-3 sec^-1\n (E)propulsive
    efficiency is %3.5f \n (D)thermal efficiency is
   %3.3f \n (E)overall efficiency is %3.5f',Cj,Ce,Is
   ,SPC,np,nth,no)
```

Scilab code Exa 7.12 To find propellant flow rate thrust developed and height attained during powered and coasting flights

```
clc
clear

//input data
m1=3600 //internal mass in kg
Cj=2070 //average effective jet velocity in m/s
tp=80 //rocket operation duration in sec
g=9.81 //acceleration due to gravity in m/s^2

//calculation
up=2*Cj //flight velocity in m/s
MR=1/exp((up+(g*tp))/Cj) //mass ratio
m2=MR*m1 //mass after rocket operation in kg
PMF=1-MR //propellant mass fraction
Mp=m1-m2 //mass of propellant in kg
mp=Mp/tp //propellent flow rate in kg/s
F=Cj*mp*10^-3 //thrust in kN
Zp=(((1+((1-(1/PMF))*log(1/MR)))*Cj*tp)-(0.5*g*tp^2)
   )*10^-3 //powered altitude gain in km
Zc=((0.5*up^2)/g)*10^-3 //coasting altitude gain in
   km
Z=Zp+Zc //maximum altitude in km

//output
```

```
printf('(A)flow rate of propellent is %3.2f kg/s\n (
   B)thrust developed is %3.3f kN\n (C)altitude
   gains during powered and coasting flights are %3
   .3f km and %3.3f km respectively',mp,F,Zp,Zc)
```

Scilab code Exa 7.13 To find effective jet velocity mass ratio and propellant mass fraction maximum slight speed Altitude gain during powered and coasting flights

```
clc
clear

//input data
s=0.2105 //effective jet speed ratio
Is=203.88 //specific impulse in sec
tp=8 //rocket operation duration i.e. burn out time
   in sec
g=9.81 //acceleration due to kravity in m/s^2

//calculation
Cj=g*Is //average effective jet velocity in m/s
up=s*Cj //maximum flight speed in m/s
MR=1/exp((up+(g*tp))/Cj) //mass ratio
PMF=1-MR //propellant mass fraction
Zp=(((1+((1-(1/PMF))*log(1/MR)))*Cj*tp)-(0.5*g*tp^2)
   )*10^-3 //powered altitude gain in km
Zc=((0.5*up^2)/g)*10^-3 //coasting altitude gain in
   km
Z=Zp+Zc //maximum altitude in km

//output
printf('(A)effective jet velocity is %3i m/s\n (B)
   mass ratio and propellent mass fraction are %3.2f
    and %3.2f respectively\n (C)maximum flight speed
    is %3.2f m/s\n (D))altitude gains during powered
```

```
and coasting flights are %3.3f km and %3.3f km respectively',Cj,MR,PMF,up,Zp,Zc)
```

Scilab code Exa 7.14 To find orbital and escape velocities of a rocket

```
clc
clear

//input data
R0=6341.6*10^3 //radius of earth at mean sea-level in m
g=9.809 //acceleration due to gravity in m/s^2
Z1=0 //altitude at sea-level in m
Z2=300*10^3 //altitude above sea-level in m

//calculation
uorb1=R0*sqrt(g/(R0+Z1)) //orbit velocity of a rocket at mean sea level in m/s
uesc1=sqrt(2)*uorb1 //escape velocity of a rocket at mean sea level in m/s
uorb2=R0*sqrt(g/(R0+Z2)) //orbit velocity of a rocket at an altitude of 300 km in m/s
uesc2=sqrt(2)*uorb2 //escape velocity of a rocket at an altitude of 300 km in m/s

//output
printf('(A)orbit and escape velocities of a rocket at mean sea level are %3i m/s and %3i m/s\n (B) orbit and escape velocities of a rocket at an altitude of 300 km are %3.1f m/s and %3.2f m/s',uorb1,uesc1,uorb2,uesc2 )
```

Chapter 8

Two Marks Questions and Answers

Scilab code Exa 8.1.34 To find Mach angle

```
clc
clear

//Input data
C=500 //Airplane velocity in m/s
T=20+273 //Temperature in K
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
a=sqrt(k*R*T) //Sound velocity in m/s
M=C/a //Mach number
alp=asind(1/M) //Mach angle in degree

//Output
printf('Mach angle is %3.3f degree',alp)
```

Scilab code Exa 8.1.35 To find values of back pressure

