

Scilab Textbook Companion for
Aircraft Propulsion
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May 24, 2016

¹Funded by a grant from the National Mission on Education through ICT, <http://spoken-tutorial.org/NMEICT-Intro>. This Textbook Companion and Scilab codes written in it can be downloaded from the "Textbook Companion Project" section at the website <http://scilab.in>

Book Description

Title: Aircraft Propulsion

Author: S. Farokhi

Publisher: J. Wiley And Sons

Edition: 1

Year: 2009

ISBN: 978-0-470-03906-9

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

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

Scilab code Exa 2.2 Isentropic process and isentropic flow

```

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

```

Scilab code Exa 2.3 Conservation principle for systems and control volumes

```

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

```

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

Scilab code Exa 2.4 Conservation principle for systems and control volumes

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

Scilab code Exa 2.5 Conservation principle for systems and control volumes

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

Scilab code Exa 2.6 Flow through a constant area duct

```
1 clear;
2 clc;
3 close;
4 disp(" Example2.6")
```

```

5 d=0.2 //Diameter in meters.
6 M1=0.2 //inlet Mach no.
7 p1=100*10^3 //inlet pressure in Pa
8 Tt1=288 //total inlet temperature in K
9 q=100*10^3 //rate of heat transfer to fluid in Watt.
10 rg=287 //Gas constant in J/kg.K.
11 gm=1.4 //gamma
12 //(a)inlet mass flow:
13 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)))));
14
15 //(b)
16 qm=q/m; //Heat per unit mass.
17 //Tt1/Tcr=0.1736, pt1/Pcr=1.2346, ((Delta(s)/R)
    1=6.3402,p1/Pcr=2.2727)
18 Tcr=Tt1/0.1736;
19
20 Pcr=p1/2.2727;
21 //From energy equation:
22 cp=(gm/(gm-1))*rg;
23 Tt2=Tt1+(q/cp);
24 q1cr=cp*(Tcr-Tt1)/1000;
25 M2=0.22;
26 //From table : pt2/Pcr=1.2281, (Delta(s)/R)2=5.7395,
    p2/Pcr=2.2477.
27 //The percent total pressure drop is (((pt1/Pcr)-(
    pt2/Pcr))/(pt1/Pcr))*100.
28 p2=2.2477*Pcr;
29 dp=((1.2346-1.2281)/1.2346)*100;
30 //Entropy rise is the difference between (delta(s)/R
    )1 and (delta(s)/R)2.
31 ds=6.3402-5.7395;
32 //Static pressure drop in duct due to heat transfer
    is
33 dps=((p1/Pcr)-(p2/Pcr))*Pcr/1000;
34 disp(m,"(a)Mass flow rate through duct in kg/s:")
35 disp(q1cr,"(b)Critical heat flux that would choke
    the duct for the M1 in kJ/kg:")

```

```

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

```

Scilab code Exa 2.7 Flow through constant area combustion chamber

```

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

```



```

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

```

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

```

1 clear;
2 clc;
3 close;
4 disp("Example2.8")
5 Tt1=50+460 //Converting the inlet temp. to the
    absolute scale i.e. in degree R
6 M1=0.5 //Initial inlet Mach no.
7 pt1=14.7 //Units in psia
8 gm=1.4 //gamma
9 R=53.34 //units in ft.lbf/lbm.degree R
10 Tcr=Tt1/0.69136
11 cp=gm*R/(gm-1)
12 //using energy equation:
13 Q1cr=cp*(Tcr-Tt1)
14 //since heat flux is 1.2(Q1cr).
15 q=1.2*Q1cr
16 Tt1cr1=Tt1+(Q1cr'/cp) //new exit total temp.
17 z=Tt1/Tt1cr1
18 M2=0.473
19 function [f]=f(M)
20     f=M/(1+((gm-1)/2)*M^2)^((gm+1)/(2*(gm-1)))
21 endfunction
22 sm=((f(M1)-f(M2))/f(M1))*100 //sm=The % spilled flow
    at the inlet
23 disp(M2,"(a) The new inlet Mach no. M2:")
24 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

```
1 clear;
2 clc;
3 close;
4 disp(" Example2.9")
5 d=0.2 //diameter in meters.
6 l=0.2 //length in meters.
7 Cf=0.005 //average wall friction coefficient.
8 M1=0.24 //inlet mach no.
9 gm=1.4 //gamma.
10 //From FANNO tbale
11 L1cr=(9.3866*d/2)/(4*Cf);
12 L2cr=L1cr-l;
13 //from FANNO table
14 M2=0.3;
15 x=2.4956;
16 y=2.0351;
17 a=4.5383;
18 b=3.6191;
19 i1=2.043;
20 i2=1.698;
21 //% total pressure drop due to friction:
22 dpt=(x-y)/(x)*100;
23 //static pressur drop:
24 dps=(a-b)/a*100;
25 //Loss pf fluid:
26 lf=(i2-i1);
27 disp(L1cr,"(a)The choking length of duct in m:")
28 disp(M2,"(b)The exit Mach no.:")
29 disp(dpt,"(c)% total pressure loss:")
30 disp(dps,"(d)The static pressure drop in %:")
31 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

```

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

```

Scilab code Exa 2.12 Subsonic diffuser

```
1 clear;
2 clc;
3 close;
4 disp(" Example2.12")
5 M1=0.7;
6 dpt=0.99; //pt2/pt1=dpt.
7 gm=1.4; //gamma
8 //A2=1.237A1.
9 a=1/1.237;
10
11 // Calculations:
12 M2 = poly(0, "M2");
13 k=(1/dpt)*(a)*(M1/(1+(0.2*(M1)^2)))^3)
14 pol = k*(1+(0.2*(M2)^2))^3 -M2;
15 W=roots(pol);
16 //disp(W)
17 i=1
18 while i<=6
19 z=W(i)
20 if imag(z)==0 then
21     if real(z)<0.7 then //since diffusing duct with
22         inlet mach no. <1
23         M2=z
24     end
25 end
26 i=i+1
27 end
28 disp(M2," (a)The exit Mach no. M2:")
29 //p=p2/p1 i.e. static pressure ratio
30 p=dpt*((1+(gm-1)*(M1)^2/2)/(1+(gm-1)*(M2)^2/2))^(gm
    /(gm-1))
```

```

31 //disp(p)
32 Cpr=(2/(gm*(M1)^2))*(p-1) //Cpr is static pressure
    recovery : (p2-p1)/q1.
33 disp(Cpr,"(b)The static pressure recovery in the
    diffuser:")
34 //Change in fluid impulse:
35 //Fwalls=I2-I1=A1p1(1+gm*M1^2)-A2p2(1+gm*M2^2)
36 //Let , u=Fwall/(p1*A1)
37 u=1+gm*(M1)^2-(1.237)*(p)*(1+(gm*(M2)^2))
38 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

