Scilab Textbook Companion for Aircraft Propulsion by S. Farokhi[1]

Created by
Mahesh Yadav
B. Tech
Others
Indian Institute Of Technology, Bombay
College Teacher
Prabhu Ramachandran
Cross-Checked by

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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 2

Compressible flow with friction and heat A review

Scilab code Exa 2.1 Brief review of thermodynamics

```
clear;
clc;
close;
disp("Example 2.1")
p=3*10^6 ; //pressure in Pa
t=298 ; //temperatue in kelvin
mw= 29; //molecular weight in kg/mol
ru=8314; //universal constant in J/kmol.K
r=ru/mw ;
//using perfect gas law to get density:
rho=p/(r*t) ;
disp(r,"Gas constant of air in J/kg.K:")
disp(rho,"Density of air in kg/m^3:")
```

Scilab code Exa 2.2 Isentropic process and isentropic flow

```
clear;
clc;
close;
disp("Example2.2")
t1=288; //inlet temperture in Kelvin
p1=100*10^3; //inlet pressure in Pa
p2=1*10^6 //exit pressure in Pa
gma=1.4; //gamma.
rg=287; //gas constant in J/kg.K
t2=t1*(p2/p1)^((gma-1)/gma);    //exit temperature
disp(t2,"Exit temperature in K:")
//first method to find exit density:
//application of perfect gas law at exit
rho=p2/(rg*t2); //rho= exit density.
disp(rho,"exit density at by method 1 in kg/m^3:")
//method 2: using isentropic relation between inlet
    and exit density.
rho1=p1/(rg*t1); //inlet density.
rho=rho1*(p2/p1)^(1/gma);
disp(rho,"exit density by method 2 in kg/m^3:")
```

Scilab code Exa 2.3 Conservation principle for systems and control volumes

```
clear;
clc;
close;
disp("Example2.3")
d1=1.2 //inlet 1 density in kg/m^3.
u1=25 // inlet 1 veocity in m/s.
a1=0.25 //inlet 1 area in m^2.
d2=0.2 //inlet 2 density in kg/m^3.
u2=225 //inlet 2 velocity in m/s.
a2=0.10 //inlet 2 area in m^2.
m1=d1*a1*u1; //rate of mass flow entering inlet 1.
```

```
m2=d2*u2*a2; //rate of mass flow entering inlet 2.
//since total mass in=total mass out,
m3=m1+m2; //m3=rate of mass flow through exit.
disp(m3,"Rate of mass flow through exit in kg/s:")
```

Scilab code Exa 2.4 Conservation principle for systems and control volumes

```
clear;
clc;
close;
disp("Example2.4")
u1=2 //speed of water going on the plate. X-
    component in m/s.
v1=0 //speed of water going on the plate. Y-
    component in m/s.
u2=1 //speed of water going on the plate. X-
    component in m/s.
v2=1.73 //speed of water going on the plate Y-
    coponent in m/s.
m=0.1 //rate of flow of mass of the water on the
    plate in kg/s.
//Using Newton's second law.
Fx=m*(u2-u1); //X-component of force exerted by
    water
disp(Fx,"Axial force needed to support the plate in
   N:")
Fy=m*(v2-v1); //Y-component of force exerted by
    water.
disp(Fy,"Lateral force needed to support the plate
    in N:")
```

Scilab code Exa 2.5 Conservation principle for systems and control volumes

```
clear;
clc;
close;
disp("Example2.5")
m=50 //mass flow rate in kg/s.
T1=298 //inlet temperature in K.
u1=150 //inlet velocity in m/s.
cp1=1004 //specific heat at constant pressure of inlet in J/kg.K.
gm=1.4 //gamma.
u2=400 // exit velocity in m/s.
cp2=1243. //specific heat at constant pressure of exit in J/kg.K.
q=42*10^6 //heat transfer rate in control volume in Watt.
me=-100*10^3 //mechanical power in Watt.
//first calculate total enthalpy at the inlet:
ht1=cp1*T1+(u1^2)/2; //ht1=Total inlet enthalpy.
//now applying conservation of energy equation:
ht2=ht1+((q-me)/m) //ht2=Total enthalpy at exit.
Tt2=ht2/cp2; //Tt2=Total exit temperature.
T2=Tt2-((u2^2)/(2*cp2)); //T2=static exit temperature.
disp(Tt2,"Exit total temperature in K:");
disp(T2,"Exit static temperature in K:");
```

Scilab code Exa 2.6 Flow through a constant area duct

```
clear;
clc;
close;
disp("Example2.6")
```

```
d=0.2 //Diameter in meters.
M1=0.2 //inlet Mach no.
p1=100*10^3 //inlet pressure in Pa
Tt1=288 //total inlet temperature in K
q=100*10^3 //rate of heat transfer to fluid in Watt.
rg=287 //Gas constant in J/kg.K.
gm=1.4 //gamma
//(a)inlet mass flow:
m=((gm/rg)^(1/2))*(p1/(Tt1)^(1/2))*3.14*(d^2)/4*(M1
    /(1+((gm-1)/2)*(M1^2))^((gm+1)/(2*(gm-1))));

//(b)
qm=q/m; //Heat per unit mass.
//Tt1/Tcr=0.1736, pt1/Pcr=1.2346, ((Delta(s)/R)
    1=6.3402,p1/Pcr=2.2727)
Tcr=Tt1/0.1736;

Pcr=p1/2.2727;
//From energy equation:
cp=(gm/(gm-1))*rg;
Tt2=Tt1+(q/cp);
q1cr=cp*(Tcr-Tt1)/1000;
M2=0.22;
//From table : pt2/Pcr=1.2281, (Delta(s)/R)2=5.7395,
     p2/Pcr=2.2477.
//The percent total pressure drop is (((pt1/Pcr)-(
    pt2/Pcr))/(pt1/Pcr))*100.
p2=2.2477*Pcr;
dp=((1.2346-1.2281)/1.2346)*100;
//Entropy rise is the difference between (delta(s)/R
    )1 and (delta(s)/R)2.
ds=6.3402-5.7395;
//Static pressure drop in duct due to heat transfer
    is
dps=((p1/Pcr)-(p2/Pcr))*Pcr/1000;
disp(m,"(a)Mass flow rate through duct in kg/s:")
disp(q1cr,"(b)Critical heat flux that would choke
    the duct for the M1 in kJ/kg:")
```

```
disp(M2,"(c)The exit Mach No.:")
disp(dp,"(d)The percent total pressure loss (%):")
disp(ds,"(e)The entropy rise (delta(s)/R):")
disp(dps,"(f)The static pressure drop Delta(p) in
    kPa")
```

Scilab code Exa 2.7 Flow through constant area combustion chamber

```
clear;
clc;
close;
disp("Example2.7")
M1=3.0 //Mach no. at inlet
pt1=45*10^3 //Total pressure t inlet in Pa
Tt1=1800 //Total temperature at inlet in K
hv=12000 //Lower heating value of hydrogen kJ/kg
gm=1.3 //gamma
R=0.287 //in kJ/kg.K
//Using RAYLEIGH table for M1=3.0 and gamma=1.3, we
    get Tt1/Tcr=0.6032, pt1/Pcr=4.0073.
Tcr=Tt1/0.6032
Pcr=pt1/4.0073
//if exit is choked, Tt2=Tcr
Tt2=Tt1/0.6032;
cp=gm*R/(gm-1);
//Energy balance across burner:
Q1cr=cp*(Tcr-Tt1);
f=(Q1cr/120000);
//total pressure loss:
dpt=1-Pcr/pt1;
disp(Tt2,"(a)Total exit temperature if exit is
    choked in K:")
disp(Q1cr,"(b)Maximum heat released per unit mass of
     air in kJ/kg:")
disp(f,"(c)fuel-to-air ratio to thermally choke the
```

```
combustor exit:")
disp(dpt,"(d)Total pressure loss (in fraction):")
```

Scilab code Exa 2.8 Heat transfer in subsonic flow in constant area duct

```
clear;
clc;
close;
disp("Example2.8")
Tt1=50+460 //Converting the inlet temp. to the
   absolute scale i.e. in degree R
M1=0.5 //Initial inlet Mach no.
pt1=14.7 //Units in psia
gm=1.4 //gamma
R=53.34 //units in ft.lbf/lbm.degree R
Tcr=Tt1/0.69136
cp=gm*R/(gm-1)
//using energy equation:
Q1cr=cp*(Tcr-Tt1)
//since heat flux is 1.2(Q1cr).
q=1.2*Q1cr
Tt1cr1=Tt1+(Q1cr'/cp) //new exit total temp.
z=Tt1/Tt1cr1
M2=0.473
function [f]=f(M)
    f=M/(1+((gm-1)/2)*M^2)^((gm+1)/(2*(gm-1)))
endfunction
sm=((f(M1)-f(M2))/f(M1))*100 //sm=The % spilled flow
    at the inlet
disp(M2,"(a)The new inlet Mach no. M2:")
disp(sm,"(b)The % spilled flow at the inlet:")
```

Scilab code Exa 2.9 Adiabatic flow of a calorically perfect gas in a constant area duct with friction

```
clear;
clc;
close;
disp("Example2.9")
d=0.2 //diameter in meters.
l=0.2 //length in meters.
Cf=0.005 //average wall friction coefficient.
M1=0.24 //inlet mach no.
gm=1.4 //gamma.
//From FANNO tbale
L1cr=(9.3866*d/2)/(4*Cf);
L2cr=L1cr-l;
//from FANNO table
M2=0.3;
x=2.4956;
y=2.0351;
a=4.5383;
b=3.6191;
i1=2.043;
i2=1.698;
//% total pressure drop due to friction:
dpt=(x-y)/(x)*100;
//static pressur drop:
dps=(a-b)/a*100;
//Loss pf fluid:
lf=(i2-i1);
disp(L1cr,"(a)The choking length of duct in m:")
disp(M2,"(b)The exit Mach no.:")
disp(dpt,"(c)% total pressure loss:")
disp(dps,"(d)The static pressure drop in %:")
disp(lf,"(e)Loss of impulse due to friction(I* times
    ):")
```

Scilab code Exa 2.10 Adiabatic flow of a calorically perfect gas in a constant area duct with friction

```
clear;
clc;
close;
disp("Example2.10")
M1=0.5
a=2 // area of cross section units in cm^2
Cf=0.005 //coefficient of skin friction
gm=1.4 //gamma
//Calculations
c=2*(2+1); //Parameter of surface.
//From FANNO table: 4*Cf*L1cr/Dh=1.0691;
Dh=4*a/c; //Hydrolic diameter.
L1cr=1.069*Dh/(4*Cf);
//maximum length will be L1cr.
//For new length(i.e. 2.16*L1cr), Mach no. M2 from
   FANNO table, M2=0.4;.
M2=0.4;
//the inlet total pressue and temp remains the same,
    therefore the mass flow rate in the duct is
   proportional to f(M):
function [f]=f(M)
    f=M/(1+((gm-1)/2)*M^2)^((gm+1)/(2*(gm-1)))
endfunction
dm=(f(M1)-f(M2))/f(M1)*100;
disp(L1cr,"(a)Maximum length of duct that will
   support given inlet condition(in cm):")
disp(M2,"(b)The new inlet condition mach no. M2:")
disp(dm,"(c)% inlet mass flow drop due to the longer
    length of the duct:")
```

Scilab code Exa 2.12 Subsonic diffuser

```
clear;
clc;
close;
disp("Example2.12")
M1=0.7;
dpt=0.99; //pt2/pt1=dpt.
gm=1.4; //gamma
//A2=1.237A1.
a=1/1.237;

//Calculations:
M2 = poly(0, "M2");
k=(1/dpt)*(a)*(M1/(1+(0.2*(M1)^2))^3)
pol = k*(1+(0.2*(M2)^2))^3 -M2;
W=roots(pol);
//disp(W)
i=1
while i<=6
z=W(i)
if imag(z)==0 then
    if real(z)<0.7 then  //since diffusing duct with inlet mach no. <1
        M2=z
    end
      end

i=i+1
end
disp(M2,"(a)The exit Mach no. M2:")
//p=p2/p1 i.e. static pressure ratio
p=dpt*((1+(gm-1)*(M1)^2/2)/(1+(gm-1)*(M2)^2/2))^(gm/(gm-1))
```

```
//disp(p)
Cpr=(2/(gm*(M1)^2))*(p-1) //Cpr is static pressure recovery : (p2-p1)/q1.
disp(Cpr,"(b)The static pressure recovery in the diffuser:")
//Change in fluid impulse:
//Fxwalls=I2-I1=A1p1(1+gm*M1^2)-A2p2(1+gm*M2^2)
//Let, u=Fxwall/(p1*A1)
u=1+gm*(M1)^2-(1.237)*(p)*(1+(gm*(M2)^2))
disp(u,"(c)The force acting on the diffuser inner wall nondimensionalized by inlet static pressure and area:")
```

Scilab code Exa 2.13 Supersonic nozzle

```
clear;
clc;
close;
disp("Example2.13")
M1=0.5 //inlet mach no.
p=10 //(p=pt1/p0) whaere pt1 is inlet total pressure and p0 is ambient pressure.
dpc=0.01 //dpc=(pt1-Pth)/pt1 i.e. total pressure loss in convergant section
f=0.99 //f=Pth/pt1
dpd=0.02 //dpd=(Pth-pt2)/Pth i.e. total pressure loss in the divergent section
j=1/0.98 //j=Pth/pt2
A=2 //a=A2/Ath. nozzle area expansion ratio.
gm=1.4 // gamma
R=287 //J/kg.K universal gas constant.
//Calculations:
//"th"" subscript denotes throat.
Mth=1 //mach no at thorat is always 1.
M2=poly(0,"M2")
```

```
k=(j)*(1/A)*(Mth/(1+(0.2*(Mth)^2))^3)
po=k*(1+(0.2*(M2)^2))^3 -M2;
W=roots(po)


i=1
s=1
while i<=6
z=W(i)
//disp(z)
if imag(z)==0 then
    if real(z)>1 then //since large nozzle pressure ratio ()
        M2=z
    end
      end

i=i+1
end
disp(M2,"(a)The exit Mach no. M2:")
//p2/pt2=1/(1+(gm-1)/2*M2^2)^(gm/(gm-1))
//pt2=(pt2/Pth)*(Pth/pt1)*(pt1/p0)*p0
//let pr=p2/p0
pr=((1/j)*f*p)/(1+(0.2*(M2)^2))^(gm/(gm-1))

disp(pr,"(b)The exit static pressure in terms of ambient pressure p2/p0:")//Fxwall=-Fxliquid=I1-I2

//let r=A1/Ath
r=(f)*(1/M1)*(((1+((gm-1)/2)*(M1)^2)/((gm+1)/2))^((gm+1)/(2*(gm-1))))
//disp(r)
//Psth is throat static pressure.
//z1=Psth/pt1=f/((gm+1)/2)^(gm/(gm-1))
z1=f/((gm+1)/2)^(gm/(gm-1))
//disp(z1)
//p1 is static pressure at inlet
//s1=p1/pt1
```

```
s1=1/(1+((gm-1)/2)*(M1)^2)^(gm/(gm-1))
//disp(s1)
//let y=Fxcwall/(Ath*pt1), where Fxwall is Fx converging-wall
y=s1*r*(1+(gm*(M1)^2))-(z1*(1+(gm*(Mth)^2)))
disp(y,"(c)The nondimensional axial force acting on the convergent nozzle:")
//similarly finding nondimensional force on the nozzle DIVERGENT section
//y1=Fxdiv-wall/Ath*pt1
//f1=p2/pt1
f1=pr*(1/p)
//disp(f1)
y1=z1*(1+(gm*(Mth)^2))-f1*A*(1+(gm*(M2)^2))
disp(y1,"(d)The nondimensional axial force acting on the divergent nozzle:")
//total axial force acting on nozzle wall: Fsum=y+y1
Fsum=y+y1
disp(Fsum,"(e)The total axial force(nondimensional) acting on the nozzle: ")
```

Scilab code Exa 2.14 Axial flow compressor

```
clear;
clc;
close;
disp("Example2.14")
p=20 //p=p2/p1 i.e. compression ratio.
gm=1.4 // gamma
//Vx1=Vx2 i.e. axial velocity remains same.
//calculations:
d=p^(1/gm) //d=d2/d1 i.e. density ratio
A=1/d // A=A2/A1 i.e. area ratio which is related to density ratio as: A2/A1=d1/d2.
//disp(A)
```

```
Fx=1-p*A  //Fx=Fxwall/p1*A1 i.e nondimensional axial
    force.
disp(Fx,"The non-dimensional axial force is :")
disp("The negative sign on the axial force
   experienced by the compressor structure signifies
    a thrust production by this component.")
```

Scilab code Exa 2.15 Combustor

```
clear;
clc;
close;
disp("Example 2.15")
t=1.8 //t=T2/T1
d=1/t //d=d2/d1 i.e. density ratio
v=1/d //v=Vx2/Vx1 axial velocity ratio
ndaf=1-(v) //nondimensional axial force acting on
   the combustor walls
disp(ndaf,"The nondimensional axial force acting on
   the combustor walls:")
disp("Negative sign signifies a thrust production by
    the device")
```