```
clc
clear

//Input data
a1=2.2 //Area ratio (A/At)
Po=10 //Stagnation Pressure in bar

//Calculation
//Two values of mach number at a1 from gas tables

M1=0.275 //Mach number from gas tables
p1=0.949 //Presure ratio (P/Po)
P1=Po*p1 //back pressure in bar

M2=2.295 //Mach number from gas tables
p2=0.0806 //Presure ratio (P/Po)
P2=Po*p2 //back pressure in bar

//Output
printf('(A)When M=%3.3f, back pressure is %3.2f bar\
   n (B)When M=%3.3f, back pressure is %3.3f bar',M1
   ,P1,M2,P2)
```

Scilab code Exa 8.1.37 To find temperature at nose of aircraft

```
clc
clear

//Input data
M=0.8 //Mach number
T=20+273 //Temperature in K
k=1.4 //Adiabatic constant

```

```
//Calculation
To=T*(1+(((k-1)/2)*M^2)) //Temperature of air at
    nose of aircraft in K
To1=To-273 //Temperature of air at nose of aircraft
    in degree Centigrade

//Output
printf('Temperature of air at nose of aircraft is %3
    .1f degree Centigrade',To1)
```

Scilab code Exa 8.1.38 To determine stagnation pressure and stagnation temperature

```
clc
clear

//Input data
P=1 //Pressure in bar
T=400 //Temperature in K
C=400 //Air velocity in m/s
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K
Cp=1005 //Specific heat capacity at constnat
    pressure in J/kg-K

//Calculation
To=T+(C^2/(2*Cp)) //Stagnation Temperature in K
Poi=P+((P*C^2)/(R*T*2)) //Stagnation Pressure (if it
     is incompressible) in bar
Poc=P*(To/T)^(k/(k-1)) //Stagnation Pressure (if it
    is compressible) in bar

//Output
printf('(Stagnation Temperature is %3.1f K\n (C)
    Stagnation Pressure:\n    If it is incompressible
```

```
    is %3.4f bar\n    If it is compressible is %3.4f
    bar',To,Poi,Poc)
```

Scilab code Exa 8.1.39 To calculate bulk modulus of elasticity of a liquid

```
clc
clear

//Input data
v1=8 //Intial volume in litres
P1=0.7 //Intial pressure in MPa
v2=7.8 //Final volume in litres
P2=2.7 //Final pressure in MPa

//Calculation
k=(P2-P1)/(log(v1/v2)) //Bulk modulus of elasticity
    of a liquid in MPa

//Output
printf('Bulk modulus of elasticity of a liquid is %3
    .3f MPa',k)
```

Scilab code Exa 8.1.40 To find highest possible velocity

```
clc
clear

//Input data
To=15+273 //Air Temperature in K
Cp=1005 //Specific heat capacity at constnat
    pressure in J/kg-K

//Calculation
```

```
Cmax=sqrt(2*Cp*To) //Highest possible velocity in m/
    s

//Output
printf('Highest possible velocity is %3.2f m/s',Cmax
    )
```

Scilab code Exa 8.3.10 To find the length of the pipe

```
clc
clear

//Input data
M=0.25 //mach number
D=0.04 //Diamter in m
f=0.002 //frictional factor

//Calculation
X=8.483 //fanno parameter from gas tables at M
Lmax=(X*D)/(4*f) //Lenggth of the pipe in m

//Output
printf('Length of the pipe is %3.3f m',Lmax)
```

Scilab code Exa 8.3.15 To find length of the pipe to achieve deceleration

```
clc
clear

//Input data
M=3 //mach number
D=0.04 //Diamter in m
f=0.002 //frictional factor
```

```

//Calculation
X=0.522 //fanno parameter from gas tables at M
L=(X*D)/(4*f) //Lenggth of the pipe in m

//Output
printf('Lenggth of the pipe is %3.2f m',L)
```

Scilab code Exa 8.3.31 To find maximum possible amount of heat transfer of combustion chamber

```
clc
clear

//Input data
M=0.2 //Mach number
To=120+273 //Stagnation Temperature in K
Cp=1005 //Specific heat capacity at constnat pressure in J/kg-K

//Calculation
t1=0.174 //Temperature ratio (To/Tot) from Rayleigh gas tables
Tot=To/t1 //Critical stagnation temperature in K
q=Cp*(Tot-To)*10^-3 //Maximum amount of heat transfer in kJ/kg