```

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

```

```

18 k=(j)*(1/A)*(Mth/(1+(0.2*(Mth)^2)))^3)
19 po=k*(1+(0.2*(M2)^2))^3 -M2;
20 W=roots(po)
21
22
23 i=1
24 s=1
25 while i<=6
26 z=W(i)
27 //disp(z)
28 if imag(z)==0 then
29     if real(z)>1 then //since large nozzle pressure
30         ratio ()
31         M2=z
32     end
33 end
34 i=i+1
35 end
36 disp(M2,"(a)The exit Mach no. M2:")
37 //p2/pt2=1/(1+(gm-1)/2*M2^2)^(gm/(gm-1))
38 //pt2=(pt2/Pth)*(Pth/pt1)*(pt1/p0)*p0
39 //let pr=p2/p0
40 pr=((1/j)*f*p)/(1+(0.2*(M2)^2))^(gm/(gm-1))
41
42 disp(pr,"(b)The exit static pressure in terms of
43     ambient pressure p2/p0:")//Fwall=-Fliquid=I1-I2
44 //let r=A1/Ath
45 r=(f)*(1/M1)*(((1+((gm-1)/2)*(M1)^2)/((gm+1)/2))^(
46     (gm+1)/(2*(gm-1))))
47 //disp(r)
48 //Psth is throat static pressure.
49 //z1=Psth/pt1=f/((gm+1)/2)^(gm/(gm-1))
50 z1=f/((gm+1)/2)^(gm/(gm-1))
51 //disp(z1)
52 //p1 is static pressure at inlet
53 //s1=p1/pt1

```

```

53 s1=1/(1+((gm-1)/2)*(M1)^2)^(gm/(gm-1))
54 //disp(s1)
55 //let y=Fxcwall/(Ath*pt1), where Fxwall is Fx
    converging-wall
56 y=s1*r*(1+(gm*(M1)^2))-(z1*(1+(gm*(Mth)^2)))
57 disp(y,"(c)The nondimensional axial force acting on
    the convergent nozzle:")
58 //similarly finding nondimensional force on the
    nozzle DIVERGENT section
59 //y1=Fxdiv-wall/Ath*pt1
60 //f1=p2/pt1
61 f1=pr*(1/p)
62 //disp(f1)
63 y1=z1*(1+(gm*(Mth)^2))-f1*A*(1+(gm*(M2)^2))
64 disp(y1,"(d)The nondimensional axial force acting on
    the divergent nozzle:")
65 //total axial force acting on nozzle wall: Fsum=y+y1
66 Fsum=y+y1
67 disp(Fsum,"(e)The total axial force(nondimensional)
    acting on the nozzle: ")

```

Scilab code Exa 2.14 Axial flow compressor

```

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

```

```

12 Fx=1-p*A //Fx=Fxwall/p1*A1 i.e nondimensional axial
    force.
13 disp(Fx,"The non-dimensional axial force is :")
14 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

```

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

```

Scilab code Exa 2.16 Axial flow turbine

```

1 clear;
2 clc;
3 close;
4 disp("Example 2.16")
5 t=0.79 //T2/T1 i.e. turbine expansion
6 gm=1.4 //gamma
7 //calculations:
8 d=t^(1/(gm-1))

```



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

Chapter 3

Engine thrust and performance parameter

Scilab code Exa 3.1 Ram drag

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

Scilab code Exa 3.2 Gross thrust of separate flow turbofan

1

```

2  clear;
3  clc;
4  close;
5  disp("Example 3.2")
6  Cv=450 //exhaust velocity at core in m/s
7  Nv=350 //exhaust velocity at nozzle in m/s
8  Cm=50 //Mass flow rate through core in kg/s
9  Nm=350 //Mass flow rate through nozzle in kg/s
10 //Calculations:
11 //Newton's second law
12 Fgc=Cm*Cv //gross thrust of the core
13 Fgf=Nm*Nv //gross thrust of the nozzle fan
14 disp(Fgc,"Gross thrust of the core in SI unit(N):")
15 disp(Fgf,"Gross thrust of the fan nozzles in SI unit
(N):")

```

Scilab code Exa 3.3 Rocket thrust

```

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

```

Scilab code Exa 3.4 Airbreathing engine performance parameters

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

Scilab code Exa 3.5 Propulsive efficiency

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

Scilab code Exa 3.6 Propulsive efficiency of turbofan engine

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

Chapter 4

Gas turbine engine cycle analysis

Scilab code Exa 4.1 The inlet parameters of the turbojet engine

```
1 clear;
2 clc;
3 close;
4 disp(" Example 4.1");
5 M0=0.85
6 p0=10000 //ambient static pressure in Pa
7 pt2=15.88*10^3 //total pressure at the engine face
   in Pa
8 gm=1.4 //gamma
9 pt0=p0*((1+((gm-1)*(M0)^2)/2)^(gm/(gm-1)))
10 Pr=pt2/pt0 //Pr=total pressure recovery
11 ie=((pt2/p0)^((gm-1)/gm)-1)/(((gm-1)/2)*M0^2) //
   inlet adiabatic efficiency.
12 de=-log(Pr)
13 disp(Pr,"(a)The inlet total pressure recovery:")
14 disp(ie,"(b)The inlet adiabatic efficiency:")
15 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

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

Scilab code Exa 4.3 The combustor parameters of the turbojet engine

```
1 clear;
2 clc;
3 close;
4 disp("Example 4.3")
5 Tt3=800 //in K
```

```

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

```

Scilab code Exa 4.4 The turbine parameters of the turbojet engine

```

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

```



```

17 Tt5=ht5/(cp5/1000)
18 y=Tt5/Tt4 //turbine expansion parameter
19 tpe=log(y)/log(1-(1-y)/tae)
20 pr=y^(gm/((gm-1)*tpe))
21 pt5=pr*pt4*1000 // turbine total exit pressure
22 pt=mt*cp5*(Tt4-Tt5)/10^6
23 disp(Tt5,"(a) Turbine exit total temperature in K :")
24 disp(tpe,"(b) Turbine polytropic efficiency:")
25 disp(pt5,"(c) Turbine exit total pressure in kPa :")
26 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

```

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

```

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

```
1 clear;
2 clc;
3 close;
4 disp(" Example 4.6")
5 Cpg=1156 //in J/kg.K
6 Pt4=1.92 //in MPa
7 gm=1.33 //gamma
8 htg=1850 //from example 4.5 in kJ/kg
9 htc=904 //from example 4.5 in kJ/kg
10 Cpc=1.04 //in kJ/kg.K
11 pl=.02 //total pressure loss ratio
12 Ttmixout=1154.7 //from example 4.5 in K.
13 //Calculations:
14 Ttg=htg/(Cpg/1000) //hotgas total temp in K.
15 Tt4=Ttg //same as nozzle entrance temp.
16 Ttc=htc/Cpc //coolant total temp.
17 Ptmixout=(1-pl)*Pt4 //mixed-out total temp.
18 //using gibbs equation
19 de=((gm/(gm-1))*log((Ttmixout/Tt4)))-log(Ptmixout/
    Pt4)
20 disp(de,"Entropy change across the turbine nozzle
    blade row:")
21 disp("The negative sign of entropy change is due to
    cooling.")
22 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

```
1 clear;
2 clc;
```

```

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

```

Scilab code Exa 4.10 Propulsive efficiency of turbojet engine

```

1 clear;
2 clc;
3 close;
4 disp(" Example4.10")
5 Vt0=160 //takeoff velocity in m/s
6 Vt9=1000 //takeoff velocity in m/s
7 Vc0=800 //cruise velocity in m/s
8 Vc9=1000 //cruise velocity in m/s
9 //using approximation: engine propulsive efficiency
    (pe)=2/(1+V9/V0)
10 pet=2/(1+(Vt9/Vt0)) //takeoff
11 pec=2/(1+(Vc9/Vc0)) //cruise
12 disp(pet," Engine propulsive efficiency while takeoff
    :")
13 disp(pec," Engine propulsive efficiency while cruise:
    ")

```

Scilab code Exa 4.11 Turbojet engine with afterburner

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