Scilab code Exa 2.16 Axial flow turbine

```
clear;
clc;
close;
disp("Example 2.16")
t=0.79 //T2/T1 i.e. turbione expansion
gm=1.4 //gamma
//calculations:
d=t^(1/(gm-1))
```

```
//disp(d)
a=1/d //area ratio
p=d^gm //pressure ratio
ndaf=1-p*a
disp(ndaf,"The nondimensional axial force:")
```

Chapter 3

Engine thrust and performance parameter

Scilab code Exa 3.1 Ram drag

```
clear;
clc;
close;
disp("Example 3.1")
M0=0.85 //Mach no.
a0=300 //speed of sound in m/s
m=50 //Air mass flow rate in kg/s
//Calculations
V0=M0*a0 //Flight speed
Dr=m*V0 //Ram drag
Dk=Dr/1000 //in kN
disp(Dk,"The ram drag for given engine in kN:")
```

Scilab code Exa 3.2 Gross thrust of separate flow turbofan

```
clear;
clc;
close;
disp("Example 3.2")
Cv=450 //exhaust velocity at core in m/s
Nv=350 //exhaust velocity at nozzle in m/s
Cm=50 //Mass flow rate through core in kg/s
Nm=350 //Mass flow rate through nozzle in kg/s
//Calculations:
//Newton's second law
Fgc=Cm*Cv //gross thrust of the core
Fgf=Nm*Nv //gross thrust of the nozzle fan
disp(Fgc,"Gross thrust of the core in SI unit(N):")
disp(Fgf,"Gross thrust of the fan nozzles in SI unit
    (N):")
```

Scilab code Exa 3.3 Rocket thrust

```
clear;
clc;
close;
disp("Example 3.3")
V9=4000 //in m/s
p9=200*10^3 //in Pa
p0=100*10^3 // in Pa
D=2 //in meter
m=200+50 // in kg/s
A=%pi*(D^2)/4 //nozzle exit area
//let p=(p9-p0)*A i.e. pressure thrust
p=(p9-p0)*A
mt=m*V9 //momentum thrust.
t=p+mt //rocket gross thrust
disp(p,"(a)The pressure thrust in SI units(N):")
disp(t,"(b)The rocket gross thrust in SI units(N):")
```

Scilab code Exa 3.4 Airbreathing engine performance parameters

```
clear;
clc;
close;
disp("Example 3.4")
m0=100 //air flow rate in kg/s
V0=0 //takeoff assumptions in m/s
mf=2 //2% of fuel-to-air ratio
Qr=43000 //Heating value of typical hydrocarbon fuel
    in kJ/kg
V9=900 //high speed exhaust jet (in m/s)
e=((m0+mf)*(V9)^2)/(2*(mf)*(Qr)*1000)
m9=m0+mf
t=m9*V9 // the engine thrust at takeoff.
disp(t,"The engine thrust at takeoff in SI units(N):
    ")
```

Scilab code Exa 3.5 Propulsive efficiency

```
clear;
clc;
close;
disp("Example 3.5")
V9=900 // in m/s
V0=200 // in m/s
e=2/(1+(V9/V0))
disp(e,"Engine propulsive efficiency:")
```

Scilab code Exa 3.6 Propulsive efficiency of turbofan engine

```
clear;
clc;
close;
disp("Example 3.6")
V9=250 //in m/s
V0=200 //in m/s
//Calculations:
e=2/(1+(V9/V0))
disp(e,"Propulsive efficiency:")
```

Chapter 4

Gas turbine engine cycle analysis

Scilab code Exa 4.1 The inlet parameters of the turbojet engine

```
clear;
clc;
close;
disp("Example 4.1");
M0=0.85
p0=10000 //ambient static pressure in Pa
pt2=15.88*10^3 //total pressure at the engine face
   in Pa
gm=1.4 //gamma
pt0=p0*((1+((gm-1)*(M0)^2)/2)^(gm/(gm-1)))
Pr=pt2/pt0 //Pr=total pressure recovery
ie=((pt2/p0)^((gm-1)/gm)-1)/(((gm-1)/2)*M0^2) //
   inlet adiabatic efficiency.
de=-log(Pr)
disp(Pr,"(a)The inlet total pressure recovery:")
disp(ie,"(b)The inlet adiabatic efficiency:")
disp(de,"(c)The nondimensional entropy rise caused
   by the inlet:")
```

Scilab code Exa 4.2 The multistage axial flow compressor parameters of the turbojet engine

```
clear;
clc;
close;
disp("Example 4.2")
m=50 //mass flow rate in kg/s
ec=0.9 //compressore polytropic efficiency
Tt2=288 //inlet total temp in K.
pt2=100000 // inlet total pressure in Pa
gm=1.4 //gama
cp=1004 //specific heat in J/kg.K
p=35 //total pressure ratio
tr=p^((gm-1)/(gm*ec)) //relation between total
    pressure and temp ratios
Tt3=Tt2*tr //Total exit temp
cae=(p^((gm-1)/gm)-1)/(tr-1) //compressor adiabatic
    efficiency
pc=m*cp*(Tt3-Tt2)/10^6 // compressor shaft power
disp(Tt3,"(a)Compressor exit total temperature in K
    :")
disp(cae,"(b)Compressor adiabatic efficiency:")
disp(pc,"(c)Comprssor shaft power in MW :")
```

Scilab code Exa 4.3 The combustor parameters of the turbojet engine

```
clear;
clc;
close;
disp("Example 4.3")
Tt3=800 //in K
```

```
pt3=2*10^6 // in Pa
m=50 //air mass flow rate in kg/s
gm=1.4 //gamma
cp3=1004 //specific heat at inlet in j/kg.K.
Qr=42000 //heating valuein kJ/kg
mf=1 //fuel flow rate in kg/s
be=0.995 //burner efficiency
p=0.96 //p=pt4/pt3
cp4=1156 //specific heat at exit in J/kg.K
f=mf/m // fuel-to-air ratio
Tt4=(((cp3/cp4)*Tt3)+((f*Qr*be*1000.)/cp4))/(1+f)
pt4=p*pt3/10^6
disp(f,"(a)Fuel-to-air ratio :")
disp(Tt4,"b(1) combustor exit total temperature in K
   :")
disp(pt4,"b(2)combustor exit total pressure in MPa")
```

Scilab code Exa 4.4 The turbine parameters of the turbojet engine

```
clear;
clc;
close;
disp("Example 4.4")
m=50 //air mass flow in kg/s
mf=1 // fuel mass flow in kg/s
tae=0.88 //turbine adiabatic efficiency
pe=45*10^6 //shaft power in Watt
cp4=1156 // in J/kg.K
Tt4=1390.0197 // in K
pt4=1.92 //units in MPa
cp5=cp4//specific heat
mt=m+mf//total mass
gm=1.33 //gamma
ht5=cp4*Tt4/1000-(pe/(mt*1000))
//disp(ht5)
```

```
Tt5=ht5/(cp5/1000)
y=Tt5/Tt4 //turbine expansion parameter
tpe=log(y)/log(1-(1-y)/tae)
pr=y^(gm/((gm-1)*tpe))
pt5=pr*pt4*1000 // turbine total exit pressure
pt=mt*cp5*(Tt4-Tt5)/10^6
disp(Tt5,"(a)Turbine exit total temperature in K :")
disp(tpe,"(b)Turbine polytropic efficiency:")
disp(pt5,"(c)Turbine exit total pressure in kPa :")
disp(pt,"(d)Turbine shaft power based on turbine expansion delta(Tt) in MW:")
```

Scilab code Exa 4.5 Mixed total enthalpy after the turbine nozzle blade

```
clear;
clc;
close;
disp("Example 4.5")
mc=0.5 //mass flow rate of coolant in kg/s
mg=50 //mass flow rate of hot gas in kg/s
htg=1850 // total enthalpy of gas in kJ/kg
htc=904 //total enthalpy of coolant in kJ/kg
Cpmixout=1594 //in j/kg.K
//Energy equation between mixed out state and mixed out state and the hot and cold stream solves this problem:
Htmixout=(mc*htc+mg*htg)/(mc+mg)
Ttmixout=Htmixout/(Cpmixout/1000)
disp(Htmixout,"Mixed-out total enthalpy after the nozzle in kJ/kg :")
disp(Ttmixout,"Mixed out temperature in K :")
```

Scilab code Exa 4.6 The internally cooled turbine parameters of the turbojet engine

```
clear;
clc;
close;
disp("Example 4.6")
Cpg=1156 //in J/kg.K
Pt4=1.92 //in MPa
gm=1.33 //gamma
htg=1850 //from example 4.5 in kJ/kg
htc=904 //from example 4.5 in kJ/kg
Cpc=1.04 //in kJ/kg.K
pl=.02 //total pressure loss ratio
Ttmixout=1154.7 //from example 4.5 in K.
//Calculations:
Ttg=htg/(Cpg/1000) //hotgas total temp in K.
Tt4=Ttg //same as nozzle entrance temp.
Ttc=htc/Cpc //coolant total temp.
Ptmixout=(1-pl)*Pt4 //mixed-out total temp.
//using gibbs equation
de=((gm/(gm-1))*log((Ttmixout/Tt4))-log(Ptmixout/
    Pt4)
disp(de,"Entropy change across the turbine nozzle
    blade row:")
disp("The negative sign of entropy change is due to
    cooling.")
disp("*Ans in book is incorrect as Ptmixout is
    calculated wrong!")
```

Scilab code Exa 4.7 The convergent divergent nozzle parameters of the turbojet engine

```
clear;
clc;
```

```
close;
disp("Example 4.7")
NPR=10 //Pressure ratio
gm=1.33 //gamma
Cp=1156 // in J/kg.K
ae=0.94 //adiabatic efficiency
tpr=((NPR)^((gm-1)/gm)-(ae*((NPR)^((gm-1)/gm)-1)))
   ^((-1)*(gm/(gm-1)))
disp(tpr,"(a)Nozzle total pressure ratio:")
de=-log(tpr) //entropy rise inadiabatic nozzle
//let p=pt9/p9
p=tpr*NPR*1 //p=pt9/p9; p0=p9 foe expanded nozzle
M9=((2/(gm-1))*((p)^(((gm-1)/gm))-1))^(1/2)
disp(M9,"(c)Nozzle exit Mach no. M9 (perfectly
   expanded)")
```

Scilab code Exa 4.10 Propulsive efficiency of turbojet engine

```
clear;
clc;
close;
disp("Example4.10")
Vt0=160 //takeoff velocity in m/s
Vt9=1000 //takeoff velocity in m/s
Vc0=800 //cruise velocity in m/s
Vc9=1000 //cruise velocity in m/s
//using approximation: engine propulsive efficiencfy
   (pe)=2/(1+V9/V0)
pet=2/(1+(Vt9/Vt0)) //takeoff
pec=2/(1+(Vc9/Vc0)) //cruise
disp(pet,"Engine propulsive efficiency while takeoff
   :")
disp(pec,"Engine propulsive efficiency while cruise:
   ")
```

Scilab code Exa 4.11 Turbojet engine with afterburner

```
clear;
clc;
close;
disp("Example 4.11")
M0=2.0 //Mach no.
p0=10//units in kPa
T0=228 //in K
gmc=1.4 //gamma compressor
Cpc=1004 //J/kg.K specific heat of compressor
pd=0.88 //compression ratio of diffuser
pc=12 // compression ratio of compressor
ec=0.9 //adiabatic efficiency of compressor
tl=8    //enthalpy ratio
Qr=42000 //kJ/kg
eb=0.98 //adiabatic efficiency of burner
pb=0.95 //compression ratio of burner
gmt=1.33 //gamma turbne
Cpt=1156 //J/kg.K specific heat turbine
et=0.82 //adiabatic efficiency of turbine
em=0.995
tlAB=11 //enthalpy ratio of afterburner (AB==
   AfterBurner)
QrAB=42000 //kJ/kg
eAB=0.98
pAB=0.93
gmAB=1.3 // gama AB
CpAB=1243 //J/kg.K
pn=0.93
a0=((gmc-1)*Cpc*T0)^(1/2)
V0=M0*a0
pt0=p0*(1+(((gmc-1)*(M0)^2)/2))^(gmc/(gmc-1)) //
   total flight pressure
```

```
Tt0=T0*(1+(((gmc-1)*(M0)^2)/2)) //total flight temp
Tt2=Tt0 //Adiabatic inlets
pt2=pt0*pd // in kPa
pt3=pt2*pc //compressor exit total pressure
k2=((gmc-1)/(gmc*ec))
//disp(k2)
tc=pc^k2 //relation between temp and pressure ratios
//disp(tc)
Tt3=Tt2*tc //total temp at compressor exit
Tt4=Cpc*T0*tl/Cpt //combustor exit total temp.
pt4=pt3*pb //combustor exit pressure
f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb*1000-Cpt*Tt4) //fuel-to-air ratio in burner
//disp(f)
Tt5=Tt4-(Cpc*((Tt3-Tt2)/(Cpt*em*(1+f)))) // turbine exit total temp
tt=Tt5/Tt4 //temp ratio in turbine
pt=tt^(gmt/(et*(gmt-1)))
pt5=pt4*pt //in kPa
pt7=pt5*pAB
Tt7=Cpc*T0*tlAB/CpAB //afterburner exit
fAB=(1+f)*((CpAB*Tt7)-(Cpt*Tt5))/((QrAB*eAB*1000)-(CpAB*Tt7))
//disp(fAB)
pt9=pt7*pn //in kPA
Tt9=Tt7 //adiabatic flow in nozzle
p9=p0
M9=((2/(gmAB-1))*((pt9/p9)^(((gmAB-1)/gmAB))-1))^(1/2) //nozzle exit
//disp(M9)
T9=Tt9/(1+((gmAB-1)*(M9)^2)/2)
a9=((gmAB-1)*CpAB*T9)^(1/2)
//disp(a9)
V9=M9*a9
//Performance parameters:
st=(1+f+fAB)*V9-V0 //st=Fn/m0; specific thrust when nozzle is perfectly expanded
ndst=((1+f+fAB)*V9/a0)-M0 //ndst=Fn/m0*ao ;
```

```
nondimensional specific thrust
TSFC=((f+fAB)/st)*10^6 //units mg/s/N
eth=(((1+f+fAB)*((V9)^2)/2)-((V0)^2)/2)/(f*Qr*1000+fAB*QrAB*1000) //cycle thermal efficiency
ep=st*V0/(((1+f+fAB)*(((V9)^2)/2))-((V0)^2)/2) //propulsive efficiency exact
epa=2/(1+V9/V0) //approx
disp("a(1)Total temperatures across the engine in K:")
disp(Tt0,"Flight total temperaure:")

disp(Tt2,"Toal temperature at compressor inlet:")
disp(Tt3,"Total temperature at compressor exit: ")
disp(Tt4,"Total temperature at burner exit:")
disp(Tt5,"Total temperature at turbine exit:")
disp(Tt7,"Total temperature at afterburner exit:")
disp(T9,"Total temperature at nozzle exit:")
disp(T9,"Nozzle exit static temperature:")
disp("a(2)Total pressures across the engine in kPa:")
disp(pt0,"Flight total pressure:")

disp(pt2,"Toal pressure at compressor inlet:")
disp(pt3,"Total pressure at compressor exit: ")
disp(pt4,"Total pressure at burner exit:")
disp(pt5,"Total pressure at turbine exit:")
disp(pt7,"Total pressure at afterburner exit:")
disp(pt9,"Total pressure at nozzle exit:")
disp(p9,"Nozzle exit static pressure:")
disp(ndst,"(b)Nondimensional specific thrust:")
disp(TSFC,"(c)Thrust specific fuel consumption TSFC (in mg/s/N):")
disp(eth,"d(1)Themal efficiency:")
disp(ep,"d(2)Exact propulsive efficiency:")
```

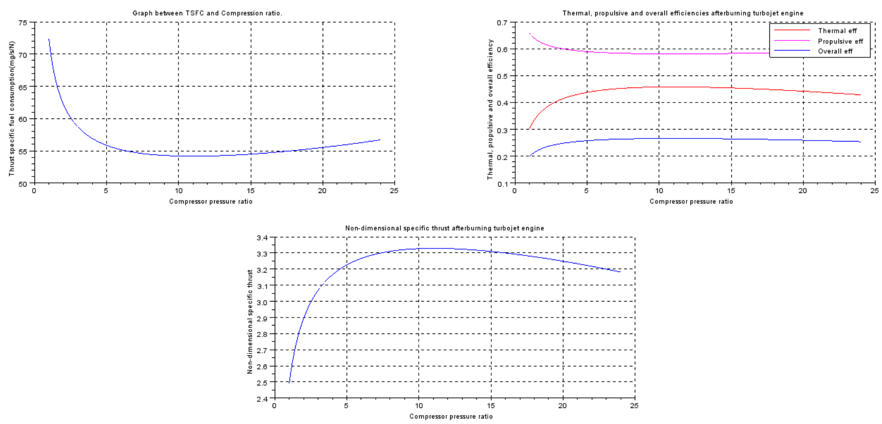

Figure 4.1: Effect of compressor pressure ratio on an afterburner turbojet engine