//Output
printf('Maximum amount of heat transfer is %3.2f kJ/kg',q)
```

Scilab code Exa 8.3.32 To find increase in specific entropy of the fluid

```
clc
clear

//Input data
p1=0.75 //Pressure ratio (Po2/Po1) Since Stagnation pressure drop is 25%
Cp=1150 //Specific heat capacity at constnat pressure in J/kg-K
k=1.33 //Adiabatic constant

//Calculation
ds=((k-1)/k)*Cp*log(1/p1) //Increase in entropy in J/kg-K

//Output
printf('Increase in entropy is %3.2f J/kg-K',ds)
```

Scilab code Exa 8.3.33 To pipe maximum heat transfer in a pipe

```
clc
clear

//Input data
Mi=2.2 //Inlet Mach number
T=100+273 //Temperature in K
Cp=1005 //Specific heat capacity at constnat pressure in J/kg-K

//Calculation
t1=0.508 //Temperature ratio (To/Tot) from isentropic gas tables @Mi
To=T/t1 //Stagnation Temperature in K
t2=0.756 //Temperature ratio (To/Tot) from Rayleigh gas tables @Mi
Tot=To/t2 //Critical stagnation temperature in K
```

```
q=Cp*(Tot-To)*10^-3 //Maximum amount of heat
    transfer in kJ/kg

//Output
printf('Maximum amount of heat transfer is %3.4f kJ/
    kg',q)
```

Scilab code Exa 8.5.16 To find pressure acting on the front of the body

```
clc
clear

//Input data
Mx=1.5 //Mach number
P=40 //Static pressure in kPa

//Calculation
p1=3.413 //Pressure ratio in (Poy/Px) from normal
    shock gas tables @Mx
Poy=p1*P //Pressure acting on front of the body in
    kPa

//Output
printf('Pressure acting on front of the body is %3.1
    f kPa',Poy)
```

Scilab code Exa 8.5.17 To find strength of shock wave

```
clc
clear

//Input data
M=2 //Mach number at shock
```

```

//Calculation
p1=4.5 //Pressure ratio (Py/Px) from normal shock
    gas tables @M
e=p1-1 //Strength of shock wave

//Output
printf('Strength of shock wave is %3.1f',e)
```

Scilab code Exa 8.5.20 To find irreversibility of duct

```
clc
clear

//Input data
Mx=7 //mach number upstream of shock
P=2 //pressure @Mx in bar
T=57+273 //Temperature @Mx in K
R=287 //Specific gas constant in J/kg-K

//Calculation
p1=0.72 //Pressure ratio (Poy/Pox) from normal shock
    gas tables @Mx
ds=R*log(1/p1) //Irreversibility in J/kg-K

//Output
printf('Irreversibility is %3.2f J/kg-K',ds)
```

Scilab code Exa 8.5.21 To find mach number and air velocity of pitot tube

```
clc
clear
```

```
//Input data
Px=45 //Static pressure in kPa
T=-20+273 //Static temperature in K
Poy=395 //Stagnation pressure in kPa
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
p1=Poy/Px //Pressure ratio
Mx=2.536 //Mach number from normal shock gas tables
    @p1
Cx=Mx*sqrt(k*R*T) //Air velocity in m/s

//Output
printf('Mach number is %3.3f\n Air velocity is %3i m
    /s',Mx,Cx)
```

Scilab code Exa 8.5.22 To find properties downstream of the shock

```
clc
clear

//Input data
Cx=750 //velocity upstream of shock in m/s
Px=1 //Pressure upstream of shock in bar
Tx=10+273 //Temperature upstream of shock in K
k=1.4 //Adiabatic constant
R=287 //Specific gas constant in J/kg-K

//Calculation
Mx=Cx/sqrt(k*R*Tx) //Mach number upstream of shock
My=0.545 //Mach number downstream of shock from
    normal shock gas tables, Mistake in textbook
t1=1.875 //Temperature ratio (Ty/Tx)
```

```
Ty=Tx*t1 //Static temperature downstream of shock in K
p1=5.583 //Pressure ratio (Py/Px)
Py=Px*p1 //Static pressure downstream of shock in bar
Cy=My*sqrt(k*R*Ty) //velocity downstream of shock in m/s

//Output
printf('Downstream of shock:\n     Velocity is %3.3f m/s\n     Pressure is %3.3f bar\n     Temperature is %3.3f K',Cy,Py,Ty)
```

Scilab code Exa 8.6.41 To find propulsive efficiency for an optimum thrust power

```
clc
clear

//Calculation

//Differentiating P=m*(Cj-u)*u and equating it to zero we get jet speed ratio as 0.5
sig=0.5 //Jet speed ratio
eff_max=((2*sig)/(1+sig)) //Propulsive efficiency for optimum thrust power, wrong notation in textbook.