```

31 Tt0=T0*(1+(((gmc-1)*(M0)^2)/2)) //total flight temp
32 Tt2=Tt0 //Adiabatic inlets
33 pt2=pt0*pd // in kPa
34 pt3=pt2*pc //compressor exit total pressure
35 k2=((gmc-1)/(gmc*ec))
36 //disp(k2)
37 tc=pc^k2 //relation between temp and pressure ratios
38 //disp(tc)
39 Tt3=Tt2*tc //total temp at compressor exit
40 Tt4=Cpc*T0*t1/Cpt //combustor exit total temp.
41 pt4=pt3*pb //combustor exit pressure
42 f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb*1000-Cpt*Tt4) //fuel-to-
    air ratio in burner
43 //disp(f)
44 Tt5=Tt4-(Cpc*((Tt3-Tt2)/(Cpt*em*(1+f)))) // turbine
    exit total temp
45 tt=Tt5/Tt4 //temp ratio in turbine
46 pt=tt^(gmt/(et*(gmt-1)))
47 pt5=pt4*pt //in kPa
48 pt7=pt5*pAB
49 Tt7=Cpc*T0*t1AB/CpAB //afterburner exit
50 fAB=(1+f)*((CpAB*Tt7)-(Cpt*Tt5))/((QrAB*eAB*1000)-(
    CpAB*Tt7))
51 //disp(fAB)
52 pt9=pt7*pn //in kPa
53 Tt9=Tt7 //adiabatic flow in nozzle
54 p9=p0
55 M9=((2/(gmAB-1))*((pt9/p9)^(((gmAB-1)/gmAB))-1))
    ^(1/2) //nozzle exit
56 //disp(M9)
57 T9=Tt9/(1+((gmAB-1)*(M9)^2)/2)
58 a9=((gmAB-1)*CpAB*T9)^(1/2)
59 //disp(a9)
60 V9=M9*a9
61 //Performance parameters:
62 st=(1+f+fAB)*V9-V0 //st=Fn/m0; specific thrust when
    nozzle is perfectly expanded
63 ndst=((1+f+fAB)*V9/a0)-M0 //ndst=Fn/m0*ao ;

```

```

        nondimensional specific thrust
64 TSFC=((f+fAB)/st)*10^6 //units mg/s/N
65 eth=((((1+f+fAB)*((V9)^2)/2)-((V0)^2)/2)/(f*Qr*1000+
        fAB*QrAB*1000) //cycle thermal efficiency
66 ep=st*V0/(((1+f+fAB)*((V9)^2)/2)-((V0)^2)/2) //
        propulsive efficiency exact
67 epa=2/(1+V9/V0) //approx
68 disp("a(1) Total temperatures across the engine in K:
        ")
69 disp(Tt0," Flight total temperaure:")
70
71 disp(Tt2," Toal temperature at compressor inlet:")
72 disp(Tt3," Total temperature at compressor exit: ")
73 disp(Tt4," Total temperature at burner exit:")
74 disp(Tt5," Total temperature at turbine exit:")
75 disp(Tt7," Total temperature at afterburner exit:")
76 disp(T9," Total temperature at nozzle exit:")
77 disp(T9," Nozzle exit static temperature:")
78 disp("a(2) Total pressures across the engine in kPa:"
        )
79 disp(pt0," Flight total pressure:")
80
81 disp(pt2," Toal pressure at compressor inlet:")
82 disp(pt3," Total pressure at compressor exit: ")
83 disp(pt4," Total pressure at burner exit:")
84 disp(pt5," Total pressure at turbine exit:")
85 disp(pt7," Total pressure at afterburner exit:")
86 disp(pt9," Total pressure at nozzle exit:")
87 disp(p9," Nozzle exit static pressure:")
88 disp(ndst,"(b)Nondimensional specific thrust:")
89 disp(TSFC,"(c)Thrust specific fuel consumption TSFC
        (in mg/s/N):")
90 disp(eth,"d(1)Themal efficiency:")
91 disp(ep,"d(2)Exact propulsive efficiency:")

```

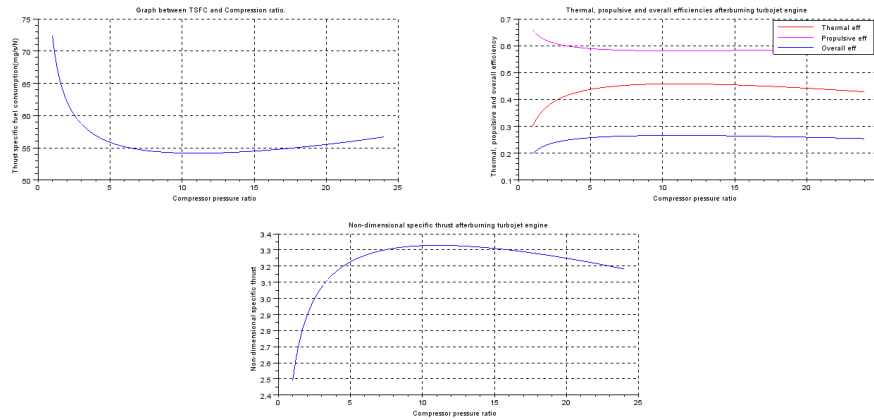


Figure 4.1: Effect of compressor pressure ratio on an afterburner turbojet engine

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

```

1 clear;
2 clc;
3 close;
4 disp(" Example4.12 ")
5 M0=2.0 //Mach no.
6 p0=10 //units in kPa
7 T0=228 // in K
8 gmc=1.4 //gamma compressor
9 Cpc=1004 //J/kg.K specific heat of compressor
10 pd=0.88
11 ec=0.9
12 t1=8
13 Qr=42000 //kJ/kg
14 eb=0.98
15 pb=0.95
16 gmt=1.33 //gamma turbne

```

```

17 Cpt=1156 //J/kg.K specific heat turbine
18 et=0.82
19 em=0.995
20 t1AB=11
21 QrAB=42000 //kJ/kg
22 eAB=0.98
23 pAB=0.93
24 gmAB=1.3 // gama AB
25 CpAB=1243 //J/kg.K
26 pn=0.93
27 nc=24;
28 pc1=[1:0.01:nc];
29 a=[];
30 count=1;
31 g2=[]
32 cg2=1;
33 g3=[]
34 cg3=1;
35 g4=[]
36 cg4=1;
37 g5=[]
38 cg5=1;
39
40 pc=1;
41 for pc=1:0.01:24
42     a0=((gmc-1)*Cpc*T0)^(1/2);
43     V0=M0*a0;
44     pt0=p0*(1+(((gmc-1)*(M0)^2)/2))^(gmc/(gmc-1));
45     //total flight pressure
46     Tt0=T0*(1+(((gmc-1)*(M0)^2)/2)); //total flight
47     temp
48     Tt2=Tt0 ;//Adiabatic inlets
49     pt2=pt0*pd; // in kPa
50     pt3=pt2*pc; //compressor exit total pressure
51     k2=((gmc-1)/(gmc*ec));
52     //disp(k2)
53     tc=pc^k2; //relation between temp and pressure
54     ratios

```