Scilab code Exa 4.12 Effect of compressor pressure ratio on an afterburner turbojet engine

```
clear;
clc;
close;
disp("Example4.12")
M0=2.0 //Mach no.
p0=10//units in kPa
T0=228 // in K
gmc=1.4 //gamma compressor
Cpc=1004 //J/kg.K specific heat of compressor
pd=0.88
ec=0.9
tl=8
Qr=42000 //kJ/kg
eb=0.98
pb=0.95
gmt=1.33 //gamma turbne
```

```
Cpt=1156 //J/kg.K specific heat turbine
et=0.82
em=0.995
tlAB=11
QrAB=42000 //kJ/kg
eAB=0.98
pAB=0.93
gmAB=1.3 // gama AB
CpAB=1243 //J/kg.K
pn=0.93
nc=24;
pc1=[1:0.01:nc];
a=[];
count=1;
g2=[]
cg2=1;
g3=[]
cg3=1;
g4=[]
cg4=1;
g5=[]
cg5=1;

pc=1;
for pc=1:0.01:24
    a0=((gmc-1)*Cpc*T0)^(1/2);
    V0=M0*a0;
    pt0=p0*(1+(((gmc-1)*(M0)^2)/2))^(gmc/(gmc-1)); //total flight pressure
    Tt0=T0*(1+(((gmc-1)*(M0)^2)/2)); //total flight temp
    Tt2=Tt0 ;//Adiabatic inlets
    pt2=pt0*pd; // in kPa
    pt3=pt2*pc; //compressor exit total pressure
    k2=((gmc-1)/(gmc*ec));
    //disp(k2)
    tc=pc^k2; //relation between temp and pressure ratios
```

```
//disp(tc)
Tt3=Tt2*tc; //total temp at compressor exit
Tt4=Cpc*T0*tl/Cpt; //combustor exit total temp.
pt4=pt3*pb; //combustor exit pressure
f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb*1000-Cpt*Tt4); //fuel-to-air ratio in burner
//disp(f)
Tt5=Tt4-(Cpc*((Tt3-Tt2)/(Cpt*em*(1+f)))); //turbine exit total temp
tt=Tt5/Tt4; //temp ratio in turbine
pt=tt^(gmt/(et*(gmt-1)));
pt5=pt4*pt; //in kPa
pt7=pt5*pAB;
Tt7=Cpc*T0*tlAB/CpAB; //afterburner exit
fAB=(1+f)*((CpAB*Tt7)-(Cpt*Tt5))/((QrAB*eAB*1000)-(CpAB*Tt7));
//disp(fAB);
pt9=pt7*pn; //in kPA
Tt9=Tt7 ;//adiabatic flow in nozzle
p9=p0;
M9=((2/(gmAB-1))*((pt9/p9)^(((gmAB-1)/gmAB))-1))^(1/2); //nozzle exit
//disp(M9)
T9=Tt9/(1+((gmAB-1)*(M9)^2)/2);
a9=((gmAB-1)*CpAB*T9)^(1/2);
//disp(a9)
V9=M9*a9;
//Performance parameters:
st=(1+f+fAB)*V9-V0; //st=Fn/m0; specific thrust when nozzle is perfectly expanded
ndst=((1+f+fAB)*V9/a0)-M0; //ndst=Fn/m0*ao ; nondimensional specific thrust
TSFC=((f+fAB)/st)*10^6 ;//units mg/s/N
eth=(((1+f+fAB)*((V9)^2)/2)-((V0)^2)/2)/(f*Qr*1000+fAB*QrAB*1000); //cycle thermal efficiency
ep=st*V0/(((1+f+fAB)*(((V9)^2)/2))-((V0)^2)/2); //propulsive efficiency exact
```

```
    epa=2/(1+V9/V0) ;//approx
    oe=ep*eth;
    a(count)=TSFC;
    count = count+1;
    g2(cg2)=eth;
    cg2=cg2+1
    g3(cg3)=ep
    cg3=cg3+1
    g4(cg4)=oe
    cg4=cg4+1
    g5(cg5)=ndst
    cg5=cg5+1;
end
x=gca()
x.data_bounds=[1,50;24,75]
subplot(2,2,1)
plot2d1(pc1,a,2);
xlabel("Compressor pressure ratio")
ylabel("Thrust specific fuel consumption(mg/s/N)")
title("Graph between TSFC and Compression ratio.")
xgrid(1)
subplot(2,2,2)
y=gca()
y.data_bounds=[1,0.2;23,0.7]
plot2d2(pc1,g2,5);
xgrid(1)
xlabel("Compressor pressure ratio")
ylabel("Thermal, propulsive and overall efficiency")
title("Thermal, propulsive and overall efficiencies
   afterburning turbojet engine")
plot2d(pc1,g3,6)
plot2d(pc1,g4,2)
legend(['Thermal eff';'Propulsive eff';'Overall eff'
   ])
subplot(2,2,3.5)
plot2d(pc1,g5,2)
xgrid(1)
xlabel("Compressor pressure ratio")
```

```
ylabel("Non−dimensional specific thrust")
title("Non−dimensional specific thrust afterburning
    turbojet engine")
```

Scilab code Exa 4.13 High bypass ratio turbofan engine

```
clear;
clc;
close;
disp("Example4.13")
M0=0.88 //Mach no.
p0=15 // pressure in kPa
T0=233 //temperatue in K
gmc=1.4 //gamma compressor
Cpc=1004 //specific heat of compressor in J/kg.K
pd=0.995 // pressure compression ratio of diffuser
pf=1.6 //pressure compression ratio of fan
ef=0.9 //fan efficiency
alfa=8
pfn=0.95 //compression ratio of convergent fan
    nozzle
pc=40 //compression ratio of compressor
ec=0.9 //compressor efficiency
tl=8 //temp. ratio
Cpt=1152 //in J/kg.K of turbine
gmt=1.33 //gamma turbine
Qr=42000000 //in J/kg
pb=0.95 //burner compression ratio
eb=0.992 //burner efficiency
em=0.95
et=0.85
pn=0.98 //primary nozzle
a0=((gmc-1)*Cpc*T0)^(1/2);
V0=M0*a0;
pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
```

```
Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
Tt2=Tt0
pt2=pt0*pd
//fan stream:
pt13=pt2*pf
tf=pf^((gmc-1)/(ef*gmc))
Tt13=Tt2*tf
pt19=pt13*pfn
p19=pt19/(1+(gmc-1)/2)^(gmc/(gmc-1))
M19=1
T19=Tt13/1.2
a19=((gmc-1)*Cpc*T19)^(1/2)
V19=a19
//V19eff=V19+((gmc*p19)/r19)*((1-p0/p19)/(gmc*V19)) i.e V19+a19^2
V19eff=V19+(a19^2)*((1-p0/p19)/(gmc*V19))
//Core stream
pt3=pt2*pc
tc=pc^((gmc-1)/(ec*gmc))
//disp(tc)
Tt3=Tt2*tc
pt4=pt3*pb
Tt4=Cpc*T0*tl/Cpt
//disp(Tt4)
f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
//disp(f)
Tt5=Tt4-((Cpc*(Tt3-Tt2)+alfa*Cpc*(Tt13-Tt2)))/((1+f)*Cpt*em)
//disp(Tt5)
tt=Tt5/Tt4
pt=tt^(gmt/(et*(gmt-1)))
pt5=pt4*pt
pt9=pt5*pn
p9=pt9/((gmt+1)/2)^(gmt/(gmt-1))
M9=1
T9=Tt5/((gmt+1)/2)
a9=((gmt-1)*Cpt*T9)^(1/2)
V9=a9
```

```
V9eff=V9+(((a9)^2)*(1-(p0/p9)))/(gmt*V9)
ndsft=alfa*(V19eff-V0)/((1+alfa)*a0)
ndsct=((1+f)*V9eff-V0)/((1+alfa)*a0)
ndst=ndsft+ndsct
rfct=ndsft/ndsct
fc=ndsft*100/(ndsft+ndsct)
cc=ndsct*100/(ndsft+ndsct)
TSFC=f/((1+alfa)*a0*(ndsft+ndsct))*10^6
eth=(alfa*V19eff^2+(1+f)*V9eff^2-(1+alfa)*V0^2)/(2*f*Qr)
ep=(2*(ndsft+ndsct)*(1+alfa)*a0*V0)/(alfa*V19eff^2+(1+f)*V9eff^2-(1+alfa)*V0^2)
eo=eth*ep
//Pressures
disp("a(1)Total pressures throughout the engine in kPa:")
disp(pt0,"Total pressure of flight:")
disp(pt2,"Total pressure at engine face:")
disp(pt13,"Total pressure at fan exit:")

disp(p19,"Static pressure at nozzle exit:")
disp(pt3,"Total pressure at compressor exit:")
disp(pt4,"Total pressure at burner exit:")
disp(pt5,"Total pressure at turbine exit:")
disp(pt9,"Total pressure at nozzle exit:")

//Temperatures
disp("a(2)Total temperatures across the engine in K:")
disp(Tt0,"Total temperature of flight:")
disp(Tt2,"Total temperature at engine face:") //Tt0=Tt2, since adiabatic!
disp(Tt13,"Total temperature at fan exit:")
disp(T19,"Static  temperature at fan nozzle exit:")
disp(Tt3,"Total temperature at compressor exit:")
disp(Tt4,"Total temperature at burner exit:")
disp(Tt5,"Total temperature at turbine exit:")
disp(T9,"Static temperature at nozzle exit:")
```

```
disp(pt19,"(b{1})Total pressure at fan nozzle exit:")
disp(p9,"(b{2})Static pressure at nozzle exit:")


//Remaining results
disp(V19,"(c{1}Actual fan nozzle exit velocity in m/s:)")
disp(V19eff,"(c{2}Effective fan nozzle exit velocity in m/s:)")
disp(V9,"(c{3})Actual core nozzle exit velocity in m/s:")
disp(V9eff,"(c{4})Effective nozzle exit velocity in m/s:")
disp(rfct,"(d)Ratio of fan-tocore thrust:")
disp(ndst,"(e)Nondimensional specific thrust:")
disp(TSFC,"(f)TSFC in mg/s/N:")
disp("(g)Engine efficiencies:")
disp(eth,"Thermal efficiency:")
disp(ep,"Propulsion effciency:")
disp(eo,"Overall efficiency:")
```

Scilab code Exa 4.14 Graph of the performance of separate exhaust turbofan engine for a range of bypass ratios from 0 to 8

```
clear;
clc;
close;
disp("Example4.14")
M0=0.88 //Mach no.
p0=15 // pressure in kPa
T0=233 //temperatue in K
gmc=1.4 //gamma compressor
```

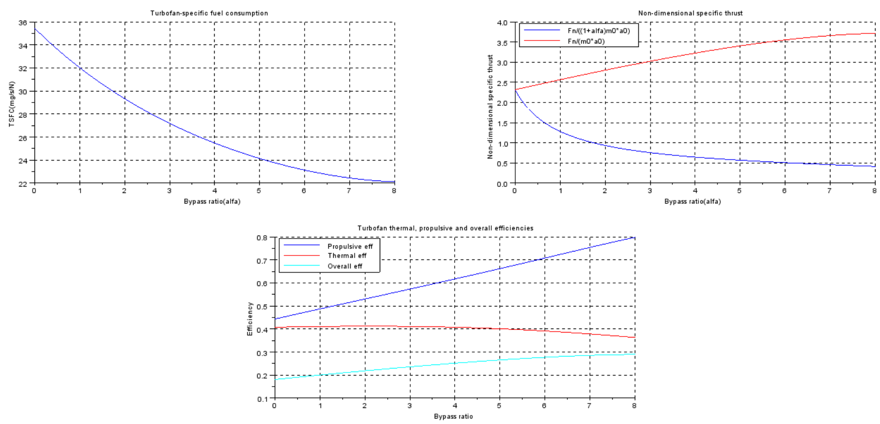

Figure 4.2: Graph of the performance of separate exhaust turbofan engine for a range of bypass ratios from 0 to 8

```
Cpc=1004 //specific heat of compressor in J/kg.K
pd=0.995 // pressure compression ratio of diffuser
pf=1.6 //pressure compression ratio of fan
ef=0.9 //fan efficiency
pfn=0.95 //compression ratio of convergent fan
   nozzle
pc=40 //compression ratio of compressor
ec=0.9 //compressor efficiency
tl=8 //temp. ratio
Cpt=1152 //in J/kg.K of turbine
gmt=1.33 //gamma turbine
Qr=42000000 //in J/kg
pb=0.95 //burner compression ratio
eb=0.992 //burner efficiency
em=0.95
et=0.85
pn=0.98 //primary nozzle
kl=8
z0=[0:0.005:kl]
x=[]
count=1
g1=[]
```

```
gc1=1
g2=[]
gc2=1
g3=[]
gc3=1
g4=[]
gc4=1
g5=[]
gc5=1
g6=[]
gc6=1
alfa=0
for alfa=0:0.005:8


a0=((gmc-1)*Cpc*T0)^(1/2);
V0=M0*a0;
pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))


Tt0=T0*(1+((gmc-1)*(M0)^2)/2)

Tt2=Tt0

pt2=pt0*pd

//fan stream:
pt13=pt2*pf
tf=pf^((gmc-1)/(ef*gmc))
Tt13=Tt2*tf
pt19=pt13*pfn
p19=pt19/(1+(gmc-1)/2)^(gmc/(gmc-1))
M19=1
T19=Tt13/1.2
a19=((gmc-1)*Cpc*T19)^(1/2)
V19=a19
//V19eff=V19+((gmc*p19)/r19)*((1-p0/p19)/(gmc*V19))
    i.e V19+a19^2
```

```
V19eff=V19+(a19^2)*((1-p0/p19)/(gmc*V19))
//Core stream
pt3=pt2*pc
tc=pc^((gmc-1)/(ec*gmc))
//disp(tc)
Tt3=Tt2*tc
pt4=pt3*pb
Tt4=Cpc*T0*tl/Cpt
//disp(Tt4)
f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
//disp(f)
Tt5=Tt4-((Cpc*(Tt3-Tt2)+alfa*Cpc*(Tt13-Tt2)))/((1+f)*Cpt*em)
//disp(Tt5)
tt=Tt5/Tt4
pt=tt^(gmt/(et*(gmt-1)))
pt5=pt4*pt
pt9=pt5*pn
p9=pt9/((gmt+1)/2)^(gmt/(gmt-1))
M9=1
T9=Tt5/((gmt+1)/2)
a9=((gmt-1)*Cpt*T9)^(1/2)
V9=a9
V9eff=V9+(((a9)^2)*(1-(p0/p9)))/(gmt*V9)
ndsft=alfa*(V19eff-V0)/((1+alfa)*a0)
ndsct=((1+f)*V9eff-V0)/((1+alfa)*a0)
ndst=ndsft+ndsct
ndsta=ndst*(1+alfa)
rfct=ndsft/ndsct
fc=ndsft*100/(ndsft+ndsct)
cc=ndsct*100/(ndsft+ndsct)
TSFC=f/((1+alfa)*a0*(ndsft+ndsct))*10^6
eth=(alfa*V19eff^2+(1+f)*V9eff^2-(1+alfa)*V0^2)/(2*f*Qr)
ep=(2*(ndsft+ndsct)*(1+alfa)*a0*V0)/(alfa*V19eff^2+(1+f)*V9eff^2-(1+alfa)*V0^2)
eo=eth*ep
x(count)=TSFC;
```

```
count=count+1;
g1(gc1)=ndst
gc1=gc1+1
g2(gc2)=ndsta
gc2=gc2+1
g3(gc3)=ep
gc3=gc3+1
g4(gc4)=eth
gc4=gc4+1
g5(gc5)=eo
gc5=gc5+1
end

subplot(2,2,1)
plot2d(z0,x,2)
xgrid
title("Turbofan-specific fuel consumption")
xlabel("Bypass ratio(alfa)")
ylabel("TSFC(mg/s/N)")
subplot(2,2,2)
plot2d(z0,g1,2)
xgrid
xlabel("Bypass ratio(alfa)")
ylabel("Non-dimensional specific thrust")
title("Non-dimensional specific thrust")
plot2d(z0,g2,5)
legend(['Fn/((1+alfa)m0*a0)';'Fn/(m0*a0)'],2)
subplot(2,2,3.5)
plot2d(z0,g3,2)
xgrid
xlabel("Bypass ratio")
ylabel("Efficiency")
title("Turbofan thermal, propulsive and overall
    efficiencies")

plot2d(z0,g4,5)
plot2d(z0,g5,4)
legend(['Propulsive eff';'Thermal eff';'Overall eff'
```

```
],2)
```