//Output
printf('Propulsive efficiency for optimum thrust power is %3.3f',eff_max)
```

Scilab code Exa 8.6.42 To find propulsive efficency

```
clc
clear

//Input dat
u=1200*(5/18) //Flight velocity in m/s
Cj=800 //Effective jet velocity in m/s

//Calculation
sig=u/Cj //jet speed ratio
eff=((2*sig)/(1+sig))*100 //Propulsive efficiency in
    %

//Output
printf('Propulsive efficiency is %3.1f percent',eff)
```

Scilab code Exa 8.7.42 To find thrust of the rocket

```
clc
clear

//Input data
m=5 //Propellent rate in kg/s
Pamb=1.013 //Ambient pressure in bar
Pe=1.02 //Nozzle exit pressure in bar
D=0.1 //Nozzle exit diameter in m
Ce=1400 //Exit jet velocity in m/s

//Calculation
Ae=%pi*D^2/4 //Exit area in m^2
F=(m*Ce)+((Pe-Pamb)*Ae) //Thrust in N

//Output
printf('Thrust is %3i N',F)
```

Scilab code Exa 8.7.44 To find the thrust developed

```
clc
clear

//Input data
Is=230 //Specific Impulse in sec
m=1 //Propellent flow in kg/s
g=9.81 //Acceleration due to gravity in m/s^2

//Calculation
F=m*Is*g //Thrust in N

//Output
printf('Thrust is %3.1f N',F)
```

Scilab code Exa 8.7.45 To find the jet velocity of a rocket

```
clc
clear

//Input data
u=1500 //Flight velocity in m/s
eff=0.75 //Propulsive efficiency

//calculation
//Converting relation eff=(2*sig)/(1+sig^2) into 2nd
    degree polynomial of sig
sig=((2-(sqrt(4-(4*eff*eff))))/(2*eff)) //Jet speed
   ratio
Cj=u/sig //Jet velocity in m/s

```

```
//Output
printf('Jet velocity is %3.2f m/s',Cj)
```

Scilab code Exa 8.7.46 To calculate thrust propulsive efficiency and thrust power of a rocket

```
clc
clear

//Input data
Cj=2700 //Jet velocity in m/s
u=1350 //Flight velocity in m/s
m=78.6 //Propellent flow in kg/s

//Calculation
F=m*Cj*10^-3 //Thrust in kN
P=F*u*10^-3 //Thrust power in MW
sig=u/Cj //Jet speed ratio
eff=((2*sig)/(1+sig^2))*100 //Propulsive efficiency in %

//Output
printf('Thrust is %3.1f kN\n Thrust power is %3.2f MW\n Propulsive efficiency is %3i percent',F,P,eff)
```

Scilab code Exa 8.7.47 To determine orbital velocity and escape velocity of a rocket

```
clc
clear

//Input data
```

```
D=12683*1000 //Diameter of Earth in m
g=9.81 //Acceleration due to gravity in m/s
h=500*1000 //Altitude in m

//Calculation
Uorb=(D/2)*sqrt(g/((D/2)+h)) //Orbital velocity in m
    /s
Uesc=sqrt(2)*Uorb //Escape velocity in m/s

//Output
printf('Orbital velocity is %3.2f m/s\n Escape
    velocity is %3.2f m/s',Uorb,Uesc)
```

Scilab code Exa 8.7.48 To determine propulsive efficiency and propulsive power of a rocket

```
clc
clear

//Input data
u=10080*(5/18) //Flight velocity in m/s
Cj=1400 //Jet velocity in m/s
m=5 //Propellent flow in kg/s

//calculation
F=m*Cj*10^-3 //Thrust in kN
P=F*u*10^-3 //Thrust power in MW
sig=u/Cj //Jet speed ratio
eff=((2*sig)/(1+sig^2)) //Propulsive efficiency

//Output
printf('Propulsive power is %3.1f MW\n Propulsive
    efficiency is %3.1f',P,eff)
```