```

52     //disp(tc)
53     Tt3=Tt2*tc; //total temp at compressor exit
54     Tt4=Cpc*T0*t1/Cpt; //combustor exit total temp.
55     pt4=pt3*pb; //combustor exit pressure
56     f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb*1000-Cpt*Tt4); //fuel
        -to-air ratio in burner
57     //disp(f)
58     Tt5=Tt4-(Cpc*((Tt3-Tt2)/(Cpt*em*(1+f)))); //
        turbine exit total temp
59     tt=Tt5/Tt4; //temp ratio in turbine
60     pt=tt^(gmt/(et*(gmt-1)));
61     pt5=pt4*pt; //in kPa
62     pt7=pt5*pAB;
63     Tt7=Cpc*T0*t1AB/CpAB; //afterburner exit
64     fAB=(1+f)*((CpAB*Tt7)-(Cpt*Tt5))/((QrAB*eAB
        *1000)-(CpAB*Tt7));
65     //disp(fAB);
66     pt9=pt7*pn; //in kPA
67     Tt9=Tt7 ;//adiabatic flow in nozzle
68     p9=p0;
69     M9=((2/(gmAB-1))*((pt9/p9)^(((gmAB-1)/gmAB))-1))
        ^(1/2); //nozzle exit
70     //disp(M9)
71     T9=Tt9/(1+((gmAB-1)*(M9)^2)/2);
72     a9=((gmAB-1)*CpAB*T9)^(1/2);
73     //disp(a9)
74     V9=M9*a9;
75     //Performance parameters:
76     st=(1+f+fAB)*V9-V0; //st=Fn/m0; specific thrust
        when nozzle is perfectly expanded
77     ndst=((1+f+fAB)*V9/a0)-M0; //ndst=Fn/m0*ao ;
        nondimensional specific thrust
78     TSFC=((f+fAB)/st)*10^6 ;//units mg/s/N
79     eth=((1+f+fAB)*((V9)^2)/2)-((V0)^2)/2)/(f*Qr
        *1000+fAB*QrAB*1000); //cycle thermal
        efficiency
80     ep=st*V0/(((1+f+fAB)*((V9)^2)/2))-((V0)^2)/2);
        //propulsive efficiency exact

```

```

81     epa=2/(1+V9/V0) ;//approx
82     oe=ep*eth;
83     a(count)=TSFC;
84     count = count+1;
85     g2(cg2)=eth;
86     cg2=cg2+1
87     g3(cg3)=ep
88     cg3=cg3+1
89     g4(cg4)=oe
90     cg4=cg4+1
91     g5(cg5)=ndst
92     cg5=cg5+1;
93 end
94 x=gca()
95 x.data_bounds=[1,50;24,75]
96 subplot(2,2,1)
97 plot2d1(pc1,a,2);
98 xlabel("Compressor pressure ratio")
99 ylabel("Thrust specific fuel consumption(mg/s/N)")
100 title("Graph between TSFC and Compression ratio.")
101 xgrid(1)
102 subplot(2,2,2)
103 y=gca()
104 y.data_bounds=[1,0.2;23,0.7]
105 plot2d2(pc1,g2,5);
106 xgrid(1)
107 xlabel("Compressor pressure ratio")
108 ylabel("Thermal, propulsive and overall efficiency")
109 title("Thermal, propulsive and overall efficiencies
        afterburning turbojet engine")
110 plot2d(pc1,g3,6)
111 plot2d(pc1,g4,2)
112 legend(['Thermal eff';'Propulsive eff';'Overall eff'
        ])
113 subplot(2,2,3.5)
114 plot2d(pc1,g5,2)
115 xgrid(1)
116 xlabel("Compressor pressure ratio")

```

```

117 ylabel("Non-dimensional specific thrust")
118 title("Non-dimensional specific thrust afterburning
        turbojet engine")

```

Scilab code Exa 4.13 High bypass ratio turbofan engine

```

1  clear;
2  clc;
3  close;
4  disp("Example4.13")
5  M0=0.88 //Mach no.
6  p0=15 // pressure in kPa
7  T0=233 //temperatue in K
8  gmc=1.4 //gamma compressor
9  Cpc=1004 //specific heat of compressor in J/kg.K
10 pd=0.995 // pressure compression ratio of diffuser
11 pf=1.6 //pressure compression ratio of fan
12 ef=0.9 //fan efficiency
13 alfa=8
14 pfn=0.95 //compression ratio of convergent fan
    nozzle
15 pc=40 //compression ratio of compressor
16 ec=0.9 //compressor efficiency
17 t1=8 //temp. ratio
18 Cpt=1152 //in J/kg.K of turbine
19 gmt=1.33 //gamma turbine
20 Qr=42000000 //in J/kg
21 pb=0.95 //burner compression ratio
22 eb=0.992 //burner efficiency
23 em=0.95
24 et=0.85
25 pn=0.98 //primary nozzle
26 a0=((gmc-1)*Cpc*T0)^(1/2);
27 V0=M0*a0;
28 pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))

```

```

29 Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
30 Tt2=Tt0
31 pt2=pt0*pd
32 //fan stream:
33 pt13=pt2*pf
34 tf=pf^((gmc-1)/(ef*gmc))
35 Tt13=Tt2*tf
36 pt19=pt13*pfn
37 p19=pt19/(1+(gmc-1)/2)^(gmc/(gmc-1))
38 M19=1
39 T19=Tt13/1.2
40 a19=((gmc-1)*Cpc*T19)^(1/2)
41 V19=a19
42 //V19eff=V19+((gmc*p19)/r19)*((1-p0/p19)/(gmc*V19))
   i.e V19+a19^2
43 V19eff=V19+(a19^2)*((1-p0/p19)/(gmc*V19))
44 //Core stream
45 pt3=pt2*pc
46 tc=pc^((gmc-1)/(ec*gmc))
47 //disp(tc)
48 Tt3=Tt2*tc
49 pt4=pt3*pb
50 Tt4=Cpc*T0*t1/Cpt
51 //disp(Tt4)
52 f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
53 //disp(f)
54 Tt5=Tt4-((Cpc*(Tt3-Tt2)+alfa*Cpc*(Tt13-Tt2)))/((1+f)
   *Cpt*em)
55 //disp(Tt5)
56 tt=Tt5/Tt4
57 pt=tt^(gmt/(et*(gmt-1)))
58 pt5=pt4*pt
59 pt9=pt5*pn
60 p9=pt9/((gmt+1)/2)^(gmt/(gmt-1))
61 M9=1
62 T9=Tt5/((gmt+1)/2)
63 a9=((gmt-1)*Cpt*T9)^(1/2)
64 V9=a9

```