Scilab code Exa 4.15 Mixed exhaust turbofan engine with afterburner

```
clear;
clc;
close;
disp("Example 4.15")
M0=2 //Mach no.
p0=10 // in kPa
T0=223 //in K
//the engine inlet total pressure loss is characterized by
pd=0.9
//The fan pressure ratio is
pf=1.9
//and polytropic efficiency of the fan is
ef=0.9
//The flow in the fan duct suffers 1% total pressure loss i.e.
pfd=0.99
//The compressor pressure ratio and polytropic efficiency are
pc=13
ec=0.9 //respectively
//The combustor exit temperature is
Tt4=1600 //in K
Qr=42000000 //fuel heating value in J/kg
pb=0.95 //total pressure ratio
eb=0.98 //burner efficiency
et=0.8 //turbine polytropic efficiency
em=0.95 //mechanical efficiency of turbine
M5=0.5 //Mach no at turbine exit
pmf=0.98 //total pressure loss due to friction in mixer
```

```
Tt7=2000 //afterburner total temp in K
QrAB=42000000 //in J/kg
pABon=0.92
eAB=0.98
pn=0.95 //total pressure ratio at nozzle
p=3.8 //p=p9/p0
gmc=1.4 //gamma compressor
Cpc=1004 //specofic heat compressor in J/kg.K
gmt=1.33 //gamma turbine
Cpt=1152 //turbine
gmAB=1.3 //afterburner
CpAB=1241 //afterburner
pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
pr=pt0/p0
tr=Tt0/T0
pt=pfd*pf/(pb*pc)
a0=((gmc-1)*Cpc*T0)^(1/2);
V0=a0*M0
Tt2=Tt0
pt2=pt0*pd
pt13=pt2*pf
tf=pf^((gmc-1)/(ec*gmc))
//disp(tf)
Tt13=Tt0*tf
Tt15=Tt13 //adiabatic
pt15=pt13*pfd
pt3=pt2*pc
tc=pc^((gmc-1)/(ec*gmc))
Tt3=Tt2*tc
pt4=pt3*pb
f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
//disp(f)
pt5=pt15 //assumption
pt=(pfd*pf)/(pb*pc)
//disp(pt)
tt=pt^(et*(gmt-1)/(gmt))
//disp(tt)
```

```
Tt5=Tt4*tt
tl=(Cpt*Tt4)/(Cpc*T0)
tr=(1+((gmc-1)*(M0^2)/2))
alfa=((em*(1+f)*tl*(1-tt))-(tr*(tc-1)))/(tr*(tf-1))
ht6M=Cpc*T0*((1+f)*tt*tl+alfa*tf*tr)/(1+alfa+f) // mixed-out total enthalpy in J/kg
Cp6M=(((1+f)/alfa)*Cpt+Cpc)/(((1+f)/alfa)+1)
gm6M=(((1+f)/alfa)*Cpt+Cpc)/(((1+f)/alfa)*(Cpt/gmt)+(Cpc/gmc))
M15=((2/(gmc-1))*(((((1+((gmt-1)*(M5^2)/2))^(gmt/(gmt-1)))^((gmc-1)/gmc))-1))^(1/2)
T15=Tt15/(1+((gmc-1)*(M15)^2)/2)
p15=pt15/(1+((gmc-1)*(M15)^2)/2)^(gmc/(gmc-1))
T5=Tt5/(1+((gmt-1)*(M5)^2)/2)
p5=pt5/(1+((gmt-1)*(M5)^2)/2)^(gmt/(gmt-1))
a15=((gm6M-1)*Cp6M*T15)^(1/2)
a5=((gm6M-1)*Cp6M*T5)^(1/2)
A=((alfa/(1+f))*(gmt/gmc)*((T15/T5)^(1/2))*(M5/M15))
C1=((1+gmt*M5^2)+(A*(1+gmc*M15^2)))/(1+A)
Tt6M=ht6M/Cp6M
C2=((gmt/gm6M)*(M5/a5)+(gmc/gm6M)*(M15*A/a15))*(((gm6M-1)*Cp6M*(Tt6M))^(1/2))/(1+A)
C=(C1/C2)^2
M6M=((C-2*gm6M-((C-2*gm6M)^2-4*(gm6M^2-(C*(gm6M-1))/2))^(1/2))/(2*(gm6M)^2-C*(gm6M-1)))^(1/2)
p6M=p5*(C1/(1+gm6M*(M6M)^2))
pt6Mi=131.23
pmi=0.9907
pM=0.9709
pt6M=pt6Mi*pmf
Tt7=2000
pABon=0.92
pt7=118.32
fAB=(CpAB*Tt7-ht6M)/(QrAB*eAB-CpAB*Tt7)
pt9=pt7*pn
p9=p0*p
M9=1.377
T9=1557.2
```

```
a9=761.4
V9=a9*M9
V9eff=V9+a9^2*(1-p0/p9)/(gmAB*V9)
ndst=((1+alfa+f+fAB)/(1+alfa))*(V9eff/a0)-M0
TSFC=((f+fAB)/((1+alfa)*a0))*10^6/(ndst)
eth=(((1+alfa+f+fAB)*((V9eff)^2))-((1+alfa)*V0^2))/(2*(f*Qr+fAB*QrAB))
ep=(2*ndst*V0*a0*(1+alfa))/((1+alfa+f+fAB)*V9eff^2-(1+alfa)*V0^2)
e0=ep*eth
disp("a(1)Total pressures throughout the engine in kPa:")
disp(pt0,"Total pressure of flight:")
disp(pt2,"Total pressure at engine face:")
disp(pt15,"Total pressure at fan exit:")
//disp(p19,"Static pressure at nozzle exit:")
disp(pt3,"Total pressure at compressor exit:")
disp(pt4,"Total pressure at burner exit:")
disp(pt5,"Total pressure at turbine exit:")
disp(pt9,"Total pressure at nozzle exit:")


disp("a(2)Total temperatures across the engine in K:")
disp(Tt0,"Total temperature of flight:")
disp(Tt2,"Total temperature at engine face:") //Tt0=Tt2, since adiabatic!
disp(Tt13,"Total temperature at fan exit:")
disp(Tt15,"Total temperature at fan duct :")
disp(Tt3,"Total temperature at compressor exit:")
disp(Tt4,"Total temperature at burner exit:")
disp(Tt5,"Total temperature at turbine exit:")
disp(alfa,"a(3)Fan bypass ratio :")
disp(f,"a(4)fuel-to-air ratio in primary :")
disp(fAB,"a(5)fuel-to-air ratio in afterburner :")
disp(TSFC,"b(1)TSFC in mg/s/N :")
disp(ndst,"b(2)Non-dimensional specific thrust :")
disp(ep,"b(3)Propulsive efficiency :")
```

```
disp(eth,"b(4)Thermal efficiency :")
disp(e0,"b(5)Overall efficiency :")
```

Scilab code Exa 4.16 Engine performance of a mixed exhaust turbofan engine with afterburner having same parameters as in previous example for a range of compressor pressure ratios from 6 to 16

```
clear;
clc;
close;
disp("Example 4.16")
M0=2 //Mach no.
p0=10 // in kPa
T0=223 //in K
//the engine inlet total pressure loss is characterized by
pd=0.9
//The fan pressure ratio is
pf=1.9
//and polytropic efficiency of the fan is
ef=0.9
//The flow in the fan duct suffers 1% total pressure loss i.e.
pfd=0.99
//The compressor pressure ratio and polytropic efficiency are
pc=6
ec=0.9 //respectively
//The combustor exit temperature is
Tt4=1600 //in K
Qr=42000000 //fuel heating value in J/kg
pb=0.95 //total pressure ratio
eb=0.98 //burner efficiency
et=0.8 //turbine polytropic efficiency
em=0.95 //mechanical efficiency of turbine
```

```
M5=0.5 //Mach no at turbine exit
pmf=0.98 //total pressure loss due to friction in
    mixer
Tt7=2000 //afterburner total temp in K
QrAB=42000000 //in J/kg
pABon=0.92
eAB=0.98
pn=0.95 //total pressure ratio at nozzle
p=3.8 //p=p9/p0
gmc=1.4 //gamma compressor
Cpc=1004 //specofic heat compressor in J/kg.K
gmt=1.33 //gamma turbine
Cpt=1152 //turbine
gmAB=1.3 //afterburner
CpAB=1241 //afterburner
z0=[6:0.1:16]
x=[]
count=1
g2=[]
gc2=1
g3=[]
gc3=1
g4=[]
gc4=1
g5=[]
gc5=1
g6=[]
gc6=1
g7=[]
gc7=1
for pc=6:0.1:16

pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
pr=pt0/p0
tr=Tt0/T0
pt=pfd*pf/(pb*pc)
a0=((gmc-1)*Cpc*T0)^(1/2);
```

```
V0=a0*M0
Tt2=Tt0
pt2=pt0*pd
pt13=pt2*pf
tf=pf^((gmc-1)/(ec*gmc))
Tt13=Tt0*tf
Tt15=Tt13 //adiabatic
pt15=pt13*pfd
pt3=pt2*pc
tc=pc^((gmc-1)/(ec*gmc))
Tt3=Tt2*tc
pt4=pt3*pb
f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
pt5=pt15 //assumption
pt=(pfd*pf)/(pb*pc)
tt=pt^(et*(gmt-1)/(gmt))
Tt5=Tt4*tt
tl=(Cpt*Tt4)/(Cpc*T0)
tr=(1+((gmc-1)*(M0^2)/2))
alfa=((em*(1+f)*tl*(1-tt))-(tr*(tc-1)))/(tr*(tf-1))
ht6M=Cpc*T0*((1+f)*tt*tl+alfa*tf*tr)/(1+alfa+f) //
    mixed-out total enthalpy in J/kg
Cp6M=(((1+f)/alfa)*Cpt+Cpc)/(((1+f)/alfa)+1)
gm6M=(((1+f)/alfa)*Cpt+Cpc)/(((1+f)/alfa)*(Cpt/gmt)
    +(Cpc/gmc))
M15=((2/(gmc-1))*((((1+((gmt-1)*(M5^2)/2))^(gmt/(gmt
    -1)))^((gmc-1)/gmc))-1))^(1/2)
T15=Tt15/(1+((gmc-1)*(M15)^2)/2)
p15=pt15/(1+((gmc-1)*(M15)^2)/2)^(gmc/(gmc-1))
T5=Tt5/(1+((gmt-1)*(M5)^2)/2)
p5=pt5/(1+((gmt-1)*(M5)^2)/2)^(gmt/(gmt-1))
a15=((gm6M-1)*Cp6M*T15)^(1/2)
a5=((gm6M-1)*Cp6M*T5)^(1/2)
A=((alfa/(1+f))*(gmt/gmc)*((T15/T5)^(1/2))*(M5/M15))
C1=((1+gmt*M5^2)+(A*(1+gmc*M15^2)))/(1+A)
Tt6M=ht6M/Cp6M
C2=((gmt/gm6M)*(M5/a5)+(gmc/gm6M)*(M15*A/a15))*(((
    gm6M-1)*Cp6M*(Tt6M))^(1/2))/(1+A)
```

```
C=(C1/C2)^2
M6M=((C-2*gm6M-((C-2*gm6M)^2-4*(gm6M^2-(C*(gm6M-1))
   /2))^(1/2))/(2*(gm6M)^2-C*(gm6M-1)))^(1/2)
p6M=p5*(C1/(1+gm6M*(M6M)^2))
pt6Mi=131.23
pmi=0.9907
pM=0.9709
pt6M=pt6Mi*pmf
Tt7=2000
pABon=0.92
pt7=118.32
fAB=(CpAB*Tt7-ht6M)/(QrAB*eAB-CpAB*Tt7)
ft=f+fAB
pt9=pt7*pn
p9=p0*p
M9=1.377
T9=1557.2
a9=761.4
V9=a9*M9
V9eff=V9+a9^2*(1-p0/p9)/(gmAB*V9)
ndst=((1+alfa+f+fAB)/(1+alfa))*(V9eff/a0)-M0
TSFC=((f+fAB)/((1+alfa)*a0))*10^6/(ndst)
eth=(((1+alfa+f+fAB)*((V9eff)^2))-((1+alfa)*V0^2))
   /(2*(f*Qr+fAB*QrAB))
ep=(2*ndst*V0*a0*(1+alfa))/((1+alfa+f+fAB)*V9eff
   ^2-(1+alfa)*V0^2)
e0=ep*eth
x(count)=TSFC;
count=count+1;
g2(gc2)=ndst
gc2=gc2+1
g3(gc3)=ep
gc3=gc3+1
g4(gc4)=eth
gc4=gc4+1
g5(gc5)=e0
gc5=gc5+1
g6(gc6)=alfa
```

```
gc6=gc6+1
g7(gc7)=ft
gc7=gc7+1
end
subplot(2,2,1)
plot2d(z0,x,2)
xgrid
title("TSFC in an AB—mixed flow turbofan engine")
xlabel("Compression pressure ratio")
ylabel("TSFC(mg/s/N)")
subplot(2,2,2)
plot2d(z0,g2,2)
xgrid
xlabel("Compressor pressure ratio")
ylabel("Non−dimensional specific thrust")
title("Specific thrust variation")
subplot(2,2,3)
plot2d(z0,g3,2)
plot2d(z0,g4,5)
plot2d(z0,g5,6)
xgrid
xlabel("Compressor pressure ratio")
ylabel("Efficiency")
title("Engine Efficiency")
legend(['Propulsive','Thermal','Overall'],2)
subplot(2,2,4)
plot2d(z0,g6,2)
xgrid
xlabel("Compressor pressure ratio")
ylabel("Bypass ratio")
title("Bypass ratio variation in an AB—mixed flow
   turbofan engine")
figure(1)
plot2d(z0,g7,2)
xgrid
xlabel("Compressure pressure ratio")
ylabel("f+fAB")
title("f+fAB")
```

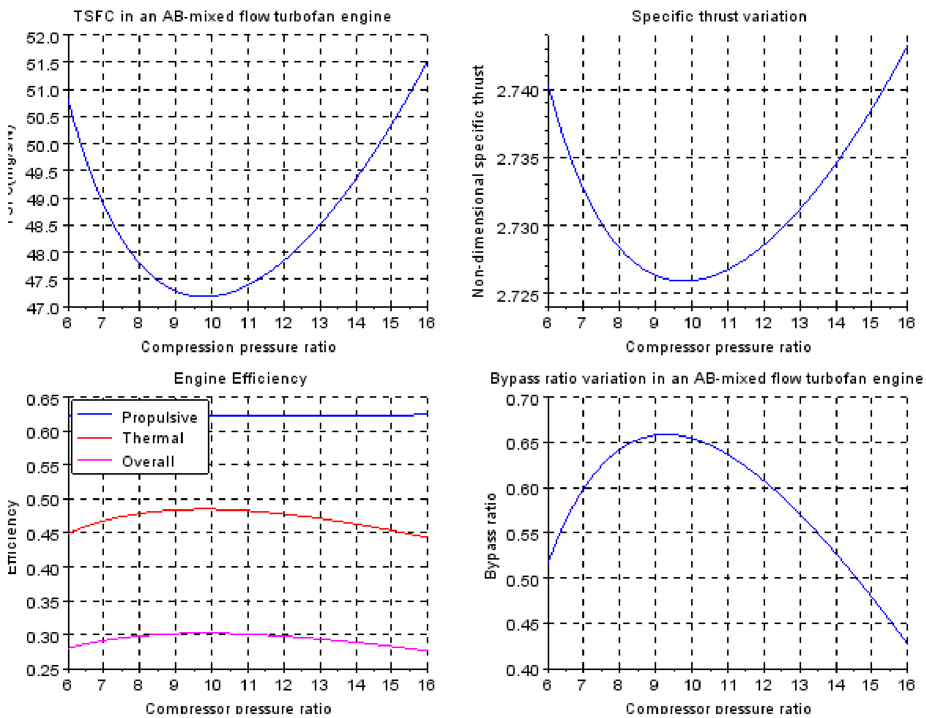

Figure 4.3: Engine performance of a mixed exhaust turbofan engine with afterburner having same parameters as in previous example for a range of compressor pressure ratios from 6 to 16

Scilab code Exa 4.17 The turboprop engine performance parameter

```
clear;
clc;
close;
disp("Example 4.17")
```

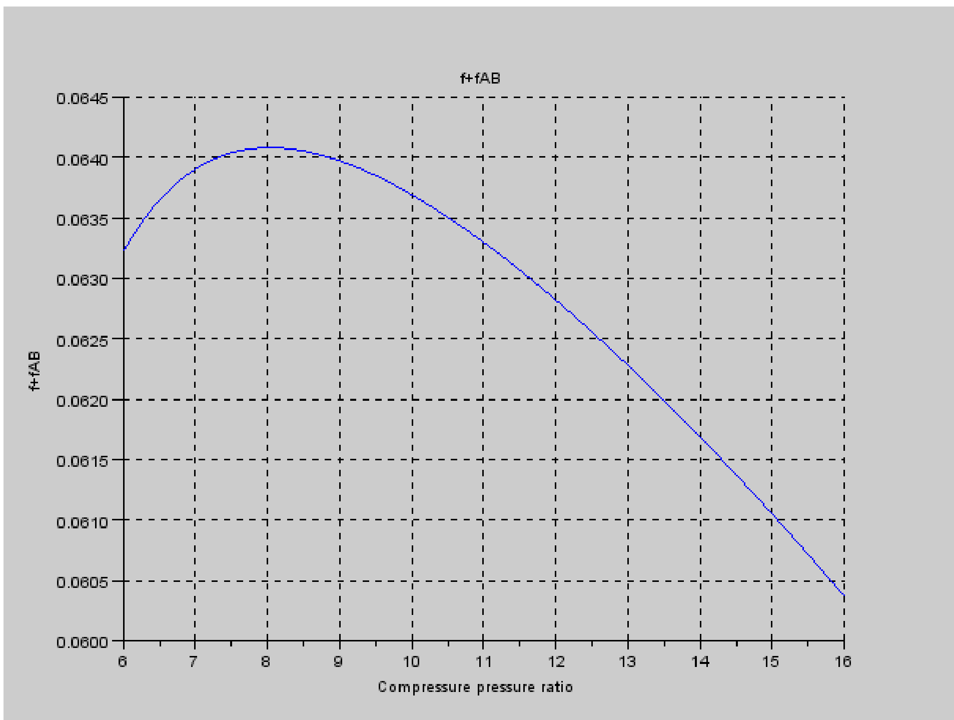

Figure 4.4: Engine performance of a mixed exhaust turbofan engine with afterburner having same parameters as in previous example for a range of compressor pressure ratios from 6 to 16

```
M0=0.7 //Mach no.
T0=228 // in K
p0=16 //kPa
eprop=0.85 // prop efficiency
m=10 //Kg/s
pd=0.98 //diffuser pressure ratio
pc=30 //compressor pressurer ratio
ec=0.92 //thermal efficiency of compressor
Tt4=1600 //in K
Qr=42000000 //in kJ/kg
eb=0.99 //thermal efficiency of burner
pb=0.96 //burner pressure ratio
etHPT=0.82
emHPT=0.99
alfa=0.85
emLPT=0.99
eLPT=0.88
egb=0.995
en=0.95
gmc=1.4 //gamma of compressor
Cpc=1004 // in J/kg.K
gmt=1.33 //gamma of turbine
Cpt=1152 // in J/kg.K
Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
a0=((gmc-1)*Cpc*T0)^(1/2);
V0=a0*M0
pt2=pt0*pd
Tt2=Tt0 //Adiabatic
pt3=pt2*pc
tc=pc^((gmc-1)/(ec*gmc))
Tt3=Tt2*tc
f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
pt4=pt3*pb
ht45=Cpt*Tt4-(Cpc*Tt3-Cpc*Tt2)/((1+f)*emHPT)
Tt45=ht45/Cpt
pt45=pt4*(Tt45/Tt4)^(gmt/((gmt-1)*etHPT))
m9=(1+f)*m
```

```
sp=(1+f)*m*eLPT*alfa*ht45*(1-(p0/pt45)^((gmt-1)/gmt)
   )/10^6
Tt5=(ht45-sp*10^6/((1+f)*m))/Cpt
tt=Tt5/Tt45
et=log(tt)/(log(1-((1-tt)/eLPT)))
pt=tt^(gmt/(et*(gmt-1)))
pt5=pt45*pt
p9=p0 //assumption
pi=p9/pt5
ti=pi^((gmt-1)/gmt)
T9i=Tt5*ti
T9=Tt5-en*(Tt5-T9i)
V9=(2*Cpt*(Tt5-T9))^(1/2)
Fprop=eprop*egb*emLPT*sp*10^3/V0
a9=((gmt-1)*Cpt*T9)^(1/2)
M9=V9/a9
pt9=p9*(1+((gmt-1)*M9^2)/2)^(gmt/(gmt-1))
pn=pt9/pt5
Fncore=m*((1+f)*V9-V0)/1000
spp=egb*emLPT*sp
Ft=Fprop+Fncore
mp=((m9*V9^2)/2-m*(V0^2)/2)/10^3
mf=m9-m
PSFC=mf*10^6/((spp*10^3)+mp)
TSFC=mf*10^3/(Ft)
eth=(spp*10^3+mp)*10^3/(mf*Qr)
ep=(Ft*V0)/(spp*10^3+mp)
eo=eth*ep
disp("a(1)Total pressures throughout the engine in
   kPa:")
disp(pt0,"Total pressure of flight:")
disp(pt2,"Total pressure at engine face:")
//disp(p19,"Static pressure at nozzle exit:")
disp(pt3,"Total pressure at compressor exit:")
disp(pt4,"Total pressure at burner exit:")
disp(pt45,"Total pressure across HPT :")
disp(pt5,"Total pressure at turbine exit:")
disp(pt9,"Total pressure at nozzle exit:")
```

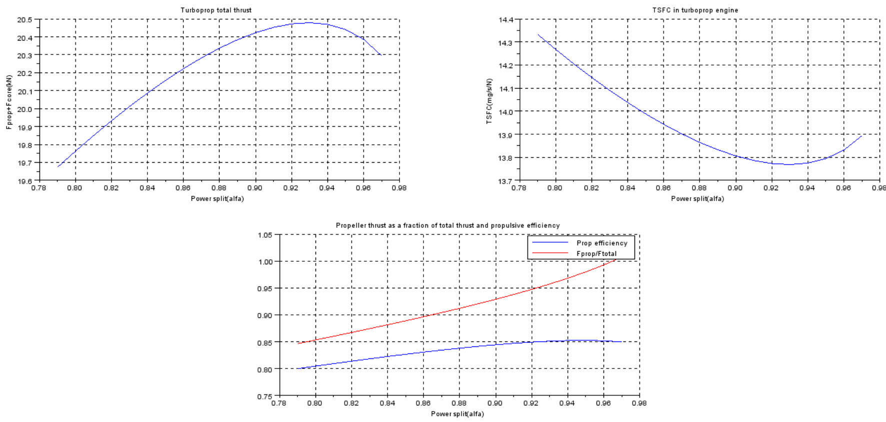

Figure 4.5: Graph of the performance parameters of the engine in above example with power split varying over a range

```

disp("a(2)Total temperatures across the engine in K:")
disp(Tt0,"Total temperature of flight:")
disp(Tt2,"Total temperature at engine face:") //Tt0=Tt2, since adiabatic!
disp(Tt3,"Total temperature at compressor exit:")
disp(Tt4,"Total temperature at burner exit:")
disp(Tt45,"Total temperature across HPT :")
disp(Tt5,"Total temperature at turbine exit:")
disp(f,"a(3)fuel-to-air ratio in burner :")
disp(Fncore,"(b)Engine core thrust in kN :")
disp(Fprop,"(c)Propeller thrust in kN :")
disp(PSFC,"(d)Power-specific fuel consumption in mg/s/kW :")
disp(TSFC,"(e)TSFC in mg/s/N :")
disp(ep,"f(1)Propulsive efficiency :")
disp(eth,"f(2)Thermal efficiency :")
disp(eo,"(g)Overall efficiency :")
```

Scilab code Exa 4.18 Graph of the performance parameters of the engine in above example with power split varying over a range

```
clear;
clc;
close;
disp("Example 4.17")
M0=0.7
T0=228 //in K
p0=16 //kPa
eprop=0.85 //efficiency of prop
m=10 //Kg/s
pd=0.98
pc=30
ec=0.92
Tt4=1600
Qr=42000000 // in kJ/kg
eb=0.99
pb=0.96
etHPT=0.82
emHPT=0.99
alfa=0.79
emLPT=0.99
eLPT=0.88
egb=0.995
en=0.95
gmc=1.4
Cpc=1004
gmt=1.33
Cpt=1152
z0=[0.79:0.01:0.97]
g1=[]
gc1=1
g2=[]
```

```
gc2=1
g3=[]
gc3=1
g4=[]
gc4=1
for alfa=0.79:0.01:0.97
Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
a0=((gmc-1)*Cpc*T0)^(1/2);
V0=a0*M0
pt2=pt0*pd
Tt2=Tt0 //Adiabatic
pt3=pt2*pc
tc=pc^((gmc-1)/(ec*gmc))
Tt3=Tt2*tc
f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
pt4=pt3*pb
ht45=Cpt*Tt4-(Cpc*Tt3-Cpc*Tt2)/((1+f)*emHPT)
Tt45=ht45/Cpt
pt45=pt4*(Tt45/Tt4)^(gmt/((gmt-1)*etHPT))
m9=(1+f)*m
sp=(1+f)*m*eLPT*alfa*ht45*(1-(p0/pt45)^((gmt-1)/gmt)
   )/10^6
Tt5=(ht45-sp*10^6/((1+f)*m))/Cpt
tt=Tt5/Tt45
et=log(tt)/(log(1-((1-tt)/eLPT)))
pt=tt^(gmt/(et*(gmt-1)))
pt5=pt45*pt
p9=p0 //assumption
pi=p9/pt5
ti=pi^((gmt-1)/gmt)
T9i=Tt5*ti
T9=Tt5-en*(Tt5-T9i)
V9=(2*Cpt*(Tt5-T9))^(1/2)
Fprop=eprop*egb*emLPT*sp*10^3/V0
a9=((gmt-1)*Cpt*T9)^(1/2)
M9=V9/a9
pt9=p9*(1+((gmt-1)*M9^2)/2)^(gmt/(gmt-1))
```

```
pn=pt9/pt5
Fncore=m*((1+f)*V9-V0)/1000
spp=egb*emLPT*sp
Ft=Fprop+Fncore
Fr=Fprop/Ft

mp=((m9*V9^2)/2-m*(V0^2)/2)/10^3
mf=m9-m
PSFC=mf*10^6/((spp*10^3)+mp)
TSFC=mf*10^3/(Ft)
eth=(spp*10^3+mp)*10^3/(mf*Qr)
ep=(Ft*V0)/(spp*10^3+mp)
eo=eth*ep
g1(gc1)=Ft;
gc1=gc1+1;
g2(gc2)=TSFC;
gc2=gc2+1
g3(gc3)=ep
gc3=gc3+1
g4(gc4)=Fr
gc4=gc4+1

end
subplot(2,2,1)
plot2d(z0,g1,2)
xgrid
title("Turboprop total thrust")
xlabel("Power split(alfa)")
ylabel("Fprop+Fcore(kN)")
subplot(2,2,2)
plot2d(z0,g2,2)
xgrid
title("TSFC in turboprop engine")
xlabel("Power split(alfa)")
ylabel("TSFC(mg/s/N)")
subplot(2,2,3.5)
plot2d(z0,g3,2)
plot2d(z0,g4,5)
```

```
xgrid
xlabel("Power split(alfa)")
title("Propeller thrust as a fraction of total
   thrust and propulsive efficiency")
legend("Prop efficiency","Fprop/Ftotal")
//plot2d(z0,g5,4)
```

Chapter 5

Aircraft engine inlet and nozzles

Scilab code Exa 5.1 Overspeed Mach no

```
clear;
clc;
close;
disp("Example 5.1")
Md=1.5
//From isentropic table,
gm=1.4 //gamma
A=1.176 //A=A1/Ath=A1/Acr
//for same A, from isentropic table for M<1
My=0.61
//for My=0.61, from normal shock table
Mx=1.8
Mos=Mx
disp(Mos,"Overspeed Mach no.")
```

Scilab code Exa 5.2 Kantrowitz Donaldson inlet

```
clear;
clc;
close;
disp("Example 5.2")
Md=2.65
Mx=Md
//for Mx=2.65, from normal shock table
My=0.4996
M1=My
//from isentropic table for M1=0.5,
A=1.34
//for Md=2.65, from isentropic table (A=A1/Acr)
A1=3.036
Af=A1/A
//from isentropic table Af,
Mth=2.35
//for Mth=2.35, from normal shock table
p=0.5615 //p=pty/ptx
disp(p,"Maximum total pressure recovery:")
```

Scilab code Exa 5.3 Variable throat isentropic C D nozzle

```
clear;
clc;
close;
disp("Example 5.3")
Md=3.3 //from isentropioc  table
A=5.629 // A=A1/Acr=A1/Ath
Mx=Md //from normal shock table
My=0.4596
M1=My
//from isentropic table
A11=1.425
pt=((1/A11-1/A)/(1/A))*100
Af=A/A11
```

```
//for Af=3.95, from isentropic table for M>1
M1th=2.95
disp(A,"Inlet design contraction ratio A1/Ath:")
disp(pt,"The % opening of the throat:")
disp(M1th,"Throat Mach no.:")
```

Scilab code Exa 5.4 Normal shock inlet

```
clear;
clc;
close;
disp("Example 5.4")
M0=1.4
//from normal shock table
p=0.9582 //p=pt2/pt0
M1=M0
//from isentropic table:
A=1.115 //A=A1/Acr
A11=1.1 //A11=Ax/A1
Af=A11*A
//from normal shock table for M>1
Mx=1.56
//from normal table
p1=0.91 //p=pt2/pt0
p2=p
disp(p,"(a)The best backpressure :")
disp(p1,"(b)The supercritical mode inlet total
    pressure recovery:")
disp(p2,"(c)Inlet pressure recovery in subcritical
    mode with 10% spillage:")
```

Scilab code Exa 5.5 External compression inlets

```
clear;
clc;
close;
disp("Example 5.5")
//th=theta and b=beta.
gm=1.4 //gamma
//OBLIQUE SHOCK 1
M0=2
th=8 //degree
//from theta-beta-M chart,
b1=37 //degree
Mn1=M0*sind(b1)
p1=0.993 //p=pt2/pt1
Mn2=((2+(gm-1)*Mn1^2)/(2*gm*Mn1^2-(gm-1)))^(1/2)
M2=Mn2/sind(b1-th)
//OBLIQUE SHOCK 2
M0=M2
th=12
//from oblique shock chart,
b2=48.7
Mn1=M0*sind(b2)
p2=0.978
Mn2=((2+(gm-1)*Mn1^2)/(2*gm*Mn1^2-(gm-1)))^(1/2)
M3=Mn2/sind(b1-th)
//NORMAL SHOCK
M0=M3
b3=90
pNS=0.977

Po=p1*p2*pNS
disp(Po,"Total pressure recovery:")
```

Scilab code Exa 5.6 Gross thrust by perfectly expanded C D nozzle

```
clear;
```

```
clc;
close;
disp("Example 5.6")
M9=1 // Mach no.
p=1/8 //p=p0/pt7
gm=1.3 //gamma
V9cd=(2*(1-p^((gm-1)/gm)))^(1/2)
px=p*((gm+1)/2)^(gm/(gm-1))
V9c=(2*(gm-1)/(gm+1))^(1/2)
FR=(V9cd/V9c)/(1+(1-px)/gm)
pr=(FR-1)*100/1
disp(pr,"% increase in gross thrust:")
```

Scilab code Exa 5.7 Effect of boundary layer formation on nozzle internal performance

```
clear;
clc;
close;
disp("Example 5.7")
p98=0.95 //p98=pt9/pt8
p87=0.98 //p98=pt8/pt7
p70=8 //p70=pt7/pt0
p97=8 //p97=pt9/pt7
Cp=1243.7 //specific heat in J/kg.K
gm=1.3 //gamma
Tt9=900 //Total temp. of the gas entering a C-D
    nozzle
Tt7=Tt9
p90=1 //p90=p9/p0
p99=p98*p87*p70*p90 //p99=pt9/p9
M9=(2/(gm-1)*(p99^((gm-1)/gm)-1))^(1/2) //exit mach
    no.
T9=Tt9/(1+(gm-1)*M9^2/2) //The nozzle exit static
    temp.
```

```
a9=((gm-1)*Cp*T9)^(1/2) //speed of sound in exit plane
V9=a9*M9 //exit velocity
V9s=(2*Cp*Tt7*(1-p97^-((gm-1)/gm)))^(1/2)
p89=p87*p70*p90 //p89=pt8/p9
V9i=(2*Cp*Tt7*(1-p89^-((gm-1)/gm)))^(1/2)
Cv=V9/V9i
disp(V9,"(a)V9 in m/s:")
disp(V9s,"(b)V9s in m/s:")
disp(V9i,"(c)V9i in m/s:")
disp(Cv,"(d)The velocity coefficient Cv:")
```

Scilab code Exa 5.8 Divergence correction factor Ca for a conical nozzle with exit flow angles varying over a range

```
clear;
clc;
close;
disp("Example 5.8")
alfa=0 //alfa=cone half angle
dx=[0:0.03:44]
x=[]
count=1
for alfa=0:0.03:44
Ca=(1+cosd(alfa))/2 //Flow angularity loss coefficient
x(count)=Ca
count=count+1
//disp(Ca,"Divergence correction factor Ca:")
end
plot2d(dx,x,2)
xgrid
title("Flow convergence loss in a conical nozzle")
```

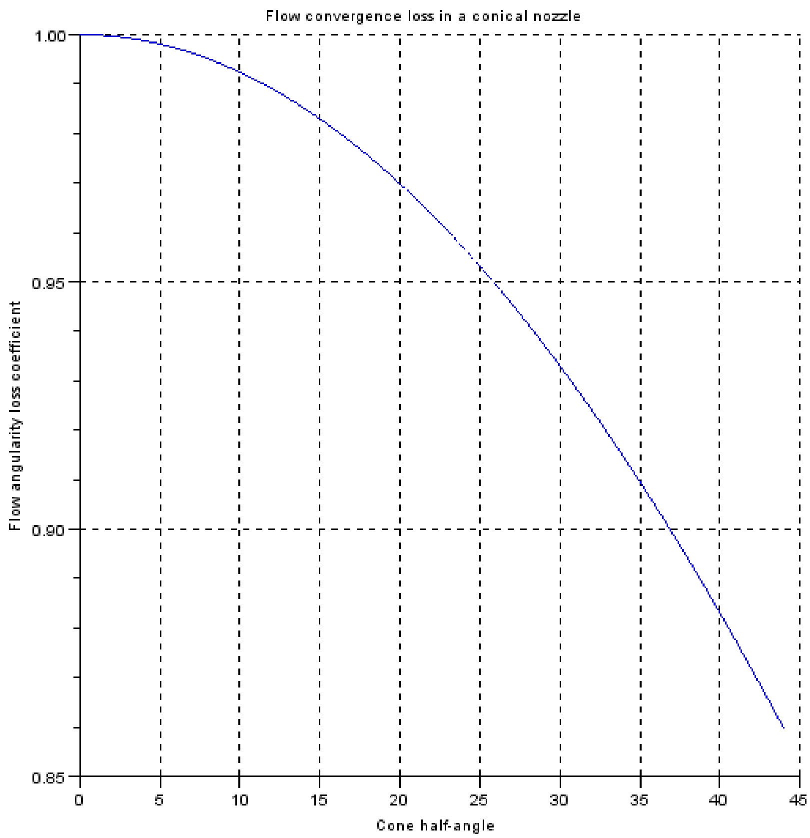

Figure 5.1: Divergence correction factor Ca for a conical nozzle with exit flow angles varying over a range