```

65 V9eff=V9+(((a9)^2)*(1-(p0/p9)))/(gmt*V9)
66 ndsft=alfa*(V19eff-V0)/((1+alfa)*a0)
67 ndsct=((1+f)*V9eff-V0)/((1+alfa)*a0)
68 ndst=ndsft+ndsct
69 rfct=ndsft/ndsct
70 fc=ndsft*100/(ndsft+ndsct)
71 cc=ndsct*100/(ndsft+ndsct)
72 TSFC=f/((1+alfa)*a0*(ndsft+ndsct))*10^6
73 eth=(alfa*V19eff^2+(1+f)*V9eff^2-(1+alfa)*V0^2)/(2*f
    *Qr)
74 ep=(2*(ndsft+ndsct)*(1+alfa)*a0*V0)/(alfa*V19eff
    ^2+(1+f)*V9eff^2-(1+alfa)*V0^2)
75 eo=eth*ep
76 // Pressures
77 disp("a(1) Total pressures throughout the engine in
    kPa:")
78 disp(pt0," Total pressure of flight:")
79 disp(pt2," Total pressure at engine face:")
80 disp(pt13," Total pressure at fan exit:")
81
82 disp(p19," Static pressure at nozzle exit:")
83 disp(pt3," Total pressure at compressor exit:")
84 disp(pt4," Total pressure at burner exit:")
85 disp(pt5," Total pressure at turbine exit:")
86 disp(pt9," Total pressure at nozzle exit:")
87
88 // Temperatures
89 disp("a(2) Total temperatures across the engine in K:
    ")
90 disp(Tt0," Total temperature of flight:")
91 disp(Tt2," Total temperature at engine face:") //Tt0=
    Tt2, since adiabatic!
92 disp(Tt13," Total temperature at fan exit:")
93 disp(T19," Static temperature at fan nozzle exit:")
94 disp(Tt3," Total temperature at compressor exit:")
95 disp(Tt4," Total temperature at burner exit:")
96 disp(Tt5," Total temperature at turbine exit:")
97 disp(T9," Static temperature at nozzle exit:")

```

```

98 disp(pt19,"(b{1})Total pressure at fan nozzle exit:"
    )
99 disp(p9,"(b{2})Static pressure at nozzle exit:")
100
101
102 //Remaining results
103 disp(V19,"(c{1}Actual fan nozzle exit velocity in m/
    s:)")
104 disp(V19eff,"(c{2}Effective fan nozzle exit velocity
    in m/s:)")
105 disp(V9,"(c{3})Actual core nozzle exit velocity in m
    /s:")
106 disp(V9eff,"(c{4})Effective nozzle exit velocity in
    m/s:")
107 disp(rfct,"(d)Ratio of fan-to-core thrust:")
108 disp(ndst,"(e)Nondimensional specific thrust:")
109 disp(TSFC,"(f)TSFC in mg/s/N:")
110 disp("(g)Engine efficiencies:")
111 disp(eth,"Thermal efficiency:")
112 disp(ep,"Propulsion efficiency:")
113 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

```

1 clear;
2 clc;
3 close;
4 disp("Example4.14")
5 M0=0.88 //Mach no.
6 p0=15 // pressure in kPa
7 T0=233 //temperatue in K
8 gmc=1.4 //gamma compressor

```

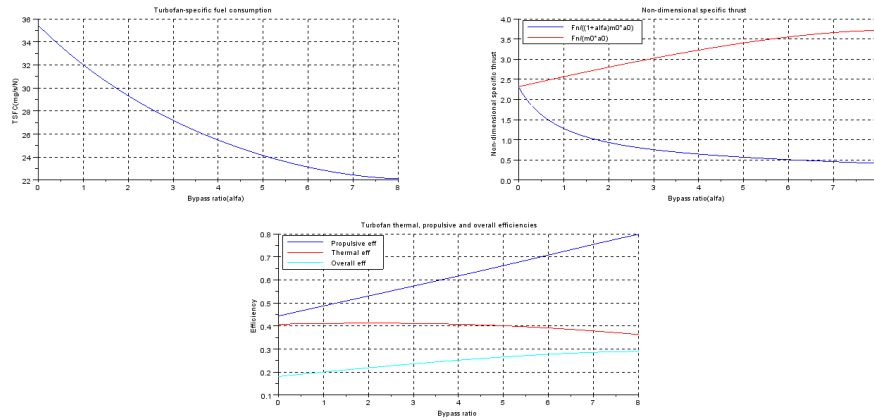


Figure 4.2: Graph of the performance of separate exhaust turbofan engine for a range of bypass ratios from 0 to 8

```

9 Cpc=1004 //specific heat of compressor in J/kg.K
10 pd=0.995 // pressure compression ratio of diffuser
11 pf=1.6 //pressure compression ratio of fan
12 ef=0.9 //fan efficiency
13 pfn=0.95 //compression ratio of convergent fan
    nozzle
14 pc=40 //compression ratio of compressor
15 ec=0.9 //compressor efficiency
16 t1=8 //temp. ratio
17 Cpt=1152 //in J/kg.K of turbine
18 gmt=1.33 //gamma turbine
19 Qr=42000000 //in J/kg
20 pb=0.95 //burner compression ratio
21 eb=0.992 //burner efficiency
22 em=0.95
23 et=0.85
24 pn=0.98 //primary nozzle
25 k1=8
26 z0=[0:0.005:k1]
27 x=[]
28 count=1
29 g1=[]

```

```

30 gc1=1
31 g2=[]
32 gc2=1
33 g3=[]
34 gc3=1
35 g4=[]
36 gc4=1
37 g5=[]
38 gc5=1
39 g6=[]
40 gc6=1
41 alfa=0
42 for alfa=0:0.005:8
43
44
45 a0=((gmc-1)*Cpc*T0)^(1/2);
46 V0=M0*a0;
47 pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
48
49
50 Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
51
52 Tt2=Tt0
53
54 pt2=pt0*pd
55
56 //fan stream:
57 pt13=pt2*pf
58 tf=pf^((gmc-1)/(ef*gmc))
59 Tt13=Tt2*tf
60 pt19=pt13*pfn
61 p19=pt19/(1+(gmc-1)/2)^(gmc/(gmc-1))
62 M19=1
63 T19=Tt13/1.2
64 a19=((gmc-1)*Cpc*T19)^(1/2)
65 V19=a19
66 //V19eff=V19+((gmc*p19)/r19)*((1-p0/p19)/(gmc*V19))
    i.e V19+a19^2

```



```

67 V19eff=V19+(a19^2)*((1-p0/p19)/(gmc*V19))
68 //Core stream
69 pt3=pt2*pc
70 tc=pc^((gmc-1)/(ec*gmc))
71 //disp(tc)
72 Tt3=Tt2*tc
73 pt4=pt3*pb
74 Tt4=Cpc*T0*t1/Cpt
75 //disp(Tt4)
76 f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
77 //disp(f)
78 Tt5=Tt4-((Cpc*(Tt3-Tt2)+alfa*Cpc*(Tt13-Tt2)))/((1+f)
    *Cpt*em)
79 //disp(Tt5)
80 tt=Tt5/Tt4
81 pt=tt^(gmt/(et*(gmt-1)))
82 pt5=pt4*pt
83 pt9=pt5*pn
84 p9=pt9/((gmt+1)/2)^(gmt/(gmt-1))
85 M9=1
86 T9=Tt5/((gmt+1)/2)
87 a9=((gmt-1)*Cpt*T9)^(1/2)
88 V9=a9
89 V9eff=V9+(((a9)^2)*(1-(p0/p9)))/(gmt*V9)
90 ndsft=alfa*(V19eff-V0)/((1+alfa)*a0)
91 ndsct=((1+f)*V9eff-V0)/((1+alfa)*a0)
92 ndst=ndsft+ndsct
93 ndsta=ndst*(1+alfa)
94 rfct=ndsft/ndsct
95 fc=ndsft*100/(ndsft+ndsct)
96 cc=ndsct*100/(ndsft+ndsct)
97 TSFC=f/((1+alfa)*a0*(ndsft+ndsct))*10^6
98 eth=(alfa*V19eff^2+(1+f)*V9eff^2-(1+alfa)*V0^2)/(2*f
    *Qr)
99 ep=(2*(ndsft+ndsct)*(1+alfa)*a0*V0)/(alfa*V19eff
    ^2+(1+f)*V9eff^2-(1+alfa)*V0^2)
100 eo=eth*ep
101 x(count)=TSFC;

```

```

102 count=count+1;
103 g1(gc1)=ndst
104 gc1=gc1+1
105 g2(gc2)=ndsta
106 gc2=gc2+1
107 g3(gc3)=ep
108 gc3=gc3+1
109 g4(gc4)=eth
110 gc4=gc4+1
111 g5(gc5)=eo
112 gc5=gc5+1
113 end
114
115 subplot(2,2,1)
116 plot2d(z0,x,2)
117 xgrid
118 title("Turbofan-specific fuel consumption")
119 xlabel("Bypass ratio(alfa)")
120 ylabel("TSFC(mg/s/N)")
121 subplot(2,2,2)
122 plot2d(z0,g1,2)
123 xgrid
124 xlabel("Bypass ratio(alfa)")
125 ylabel("Non-dimensional specific thrust")
126 title("Non-dimensional specific thrust")
127 plot2d(z0,g2,5)
128 legend(['Fn/((1+alfa)m0*a0)'; 'Fn/(m0*a0)'],2)
129 subplot(2,2,3.5)
130 plot2d(z0,g3,2)
131 xgrid
132 xlabel("Bypass ratio")
133 ylabel("Efficiency")
134 title("Turbofan thermal, propulsive and overall
        efficiencies")
135
136 plot2d(z0,g4,5)
137 plot2d(z0,g5,4)
138 legend(['Propulsive eff'; 'Thermal eff'; 'Overall eff']

```

],2)

Scilab code Exa 4.15 Mixed exhaust turbofan engine with afterburner

```
1 clear;
2 clc;
3 close;
4 disp("Example 4.15")
5 M0=2 //Mach no.
6 p0=10 // in kPa
7 T0=223 //in K
8 //the engine inlet total pressure loss is
   characterized by
9 pd=0.9
10 //The fan pressure ratio is
11 pf=1.9
12 //and polytropic efficiency of the fan is
13 ef=0.9
14 //The flow in the fan duct suffers 1% total pressure
   loss i.e.
15 pfd=0.99
16 //The compressor pressure ratio and polytropic
   efficiency are
17 pc=13
18 ec=0.9 //respectively
19 //The combustor exit temperature is
20 Tt4=1600 //in K
21 Qr=42000000 //fuel heating value in J/kg
22 pb=0.95 //total pressure ratio
23 eb=0.98 //burner efficiency
24 et=0.8 //turbine polytropic efficiency
25 em=0.95 //mechanical efficiency of turbine
26 M5=0.5 //Mach no at turbine exit
27 pmf=0.98 //total pressure loss due to friction in
   mixer
```

```

28 Tt7=2000 //afterburner total temp in K
29 QrAB=42000000 //in J/kg
30 pABon=0.92
31 eAB=0.98
32 pn=0.95 //total pressure ratio at nozzle
33 p=3.8 //p=p9/p0
34 gmc=1.4 //gamma compressor
35 Cpc=1004 //specofic heat compressor in J/kg.K
36 gmt=1.33 //gamma turbine
37 Cpt=1152 //turbine
38 gmAB=1.3 //afterburner
39 CpAB=1241 //afterburner
40 pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
41 Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
42 pr=pt0/p0
43 tr=Tt0/T0
44 pt=pdf*pf/(pb*pc)
45 a0=((gmc-1)*Cpc*T0)^(1/2);
46 V0=a0*M0
47 Tt2=Tt0
48 pt2=pt0*pd
49 pt13=pt2*pf
50 tf=pf^((gmc-1)/(ec*gmc))
51 //disp(tf)
52 Tt13=Tt0*tf
53 Tt15=Tt13 //adiabatic
54 pt15=pt13*pdf
55 pt3=pt2*pc
56 tc=pc^((gmc-1)/(ec*gmc))
57 Tt3=Tt2*tc
58 pt4=pt3*pb
59 f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
60 //disp(f)
61 pt5=pt15 //assumption
62 pt=(pdf*pf)/(pb*pc)
63 //disp(pt)
64 tt=pt^(et*(gmt-1)/(gmt))
65 //disp(tt)

```

```

66 Tt5=Tt4*tt
67 t1=(Cpt*Tt4)/(Cpc*T0)
68 tr=(1+((gmc-1)*(M0^2)/2))
69 alfa=((em*(1+f)*t1*(1-tt))-(tr*(tc-1)))/(tr*(tf-1))
70 ht6M=Cpc*T0*((1+f)*tt*t1+alfa*tf*tr)/(1+alfa+f) //
    mixed-out total enthalpy in J/kg
71 Cp6M=((1+f)/alfa)*Cpt+Cpc)/(((1+f)/alfa)+1)
72 gm6M=((1+f)/alfa)*Cpt+Cpc)/(((1+f)/alfa)*(Cpt/gmt)
    +(Cpc/gmc))
73 M15=((2/(gmc-1))*(((1+((gmt-1)*(M5^2)/2))^(gmt/(gmt
    -1))))^(gmc-1)/gmc))-1)^(1/2)
74 T15=Tt15/(1+((gmc-1)*(M15)^2)/2)
75 p15=pt15/(1+((gmc-1)*(M15)^2)/2)^(gmc/(gmc-1))
76 T5=Tt5/(1+((gmt-1)*(M5)^2)/2)
77 p5=pt5/(1+((gmt-1)*(M5)^2)/2)^(gmt/(gmt-1))
78 a15=((gm6M-1)*Cp6M*T15)^(1/2)
79 a5=((gm6M-1)*Cp6M*T5)^(1/2)
80 A=((alfa/(1+f))*(gmt/gmc)*((T15/T5)^(1/2)))*(M5/M15))
81 C1=((1+gmt*M5^2)+(A*(1+gmc*M15^2)))/(1+A)
82 Tt6M=ht6M/Cp6M
83 C2=((gmt/gm6M)*(M5/a5)+(gmc/gm6M)*(M15*A/a15))*(((
    gm6M-1)*Cp6M*(Tt6M))^(1/2))/(1+A)
84 C=(C1/C2)^2
85 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)
86 p6M=p5*(C1/(1+gm6M*(M6M)^2))
87 pt6Mi=131.23
88 pmi=0.9907
89 pM=0.9709
90 pt6M=pt6Mi*pmf
91 Tt7=2000
92 pABon=0.92
93 pt7=118.32
94 fAB=(CpAB*Tt7-ht6M)/(QrAB*eAB-CpAB*Tt7)
95 pt9=pt7*pn
96 p9=p0*p
97 M9=1.377
98 T9=1557.2