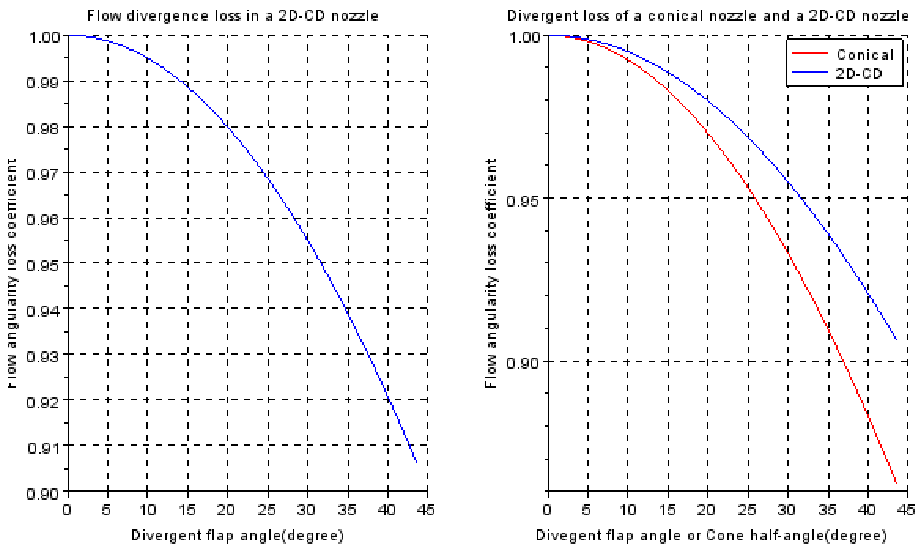

Figure 5.2: Graph of divergence correction factor for a two dimensional nozzle with exit flow angles varying over a range

```
xlabel("Cone half-angle")
ylabel("Flow angularity loss coefficient")
```

Scilab code Exa 5.9 Graph of divergence correction factor for a two dimensional nozzle with exit flow angles varying over a range

```
clear;
clc;
close;
disp("Example 5.9")
alfa=0.1
dx=[0.1:0.5:44]
x=[]
```

```
g1=[]
g1=1
count=1
g2=[]
gc1=1
for alfa=0.1:0.5:44
Ca=(sind(alfa))/(alfa*%pi/180)
Cac=(1+cosd(alfa))/2
x(count)=Ca
count=count+1
g1(gc1)=Cac
gc1=gc1+1
end
subplot(1,2,1)
plot2d(dx,x,2)
xgrid
title("Flow divergence loss in a 2D-CD nozzle")
xlabel("Divergent flap angle(degree)")
ylabel("Flow angularity loss coefficient")
subplot(1,2,2)
plot2d(dx,g1,5)
plot2d(dx,x,2)
xgrid
legend(["Conical","2D-CD"])
xlabel("Divegent flap angle or Cone half-angle(
    degree)")
ylabel("Flow angularity loss coefficient")
title("Divergent loss of a conical nozzle and a 2D-
    CD nozzle")
```

Scilab code Exa 5.10 Graph of the ratio of nozzle throat area with the afterburner on and off for a range of turbine expansion parameter

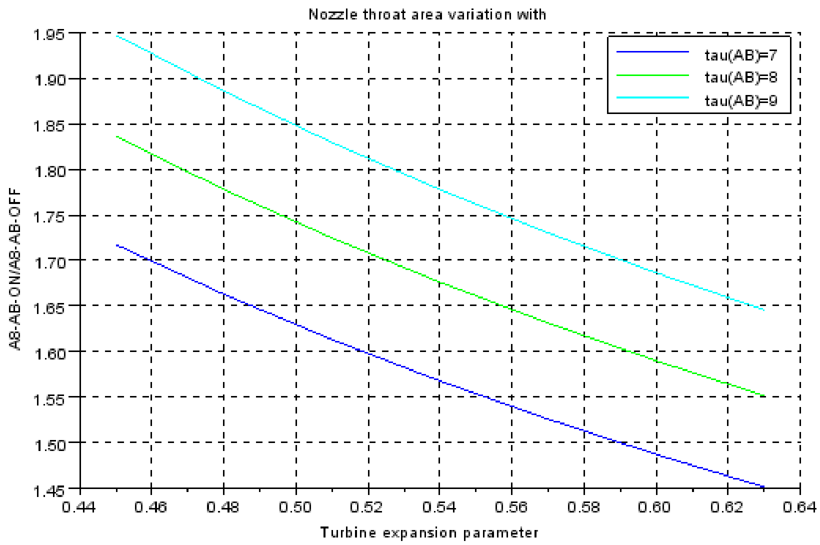

Figure 5.3: Graph of the ratio of nozzle throat area with the afterburner on and off for a range of turbine expansion parameter

```

clear;
clc;
close;
disp("Example 5.10")
p=0.96 //p=p't8/pt8
f=0.02
fAB=0.04

z0=[0.45:0.03:0.65]
gmr=1.3/1.33 //gm=gm/gm' gm=gamma
gm=1.33
gm1=1.3
tlAB=7
tl=6
i=2
for tlAB=7:1:9
    tt=6.5
```

```
    g1=[]
gc1=1

    for tt=0.45:0.03:0.65
        A=(1+f+fAB)/(1+f)*((gmr)^(1/2))*1/p*((tlAB/(tl*tt))^(1/2))*((((gm1+1)/2)^((gm1+1)/(2*(gm1-1))))/(((gm+1)/2)^((gm+1)/(2*(gm-1)))))
        g1(gc1)=A
        gc1=gc1+1
    end

    plot2d(z0,g1,i)
    xgrid
    i=i+1
    xlabel("Turbine expansion parameter")
    ylabel("A8-AB-ON/A8-AB-OFF")
    title("Nozzle throat area variation with ")
    legend(["tau(AB)=7","tau(AB)=8","tau(AB)=9"])
end
```

Scilab code Exa 5.12 Hypersonic nozzle

```
clear;
clc;
close;
disp("Example 5.12")
gm=1.1
M0=2.5
g1=[]

z0=[0:0.1:4]
i=2
```

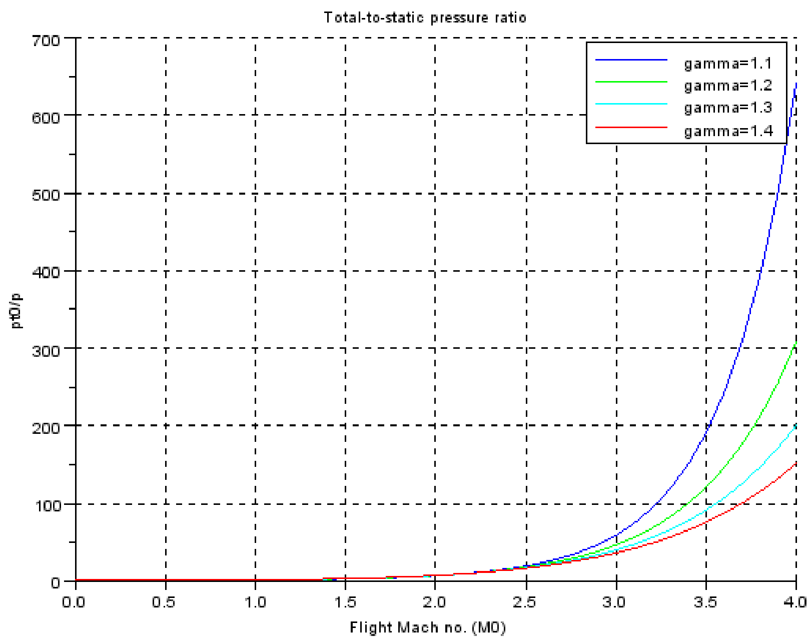

Figure 5.4: Hypersonic nozzle

```
for gm=1.1:0.1:1.4
    gc1=1
for M=0:0.1:4
p0=(1+(gm-1)/2*(M^2))^(gm/(gm-1))
p20=.4*p0-.5*p0
M=3
p42=0.37
NPR=p20*p42
g1(gc1)=p0
gc1=gc1+1
end

plot2d(z0,g1,i)
xgrid
title("Total-to-static pressure ratio")
xlabel("Flight Mach no. (M0)")
ylabel("pt0/p")
legend(["gamma=1.1","gamma=1.2","gamma=1.3","gamma
    =1.4"])
i=i+1

end
```

Scilab code Exa 5.13 Graph of the ratio of mixed to separate flow turbofan engine for a range of hot to cold temperature ratio and a varying bypass ratio upto 8

```

clear;
clc;
close;
disp("Example 5.13")
//T=Th/Tc
```

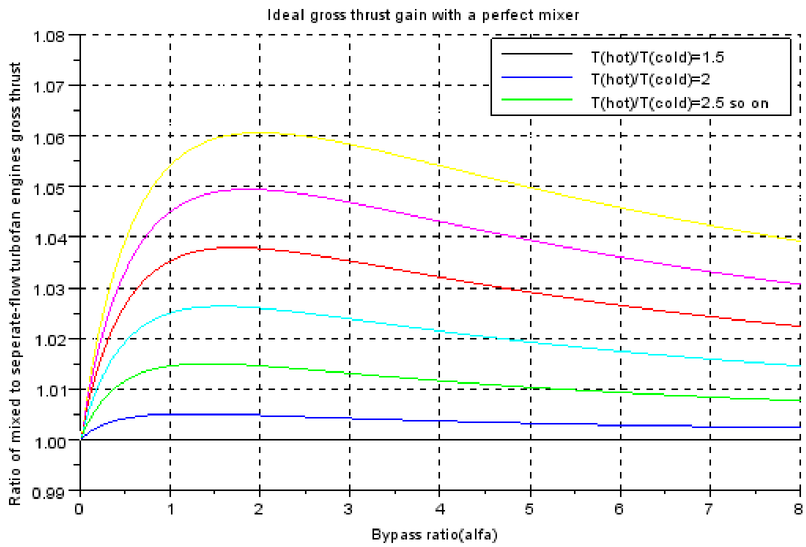

Figure 5.5: Graph of the ratio of mixed to separate flow turbofan engine for a range of hot to cold temperature ratio and a varying bypass ratio upto 8

```
z0=[0:0.05:8]
i=1
for T=1:0.5:4.5
g1=[]
gc1=1
for alfa=0:0.05:8

FR=((1+alfa)^(1/2)*(T+alfa)^(1/2))/(T^(1/2)+alfa)
g1(gc1)=FR
gc1=gc1+1
end

//a.data_bounds=[0,1;8,1.08]
plot2d(z0,g1,i)
xgrid
i=i+1
xlabel("Bypass ratio(alfa)")
ylabel("Ratio of mixed to seperate-flow turbofan
```

```
    engines gross thrust")
legend("T(hot)/T(cold)=1.5","T(hot)/T(cold)=2","T(
    hot)/T(cold)=2.5 so on")
title("Ideal gross thrust gain with a perfect mixer"
    )
end
```

Chapter 6

Combustion chambers and afterburners

Scilab code Exa 6.1 Moles in a mixture

```
clear;
clc;
close;
disp("Example 6.1")
nH2=12/2 //molecular mass og hydrogen =2kg/kmol
nO2=8/32 //Molecular mass of O2=32kg/kmol
disp(nH2,"No. of kilomoles of H2:")
disp(nO2,"No. of kilomoles of O2:")
```

Scilab code Exa 6.3 Heating values of hydrogen

```
clear;
clc;
close;
disp("Example 6.3")
T=298.16 //in K
```

```
dhf=-241827 //heat of formation of H2O(g in kJ.
n=1 //kmol
Qr=n*dhf //kJ/kmol
LHV=(-1)*Qr/2
disp(LHV,"LHV in kJ/kg:")
HHV=LHV+9*2443
disp(HHV,"HHV in kJ/kg:")
```

Scilab code Exa 6.5 Chemical reaction and flame temperature

```
clear;
clc;
close;
disp("Example 6.5")
//from equation CH4+2.4(O2+3.76N2)-->CO2+2H2O+0.4O2+9.02N2
f=(12+4)/(2.4*(32+3.76*28)) //fuel to air ratio based on mass.
fs=(12+4)/(2*(32+3.76*28)) //fuel to air ratio based on stoichometric condition.
feq=f/fs
disp(f,"(a1)fuel to air ratio based on mass:")
disp(fs,"(a2)fuel to air ratio based on stoichometric condition:")
disp(feq,"(b)Equivalent ratio:")
dH=-802303 //kJ
dC=484.7 //kJ
Dt=(-1)*dH/dC //Dt=T2-Tf
Tf=25+273
T2=Dt+Tf
disp(T2,"(c)The diabatic flame temperature in K:")
```

Scilab code Exa 6.6 Mole fraction at equilibrium

```
clear;
clc;
close;
disp("Example 6.6")
Kp=0.1
x=poly(0,"x")
pm=1
y=4*(x)^2*pm-Kp+Kp*(x)^2
d=roots(y)
for i=1:1:2

if real(d(i))>0 then
    disp(d(i),"(a)Mole fraction of N2 at equilibrium when pm is 1 atm:")
end
end
//part (b)
Kp=0.1
x=poly(0,"x")
pm=10
y=4*(x)^2*pm-Kp+Kp*(x)^2
d=roots(y)
for i=1:1:2

if real(d(i))>0 then
    disp(d(i),"(b)Mole fraction of N2 at equilibrium when pm is 10 atm:")
end
end
```

Chapter 7

Axial compressor aerodynamics

Scilab code Exa 7.1 Specific work at pitchline and the rotor torque per unit mass flow rate

```
clear;
clc;
close;
disp("Example 7.1")
w=5600 //rpm
rm=0.5 //m
Ct2=145 //m/s
Um=w*2*%pi*rm/60 //Rotor tangential speed at
    pitchline in m/s
Ct1=0
dU=Ct2-Ct1
wc=Um*dU/1000 // in kJ/kg
tpm=rm*(dU)
disp(wc,"Specific work at pitchline in kJ/kg:")
disp(tpm,"Rotor torque per unit mass flow rate in m
    ^2/s:")
```

Scilab code Exa 7.2 Stage parameters

```
clear;
clc;
close;
disp("Example 7.2")
rm=0.5
Um=212 //m/s
Czm=155 //m/s
Ct1m=28 //m/s
Rm=0.6
alfar=1 //alfar=alfa3/alfa1.
w=Um*60/(rm*2*%pi)
disp(w,"(a)Rotor angular speed w in rpm")
Ct2m=2*Um*(1-Rm)-Ct1m
disp(Ct2m,"(b)Rotor exit swirl in m/s:")
wcm=Um*(Ct2m-Ct1m)/1000
disp(wcm,"(c)Rotor specific work at pitchline Wcm in kJ/kg :")
Wt2m=Ct2m-Um
disp(Wt2m,"(d)Rotor relative velocity vector at rotor exit in m/s:")
disp("Hence vector is 155k-70.4e")
//Since alfa3=alfa1, rotor and stator torques are equal and opposite each other.
trm=rm*(Ct2m-Ct1m)
tsm=-1*trm
disp(trm,"(e)Rotor torque per unit mass flow rate in m^2/s:")
disp(tsm,"stotor torque per unit mass flow rate in m^2/s")
pshm=(Ct2m-Ct1m)/Um
phm=Czm/Um
disp(pshm,"(f)Stage loading parameter at pitchline :")
disp(phm,"(g)Flow coefficient :")
```

Scilab code Exa 7.3 Stage parameters

```
clear;
clc;
close;
disp("Example 7.3")
Um1=200 // in m/s
Um2=Um1
Cz1=150 //in m/s
Cz2=Cz1
b2=-35 //in degree
Cm=7 //in cm
Sm=7 //in cm
W1m=((Um1^2)+Cz1^2)^(1/2)
Wt2m=Cz2*tand(-35)
W2m=((Cz1)^2+(Wt2m)^2)^(1/2)
disp(W1m,"(a)W1m in m/s:")
disp(W2m,"W2m in m/s :")
sigma=Cm/Sm
Wt1m=-1*Um1
Dm=1-(W2m/W1m)+(abs(Wt2m-Wt1m))/(2*sigma*W1m)
disp(Dm,"(b)D-factor Dm :")
Tm=Sm/100*abs(Wt1m-Wt2m)
disp(Tm,"(c)Circulation Tm in m^2/s:")
```

Scilab code Exa 7.4 de Haller criterion

```
clear;
clc;
close;
disp("Example 7.4")
W1=300 //in m/s
wrm=0.03
W2min=0.72*W1
Cp=1-(W2min/W1)^2-wrm
```

```
disp(W2min,"(a)Minimum W2 in m/s :")
disp(Cp,"(b)Static pressure rise coefficient :")
```