```

```

99  a9=761.4
100 V9=a9*M9
101 V9eff=V9+a9^2*(1-p0/p9)/(gmAB*V9)
102 ndst=((1+alfa+f+fAB)/(1+alfa))*(V9eff/a0)-M0
103 TSFC=((f+fAB)/((1+alfa)*a0))*10^6/(ndst)
104 eth=((1+alfa+f+fAB)*((V9eff)^2))-((1+alfa)*V0^2))
      /(2*(f*Qr+fAB*QrAB))
105 ep=(2*ndst*V0*a0*(1+alfa))/((1+alfa+f+fAB)*V9eff
      ^2-(1+alfa)*V0^2)
106 e0=ep*eth
107 disp("a(1) Total pressures throughout the engine in
      kPa:")
108 disp(pt0," Total pressure of flight:")
109 disp(pt2," Total pressure at engine face:")
110 disp(pt15," Total pressure at fan exit:")
111 //disp(p19," Static pressure at nozzle exit:")
112 disp(pt3," Total pressure at compressor exit:")
113 disp(pt4," Total pressure at burner exit:")
114 disp(pt5," Total pressure at turbine exit:")
115 disp(pt9," Total pressure at nozzle exit:")
116
117
118 disp("a(2) Total temperatures across the engine in K:
      ")
119 disp(Tt0," Total temperature of flight:")
120 disp(Tt2," Total temperature at engine face:") //Tt0=
      Tt2, since adiabatic!
121 disp(Tt13," Total temperature at fan exit:")
122 disp(Tt15," Total temperature at fan duct :")
123 disp(Tt3," Total temperature at compressor exit:")
124 disp(Tt4," Total temperature at burner exit:")
125 disp(Tt5," Total temperature at turbine exit:")
126 disp(alfa,"a(3)Fan bypass ratio :")
127 disp(f,"a(4) fuel-to-air ratio in primary :")
128 disp(fAB,"a(5) fuel-to-air ratio in afterburner :")
129 disp(TSFC,"b(1)TSFC in mg/s/N :")
130 disp(ndst,"b(2)Non-dimensional specific thrust :")
131 disp(ep,"b(3) Propulsive efficiency :")

```

```
132 disp(eth,"b(4) Thermal efficiency :")
133 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

```
1 clear;
2 clc;
3 close;
4 disp("Example 4.16")
5 M0=2 //Mach no.
6 p0=10 // in kPa
7 T0=223 //in K
8 //the engine inlet total pressure loss is
   characterized by
9 pd=0.9
10 //The fan pressure ratio is
11 pf=1.9
12 //and polytropic efficiency of the fan is
13 ef=0.9
14 //The flow in the fan duct suffers 1% total pressure
   loss i.e.
15 pfd=0.99
16 //The compressor pressure ratio and polytropic
   efficiency are
17 pc=6
18 ec=0.9 //respectively
19 //The combustor exit temperature is
20 Tt4=1600 //in K
21 Qr=42000000 //fuel heating value in J/kg
22 pb=0.95 //total pressure ratio
23 eb=0.98 //burner efficiency
24 et=0.8 //turbine polytropic efficiency
25 em=0.95 //mechanical efficiency of turbine
```

```

26 M5=0.5 //Mach no at turbine exit
27 pmf=0.98 //total pressure loss due to friction in
    mixer
28 Tt7=2000 //afterburner total temp in K
29 QrAB=42000000 //in J/kg
30 pABon=0.92
31 eAB=0.98
32 pn=0.95 //total pressure ratio at nozzle
33 p=3.8 //p=p9/p0
34 gmc=1.4 //gamma compressor
35 Cpc=1004 //specofic heat compressor in J/kg.K
36 gmt=1.33 //gamma turbine
37 Cpt=1152 //turbine
38 gmAB=1.3 //afterburner
39 CpAB=1241 //afterburner
40 z0=[6:0.1:16]
41 x=[]
42 count=1
43 g2=[]
44 gc2=1
45 g3=[]
46 gc3=1
47 g4=[]
48 gc4=1
49 g5=[]
50 gc5=1
51 g6=[]
52 gc6=1
53 g7=[]
54 gc7=1
55 for pc=6:0.1:16
56
57 pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
58 Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
59 pr=pt0/p0
60 tr=Tt0/T0
61 pt=pfd*pf/(pb*pc)
62 a0=((gmc-1)*Cpc*T0)^(1/2);

```



```

63 V0=a0*M0
64 Tt2=Tt0
65 pt2=pt0*pd
66 pt13=pt2*pf
67 tf=pf^((gmc-1)/(ec*gmc))
68 Tt13=Tt0*tf
69 Tt15=Tt13 //adiabatic
70 pt15=pt13*pdf
71 pt3=pt2*pc
72 tc=pc^((gmc-1)/(ec*gmc))
73 Tt3=Tt2*tc
74 pt4=pt3*pb
75 f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
76 pt5=pt15 //assumption
77 pt=(pdf*pf)/(pb*pc)
78 tt=pt^(et*(gmt-1)/(gmt))
79 Tt5=Tt4*tt
80 t1=(Cpt*Tt4)/(Cpc*T0)
81 tr=(1+((gmc-1)*(M0^2)/2))
82 alfa=((em*(1+f)*t1*(1-tt))-(tr*(tc-1)))/(tr*(tf-1))
83 ht6M=Cpc*T0*((1+f)*tt*t1+alfa*tf*tr)/(1+alfa+f) //
    mixed-out total enthalpy in J/kg
84 Cp6M=((((1+f)/alfa)*Cpt+Cpc)/(((1+f)/alfa)+1)
85 gm6M=((((1+f)/alfa)*Cpt+Cpc)/(((1+f)/alfa)*(Cpt/gmt)
    +(Cpc/gmc))
86 M15=((2/(gmc-1))*(((1+((gmt-1)*(M5^2)/2))^(gmt/(gmt
    -1))))^(gmc-1)/gmc)-1))^(1/2)
87 T15=Tt15/(1+((gmc-1)*(M15)^2)/2)
88 p15=pt15/(1+((gmc-1)*(M15)^2)/2)^(gmc/(gmc-1))
89 T5=Tt5/(1+((gmt-1)*(M5)^2)/2)
90 p5=pt5/(1+((gmt-1)*(M5)^2)/2)^(gmt/(gmt-1))
91 a15=((gm6M-1)*Cp6M*T15)^(1/2)
92 a5=((gm6M-1)*Cp6M*T5)^(1/2)
93 A=((alfa/(1+f))*(gmt/gmc)*((T15/T5)^(1/2))*(M5/M15))
94 C1=((1+gmt*M5^2)+(A*(1+gmc*M15^2)))/(1+A)
95 Tt6M=ht6M/Cp6M
96 C2=((gmt/gm6M)*(M5/a5)+(gmc/gm6M)*(M15*A/a15))*(((
    gm6M-1)*Cp6M*(Tt6M))^(1/2))/(1+A)

```

```

97 C=(C1/C2)^2
98 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)
99 p6M=p5*(C1/(1+gm6M*(M6M)^2))
100 pt6Mi=131.23
101 pmi=0.9907
102 pM=0.9709
103 pt6M=pt6Mi*pmf
104 Tt7=2000
105 pABon=0.92
106 pt7=118.32
107 fAB=(CpAB*Tt7-ht6M)/(QrAB*eAB-CpAB*Tt7)
108 ft=f+fAB
109 pt9=pt7*pn
110 p9=p0*p
111 M9=1.377
112 T9=1557.2
113 a9=761.4
114 V9=a9*M9
115 V9eff=V9+a9^2*(1-p0/p9)/(gmAB*V9)
116 ndst=((1+alfa+f+fAB)/(1+alfa))*(V9eff/a0)-M0
117 TSFC=((f+fAB)/((1+alfa)*a0))*10^6/(ndst)
118 eth=((1+alfa+f+fAB)*((V9eff)^2)-((1+alfa)*V0^2))
    /(2*(f*Qr+fAB*QrAB))
119 ep=(2*ndst*V0*a0*(1+alfa))/((1+alfa+f+fAB)*V9eff
    ^2-(1+alfa)*V0^2)
120 e0=ep*eth
121 x(count)=TSFC;
122 count=count+1;
123 g2(gc2)=ndst
124 gc2=gc2+1
125 g3(gc3)=ep
126 gc3=gc3+1
127 g4(gc4)=eth
128 gc4=gc4+1
129 g5(gc5)=e0
130 gc5=gc5+1
131 g6(gc6)=alfa

```