Scilab code Exa 7.5 Stage parameters

```
clear;
clc;
close;
disp("Example 7.5")
ps=1.5
es=0.9
gm=1.4
ts=1+(1/es)*(ps^((gm-1)/gm)-1)
ec=(gm-1)/gm*(log(ps))/log(ts)
disp(ts,"Total temperature ratio :")
disp(ec,"Compressor polytropic efficiency :")
```

Scilab code Exa 7.6 Stage parameters

```
clear;
clc;
close;
disp("Example 7.6")
W1=460 //in m/s
b1=45 //degrees
W2=376
b2=30
c=5.25
w=0.05
s=3.5
Wt1=W1*sind(45)
Wt2=W2*sind(30)
Wtm=(Wt1+Wt2)/2
```

```
Wz1=W1*cosd(45)
Wz2=W2*cosd(30)
Wz=(Wz1+Wz2)/2
bm=(atan(Wtm/Wz))*180/%pi
sigma=c/s
Cd=w/sigma*cosd(bm)
T=s/100*(abs(Wt1-Wt2))
Wm=(Wz^2+Wtm^2)^(1/2)
C1=2*T/(Wm*(c/100))-Cd*tand(bm)
disp(bm,"(a)mean relative flow angle :")
disp(Cd,"(b)The rotor section (2D) drag coefficient
    :")
disp(T,"(c)The rotor circulation in m^2/s :")
disp(C1,"(d)The rotor sectional (2D) lift
    coefficient :")
```

Scilab code Exa 7.7 Comparison of the degree of reaction profile of a compressor stage with and without an IVG for a range of hub tip radii that result in a positive degree of reaction

```
clear;
clc;
close;
disp("Example 7.7")
Rm=0.5
b=0 //b=b/w
i=1
for b=0:0.1:0.5
r=0.5
vr=[]
x=[]
count=1
    for r=0.5:0.05:1.5
```

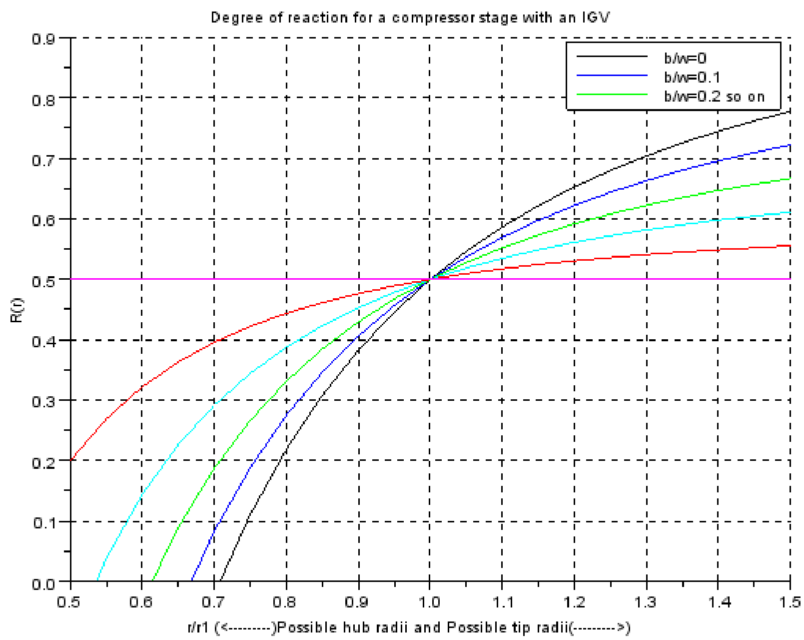

Figure 7.1: Comparison of the degree of reaction profile of a compressor stage with and without an IVG for a range of hub tip radii that result in a positive degree of reaction

```

R=(1-b)-((1-b)-Rm)/(r)^2
x(count)=R
count=count+1
end
vr=[0.5:0.05:1.5]
a=gca();
a.data_bounds=[0.5,0;1.5,0.9]

plot2d(vr,x,i)
i=i+1
xgrid
xlabel("r/r1 (<----------)Possible hub radii and Possible tip radii(---------->)")
ylabel("R(r)")
title("Degree of reaction for a compressor stage with an IGV")
legend("b/w=0","b/w=0.1","b/w=0.2 so on")
end
```

Chapter 8

Centrifugal compressor aerodynamics

Scilab code Exa 8.1 Graph of the ratio of Mach index to the impeller tip tangential Mach no for a range of inlet Mach no

```
clear;
clc;
close;
disp("Example 8.1")
z0=[0.2:0.05:0.6]
g1=[]
gc1=1
gm=1.4
for M1=0.2:0.05:0.6

y=1/((1+((gm-1)/2)*M1^2)^(1/2))

g1(gc1)=y
gc1=gc1+1
end
a=gca()
```

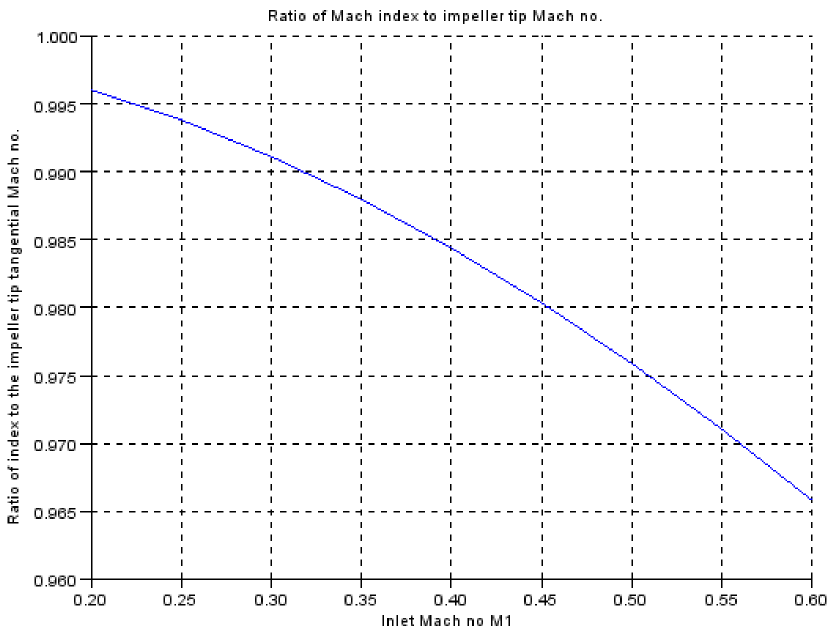

Figure 8.1: Graph of the ratio of Mach index to the impeller tip tangential Mach no for a range of inlet Mach no

```
a.data_bounds=[0.2,0.96;0.6,1]

plot2d(z0,g1,2)
xgrid
xlabel("Inlet Mach no M1")
ylabel("Ratio of index to the impeller tip tangential Mach no.")
title("Ratio of Mach index to impeller tip Mach no.")
```

Scilab code Exa 8.3 Radial diffuser

```
clear;
clc;
close;
disp("Example 8.3")
M1=1.2 //Mach no at impeller tip
gm=1.4 //gamma
p31=(1+(gm-1)*M1^2)^(gm/(gm-1)) //p=p3/p1
p32=p31^(1/2) //p31=p3/p2
Cp=(2/(gm*M1^2))*(2.2-1) //static pressure rise in radial diffuser
disp(p31,"(a)The static pressure the rotor and diffuser p3/p1 :")
disp(p32,"The static pressure ratio across the diffuser p3/p2")
disp(Cp,"Diffuser static pressure rise :")
```

Scilab code Exa 8.4 Graph of the inducer D factor for solidity of one and over a range of impeller tip Mach numbers and radius ratios

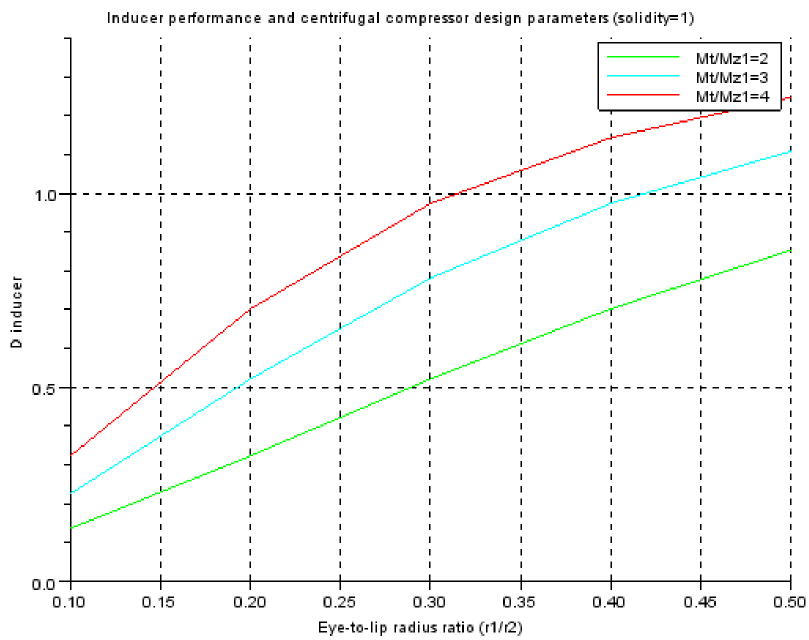

Figure 8.2: Graph of the inducer D factor for solidity of one and over a range of impeller tip Mach numbers and radius ratios

```
clear;
clc;
close;
disp("Example 8.4")
M=2
i=2
sigma=1
z0=[0.1:0.1:0.5]
gm=1.4

for M=2:4
    g1=[]
gc1=1
    for r=[0.1:0.1:0.5]
y=1-(1/(1+(r^2)*(M^2)))+((M*r)/(2*sigma*(1+(r^2)*(M^2))^(1/2)))
g1(gc1)=y
gc1=gc1+1
end
i=i+1
plot2d(z0,g1,i)
xgrid
xlabel("Eye-to-lip radius ratio (r1/r2)")
ylabel("D inducer")
title("Inducer performance and centrifugal compressor design parameters (solidity=1)")
legend("Mt/Mz1=2","Mt/Mz1=3","Mt/Mz1=4")
end
```

Scilab code Exa 8.6 Performance parameters of a centrifugal compressor

```
clear;
clc;
close;
disp("Example 8.6")
```

```
Tt1=288
Cp=1004
gm=1.4
ett=0.8
p=6.8 //pt3/pt1
C1=200
pt1=101
Tt3=Tt1*(1+(1/ett)*(p^((gm-1)/gm)-1))
Tt2s=Tt1*p^((gm-1)/gm)
T1=Tt1-C1^2/(2*Cp)
ets=(Tt2s-T1)/(Tt3-T1)
disp(ets,"Compressor total-to-static efficiency :")
```

Chapter 9

Aerothermodynamics of Gas Turbines

Scilab code Exa 9.1 Axial flow turbine

```
clear;
clc;
close;
disp("Example 9.1")
 Tt1=1800
 M1=0.55
 alfa1=0
 gm=1.33
 Cp=1157
 alfa2=60
 T1=Tt1/(1+(gm-1)*M1^2/2)
 a1=((gm-1)*Cp*T1)^(1/2)
 C1=a1*M1
 C2=C1/cosd(alfa2)
 Tt2=Tt1
 T2=Tt2-C2^2/(2*Cp)
 a2=((gm-1)*Cp*T2)^(1/2)
 M2=C2/a2
 Ct2=C1*tand(alfa2)
```

```
r=0.35
t=0-r*Ct2
disp(C1,"(a)Inlet velocity C1 in m/s :")
disp(M2,"(b)The exit absolute Mach no. M2 :")
disp(t,"(c)Nozzle torque per unit mass flow rate
    for r1=r2=0.35m :")
```

Scilab code Exa 9.2 Axial flow turbine

```
clear;
clc;
close;
disp("Example 9.2")
M2=1.0 //i.e choked
Tt2=1800
gm=1.33
C1=445
Cp=1157
T2=Tt2/(1+(gm-1)*M2^2/2)
a2=((gm-1)*Cp*T2)^(1/2)
M2=1
C2=M2*a2
alfa2=acos(C1/C2)*180/%pi
disp(alfa2,"Nozzle exit flow angle if M2=1 in
    degrees:")
```

Scilab code Exa 9.3 Axial flow turbine

```
clear;
clc;
close;
disp("Example 9.3")
C1=411
```

```
alfa2=60
C2=800
W2=450
alfa3=13
C3=411
Cz2=C2*cosd(60)
Cz3=C3*cosd(13)
Ct2m=Cz3*tand(60)
Wt2m=(450^2-400^2)^(1/2)
Um=Ct2m-Wt2m
Ct3=C3*sind(13)
Rm=1-(Ct2m+Ct3)/(2*Um)
disp(Cz2,"(a)The axial velocities up- and downstream
    of the rotor in m/s:")
disp(Cz3)
disp(Um,"(b)The rotor velocity Um in m/s:")
disp(Rm,"(c)The degree of reaction at this radius :"
   )
```

Scilab code Exa 9.4 Loss of turbine efficiency

```
clear;
clc;
close;
disp("Exmple 9.4")
Cd=0.5
bm=-20
r=1.25
phi=0.5
chi=1
t=0.02

De=Cd*t*r*(1-(chi/phi)*tand(bm))^(1/2)
disp(De,"Loss of the turbine efficiency (eta0 times)
    :")
```

Scilab code Exa 9.5 Turbine cooling

```
clear;
clc;
close;
disp("Example 9.5")
Tt=1700 //total gas temp at exit
gm=1.33 //gamma
Cp=1157 //in J/kg.K
M2=1 //local gas Mach no.
Pr=0.71 // Prandtl no.
W2=455 // gas speed relative to rotor
Tg=Tt/(1+(gm-1)*(M2^2)/2)
disp(Tg,"(a)The gas static temperature Tg in K:")
a2=((gm-1)*Cp*Tg)^(1/2)
C2=a2
r=Pr^(1/3)
Taw=Tg+Pr^(1/3)*C2^2/(Cp)
disp(Taw,"(b)The adiabatic wall temperatue Taw on
    the nozzle for a turbulent boundary layer in K:")
Ttr=Tg+(W2^2)/(2*Cp)
Tawl=Tg+Pr^(1/2)*C2^2/(Cp)
disp(Tawl,"The adiabatic wall temperature on the
    nozzle for a laminar boundary layer in K: ")
disp(Ttr,"(d)The rotor temperature of the gas on the
     rotor in K:")
```

Scilab code Exa 9.6 Convective cooling

```
clear;
clc;
```

```
close;
disp("Example 9.6")
T0=288 //in K
p0=100 //in kPa
Tt3=800 //in K
gm=1.4
Cpc=1.0045 //kJ/Kg.K
pc=25
ec=0.9
Tt4=2000 //in K
gmc=1.33
Cpg=1.188 //kJ/Kg.K
Stg=0.005 //Gas-side Stanton no.
Taw=2000 //in K
ptg=2.5 //in Mpa
Tawd=1200 // desired temp. in K
d=2 //thickness of internally cooled wall in mm
bms=2 //blade mean solidity in HPT
kw=14.9 //in W/m.K
Twc=870 //in K
S=1/2 //S=Stc/Stg
e=(Cpc/Cpg)*S*(Twc-Tt3)/(Tt4-Tawd)
disp(e,"Cooling fraction :")
```

Chapter 10

Aircraft engine component matching and off design analysis

Scilab code Exa 10.1 Graph of graph generator pumping characteristics verses percent Nc2 design

```
clear;
clc;
close;
disp("Example 10.1")
cmap
   =[14.1,6.50,20.0,0.82;13.5,5.88,18.1,0.84;13,5.32,16.4,0.83;12.5,4
disp(cmap,"Compressor map data in table:")
Cpc=1004
Cpt=1156
f=0.03 //fuel-to-air ratio
em=0.995 //efficiency
T=6 //T=Tt4/Tt2
pb=0.95 //burner pressure ratio
```

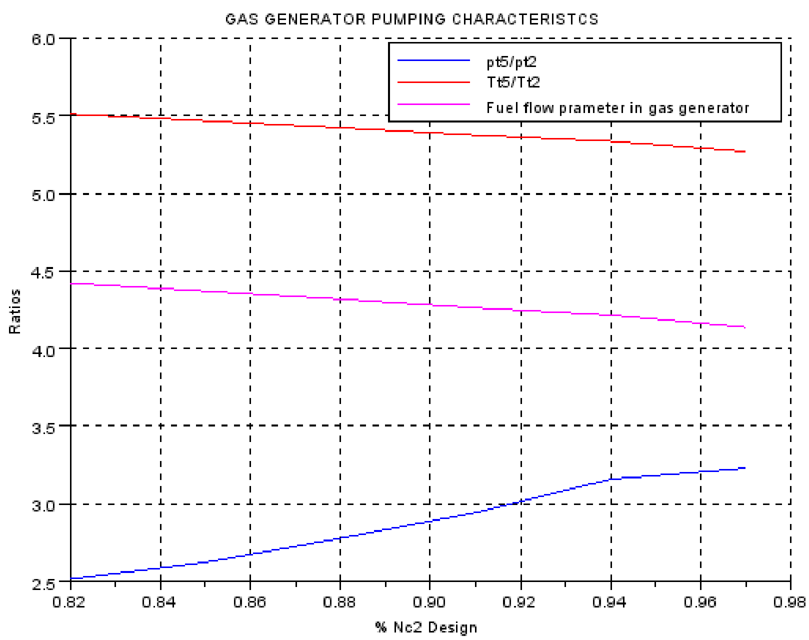

Figure 10.1: Graph of graph generator pumping characteristics verses percent Nc2 design

```
gmt=1.33 //gamma turbine
gmc=1.4
i=6
b=1
g1=[]
gc1=1
g2=[]
gc2=1
g3=[]
gc3=1
g4=[]
gc4=1
z0=[0.82:0.03:0.97]
for b=1:6
    Nc2=cmap(i,1)
    pc=cmap(i,2)
    mc2=cmap(i,3)
    ec=cmap(i,4)
    i=i-1
tc=1+(1/ec)*(pc^((gmc-1)/gmc)-1)
ffp=T-tc
tt=1-(Cpc/Cpt)*((tc-1)/(em*(1+f)*(T)))
Nc4=Nc2/T^(1/2)
mc4=mc2*((1+f)*(T)^(1/2))/(pb*pc)
pt=(1-(1-tt)/ec)^(gmt/(gmt-1)) //Assuming et=ec i.e.
    same efficiency
var=T-tc //fuel flow parameter in gas generator
p52=pb*pc*pt
T52=T-(Cpc/Cpt)*(tc-1)/(em*(1+f))
g1(gc1)=p52
gc1=gc1+1
g3(gc3)=T52
gc3=gc3+1
g4(gc4)=var
gc4=gc4+1

end
plot2d(z0,g1,2)
```

```
xlabel("% Nc2 Design")
ylabel("Ratios")
title("GAS GENERATOR PUMPING CHARACTERISTCS")
xgrid
plot2d(z0,g3,5)
plot2d(z0,g4,6)
legend("pt5/pt2","Tt5/Tt2","Fuel flow prameter in
    gas generator")
```

Scilab code Exa 10.2 Off design analysis of a turbojet engine

```
clear;
clc;
close;
disp("Example 10.2")
M0=0
p0=0.1 //in MPa
T0=15+273
pd=0.98
pc=25
ec=0.9
Qr=42800000 //in J/kg
pb=0.98
eb=0.99
Tt4=1500+273
et=0.85
em=0.995
mc2=73
Nc2=6000 //in rpm
Mz2=0.6
pn=0.97
p=1 //p=p9/p0
//in this engine is operating in the following off-
    design conditions
Mo0=0.8
```

```
po0=33
To0=-15+273
Tt4o=1375+273
pdo=0.995
po=1
gm=1.4

td=T0/Tt4
tcd=pc^((gm-1)/(ec*gm))
tod=(To0*(1+(gm-1)*Mo0^2/2)/Tt4o)
tcod=1+(td/tod)*(tcd-1)
pcod=(tcod)^((ec*gm)/(gm-1))
disp(pcod,"(a)pressure ratio in combustor,O-D :")
mratio=(pcod/pc)*(tod/td)^(1/2)
mc2od=mc2*mratio
disp(mc2od,"(b)mc2,O-D (in kg/s) :")
Nc2r=(td/tod)^(1/2)
Nc2od=Nc2r*Nc2
disp(Nc2od,"(c)Nc2,O-D (in rpm):")
pref=101.33 //in kPa
pto0=po0*(1+(gm-1)/2*Mo0^2)^(gm/(gm-1))
pto2=pdo*pto0
Tref=288.2
Tto2=To0*(1+(gm-1)/2*Mo0^2)
the2=Tto2/Tref
del2=pto2/pref
m2=mc2od*del2/(the2)^(1/2)
M2od=poly(0,"M2od")
pol=0.6*((1+(gm-1)/2*M2od^2)/(1+(gm-1)/2*0.6^2))
   ^3-(73/64.5)*M2od
rr=roots(pol)
//disp(rr)
i=1
while i < 7
if imag (rr(i))==0 then
    if real(rr(i))<1 then
        disp(rr(i),"(d)Mz2,O-D")
    end
```

```
end
i=i+1
end
```

Scilab code Exa 10.3 Off design analysis of an afterburner turbojet engine

```
clear;
clc;
close;
disp("Example 10.3")
M0=0
po=101.33 //in kPa
T0=288.2
gmc=1.4
Cpc=1004
pd=0.95
pc=20
ec=0.9
mc2=33
Nc2=7120
Mz2=0.6
Qr=428000000
pb=0.98
eb=0.97
Tt4=1850
gmt=1.33
Cpt=1156
et=0.8
em=0.995
QrAB=4280000
pAB=0.95
eAB=0.98
Tt7=2450
pAB=1.3
CpcAB=1243
```

```
pn=0.93
p=1 //p=p9/p0
Mo0=2
po0=20
To0=223
gm0=1.4
Cpc0=1004
pdo=0.8
ec0=0.9
Qr=42800000
pb0=0.98
ebo=0.97
Tt4o=1850
gmto=1.33
cpto=1156
eto=0.8
emo=0.995
QrABo=42800000
pABo=0.95
eab=0.98
Tt7o=2450
gmABo=1.3
Cpco=1243
pno=0.93
po=1
a0=276.4

Tt2=T0
tc=pc^((gmc-1)/(ec*gmc))
Tt3=tc*Tt2
f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
tt=1-(1/((1+f)*em))*(Cpc*Tt2/(Cpt*Tt4))*(tc-1)
disp(tt,"Turbine expansion parameter at on and off design :")
//Off-design analysis:
Tt2o=To0*(1+(gmc-1)/2*(Mo0^2))
tcOD=1+(1.036)*0.995*(1156*1850/(1004*401.4))*(1-0.7915)
```

```
pcOD=tcOD^((gmc)*ec/((gmc-1)))
disp(pcOD,"New compressor pressure ratio :")
mc2D=pcOD/pc*((Tt4o/Tt2)/(Tt4o/Tt2o))^(1/2)
mc2OD=mc2*mc2D
disp(mc2OD,"Off-line mc2 rate in Kg/s :")
Nc2r=((Tt4o/Tt2o)/(Tt4/Tt2))^(1/2)
Nc2OD=Nc2r*Nc2
disp(Nc2OD,"Off-design Nc2,O-D in rpm:")
pref=101.33 //in kPa
pt0=po0*(1+(gmc-1)/2*Mo0^2)^((gmc)/(gmc-1))
pt2=pdo*pt0
del2=pt2/pref
Tref=288.2
the2=Tt2o/Tref
m2=mc2OD*del2/(the2)^(1/2)
disp(m2,"Off-design mass flow in kg/s")
Tt3=859.2
Tt4=1850
fOD=0.03305
tcr=(1+fOD)/(1+f)
pt5=413.7// kPa
pt7=393.04
fAB=0.0367
pt9=365.52
M9=2.524
T9=1253
V9=1725

ndst=(1+f+fAB)*V9/a0-M9
disp(ndst,"Nondimensional specific thrust :")
TSFC=55.94 //in mg/s/N
disp(TSFC,"Thrust specific fuel consumption(TSFC) in mg/s/N :")
```

Chapter 11

Chemical rocket and hypersonic propulsion

Scilab code Exa 11.1 Space Shuttle Main Engine diameter from given thrust

```
clear;
clc;
close;
disp("Example 11.1")

Ts=470000 //in lb
Tv=375000 //in lb
A2=(Ts-Tv)/(14.7*144)
D=(4*A2/%pi)^(1/2)
disp(D,"Diameter of the SSME nozzle exit area :")
```

Scilab code Exa 11.2 Rocket thrust and exhaust velocity

```
clear;
clc;
close;
```

```
disp("Example 11.2")

m=1000 //in kg/s
g=9.8 //m/s^2
Is=340 //in s
F=m*g*Is
disp(F,"(a)Rocket thrust F in N :")
c=F/m
disp(c,"(b)Effective exhaust velocity c in m/s :")
```

Scilab code Exa 11.3 Thrust coefficient of a rocket engine

```
clear;
clc;
close;
disp("Example 11.3")

pc=200 //in atm
p2=1 //in atm
gm=1.3
Ath=25 //in m^2
Cf=((2*gm^2)/(gm-1)*(2/(gm+1))^((gm+1)/(gm-1))*(1-(
    p2/pc)^((gm-1)/gm)))^(1/2)
disp(Cf,"(a)Optimum thrust coefficient Cf,opt :")
pc=200*101 //converting to MPa
F=Ath*Cf*pc
disp(F,"(b)thrust F in N")
pc=200
M2=((2/(gm-1))*((pc/p2)^((gm-1)/gm)-1))^(1/2)
disp(M2,"(c)Nozzle exit Mach no. M2 :")
A=1/M2*(2/(gm+1)*(1+(gm-1)/2*M2^2))^((gm+1)/(2*(gm
    -1)))
disp(A,"(d)Nozzle area expansion ratio A2/Ath :")
```

Scilab code Exa 11.4 Characteristic velocity

```
clear;
clc;
close;
disp("Example 11.4")

Tc=2999 //in K
Ccr=2432 //in m/s
gm=1.26
f=4.02
R=((Ccr*gm*(2/(gm+1))^((gm+1)/(2*(gm-1))))^2)/(gm*Tc
    )
disp(R,"Combustion gas constant R in J/kg.K:")
RU=8314.6 //in j/kmol.K
MW=RU/R
disp(MW,"Molecular weight of the mixture in kg/kmol
    :")
```

Scilab code Exa 11.5 Combustion of hydrogen and oxygen

```
clear;
clc;
close;
disp("Example 11.5")

f=4
MW=(2*18+2*2)/4 //from equation
disp(f,"(a)The oxidizer-to-fuel mixture ratio :")
disp(MW,"(b)The molecular weight of the mixture of
    gases in the product of combustion in kg/kmol:")
```

Scilab code Exa 11.6 Rocket in a zero gravity vaccum flight

```
clear;
clc;
close;
disp("Example 11.6")

g=9.8 //in m/s^2
Is=400 //in s

delv1=g*Is*log(1/0.1) //for pmf=0.9
delv2=g*Is*log(1/0.05) //for pmf=0.95
delp=(delv2-delv1)/delv1*100
disp(delp,"% improvement in delv :")
```

Scilab code Exa 11.7 Rocket performance including the effect of gravity

```
clear;
clc;
close;
disp("Example 11.7")

g=9.8 //in m/s^2
Is=420 //in s
the=90 //in degree
tb=30 //in s
gavg=9.65 //in m/s^2
MR=0.1
delv1=-g*Is*log(MR) //in m/s
delv2=-g*Is*log(MR)-gavg*tb
delp=abs(delv2-delv1)/delv1*100
disp(delp,"% reduction in terminal speed :")
```

Scilab code Exa 11.8 Rocket flight performance including the effects of gravity and aerodynamic drag

```
clear;
clc;
close;
disp("Example 11.8")

mf=0.8
g=9.8 //in m/s^2
Is=345 //in s
delvt=-g*Is*log(1-mf)
m=500000 //in kg
q0=100000 //in Pa
tb=60 //in s
Af=20 //in m^2
Cd=0.3 //mean drag coefficient
delvd=log(1-mf)*(Af/m)*q0*(tb/(1-mf))*Cd
delv=delvt+delvd
disp(delv,"Terminal speed of rocket vehical
    excluding gravitatinal effect in m/s :")
```

Scilab code Exa 11.9 Propulsive and overall efficiencies

```
clear;
clc;
close;
disp("Example 11.9")

 g=9.8 //in m/s^2
 Is=421 //in s
```

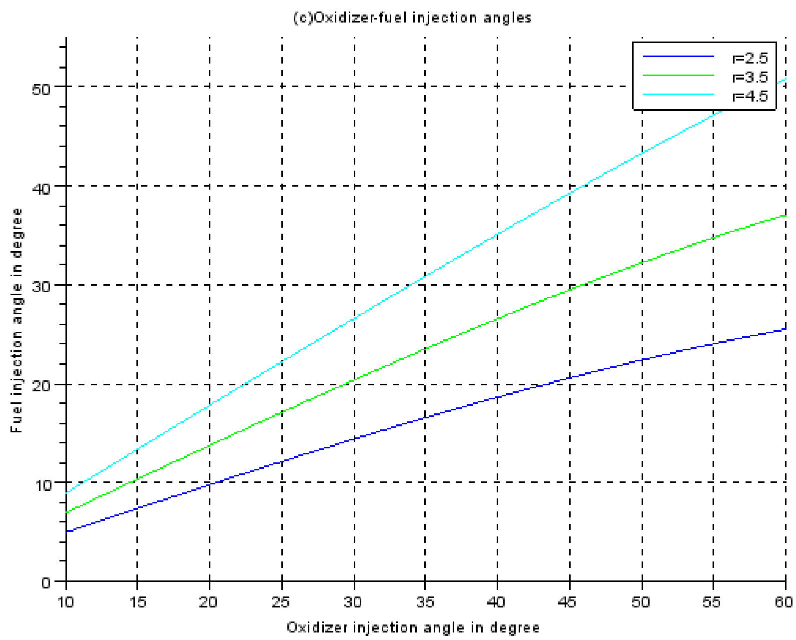

Figure 11.1: Liquid propellant combustion chambers in rocket

```
Qr=120000000
v=5000 //in m/s
c=g*Is
disp(c,"(a)Effective exhaust speed c in m/s :")
ep=2*(v/c)/(1+(v/c)^2)
disp(ep,"(b)propulsive efficiency :")
eo=c*v/Qr
disp(eo,"(c)Overall efficiency :")
```

Scilab code Exa 11.10 Liquid propellant combustion chambers in rocket

```
clear;
clc;
close;
disp("Example 11.10")

Cdf=0.82
Cdo=0.65
dpf=200 //kPa
dp0=200 //in kPa
rhof=85 //kg/m^3
rho0=1350 //kg/m^3
r=2.5
A=r*Cdf/Cdo*(dpf/dp0*rhof/rho0)^(1/2)
disp(A,"(a)Oxidizer-to-fuel oriface aera ratio A0/Af:")
vf=Cdf*(2*dpf/rhof)^(1/2)
v0=((2*dp0/rho0)^(1/2))*Cdo
disp(vf,"(b)Fuel oriface discharge speed in m/s:")
disp(v0,"Oxidizer oriface discharge speed in m/s:")
disp("(c)The graph between injection angle versus oxidizer injection angle for axial resultant stream 0 ")
//for graph

z0=10:0.05:60
i=2
for r=2.5:1:4.5
    g1=[]
gc1=1

for gm0=10:0.05:60
gmf=asind((r*(v0/vf)*sind(gm0)))
g1(gc1)=gmf
gc1=gc1+1
end
plot2d(z0,g1,i)
xgrid
i=i+1
```

```
xlabel("Oxidizer injection angle in degree")
ylabel("Fuel injection angle in degree")
title("(c)Oxidizer-fuel injection angles")
legend("r=2.5","r=3.5","r=4.5")
end
```

Scilab code Exa 11.11 Solid propellant combustion chamber in rockets

```
clear;
clc;
close;
disp("Example 11.11")

p=7 //in MPa,
n=0.5 //and
a=5 //cm/s
Tdg=15 //in degree C
Td=15+273 //in K
br=0.002 //per degree C
pk=0.004 //per degree C
t=60//s,

DT=30 // temp difference in degree C
pc=p*(1+pk*DT)
disp(pc,"(a)The new chamber pressure when the
   initial grain temp. is 45 degree C in MPa")
r=a*(pc/p)^n
r=r*(1+br*DT) //correcting for the effect of the
   grain temperature on burning rate.
disp(r,"Burning rate when grain temp. is 45 degree C
   ")
L=a*t/100
tb=L*100/r //time to burn 3m of end burning grain at
    5.61cm/s
tbn=t*(p/pc) //burn time for a constant total
```

```
   impulse

dt=t-tb
disp(dt,"(b)The corresponding reduction in burn time
     in seconds:")
```

Scilab code Exa 11.12 Regenerative cooling in liquid propellant rocket combustor in rocket

```
clear;
clc;
close;
disp("Example 11.12")
Tg=2750 //in K
Ttg=Tg
Tc=300 // coolant bulk temp. in K
tw=0.002 //Wall thickness in m
kw=43 //thermal conductivity of the wall in W/m.C
hg=657 //Gas side film coefficient in W/m^2K
hc=26000 //Coolant side film coefficient in W/m^2K
eg=0.05 //emissivity of the gas
sigma=5.67*10^(-8)//in W/m^2K
Taw=Ttg

rhf=eg*sigma*Tg^4/1000
disp(rhf,"(a)The radiation heat flux in kW/m^2 :")
qw=(Ttg-Tc+(rhf*1000/hg))/((1/hg)+(tw/kw)+(1/hc))
   /1000
disp(qw,"(b)The total heat flux in kW/m^2:")
qc=qw-rhf
disp(qc,"(c)The convection heat in kW/m^2:")
Twg=Taw-qc*1000/hg
disp(Twg,"(d)Wall temp. on the gas side in K:")
Twc=Tc+(qw*1000/hc)
disp(Twc,"(e)Wall temp. on the coolant side in K:")
```

Scilab code Exa 11.13 Multiphase flow in rocket nozzle

```
clear;
clc;
close;
disp("Example 11.13")

Cpg=2006 //in J/kg.K
Cs=903 //J/kg.K
X1=0.18
X2=0.16
Tr=1.057
Ir=(((1-X1)*Cpg+X1*Cs)*Tr/((1-X2)*Cpg+X2*Cs))^(1/2)
    //Ratio of specific impulse
disp(Ir,"Raio of specific impulse :")
```