```

132 gc6=gc6+1
133 g7(gc7)=ft
134 gc7=gc7+1
135 end
136 subplot(2,2,1)
137 plot2d(z0,x,2)
138 xgrid
139 title("TSFC in an AB-mixed flow turbofan engine")
140 xlabel("Compression pressure ratio")
141 ylabel("TSFC(mg/s/N)")
142 subplot(2,2,2)
143 plot2d(z0,g2,2)
144 xgrid
145 xlabel("Compressor pressure ratio")
146 ylabel("Non-dimensional specific thrust")
147 title("Specific thrust variation")
148 subplot(2,2,3)
149 plot2d(z0,g3,2)
150 plot2d(z0,g4,5)
151 plot2d(z0,g5,6)
152 xgrid
153 xlabel("Compressor pressure ratio")
154 ylabel("Efficiency")
155 title("Engine Efficiency")
156 legend(['Propulsive','Thermal','Overall'],2)
157 subplot(2,2,4)
158 plot2d(z0,g6,2)
159 xgrid
160 xlabel("Compressor pressure ratio")
161 ylabel("Bypass ratio")
162 title("Bypass ratio variation in an AB-mixed flow
        turbofan engine")
163 figure(1)
164 plot2d(z0,g7,2)
165 xgrid
166 xlabel("Compressor pressure ratio")
167 ylabel("f+fAB")
168 title("f+fAB")

```

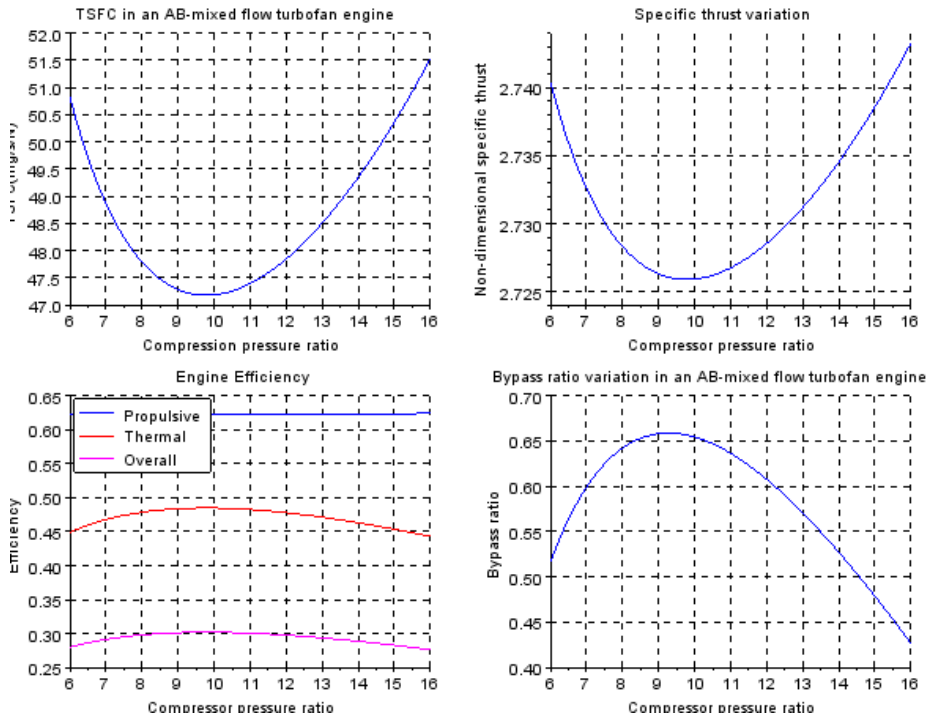


Figure 4.3: Engine performance of a mixed exhaust turbofan engine with afterburner having same parameters as in previous example for a range of compressor pressure ratios from 6 to 16

Scilab code Exa 4.17 The turboprop engine performance parameter

```

1 clear;
2 clc;
3 close;
4 disp(" Example 4.17")

```

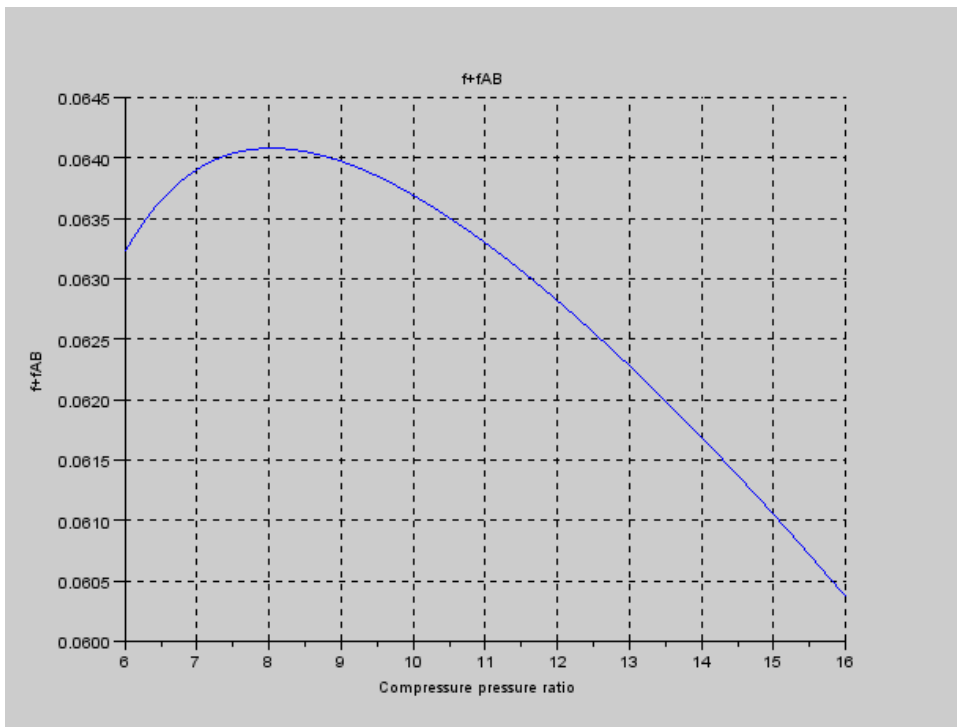


Figure 4.4: Engine performance of a mixed exhaust turbofan engine with afterburner having same parameters as in previous example for a range of compressor pressure ratios from 6 to 16

```

5 M0=0.7 //Mach no.
6 T0=228 // in K
7 p0=16 //kPa
8 eprop=0.85 // prop efficiency
9 m=10 //Kg/s
10 pd=0.98 //diffuser pressure ratio
11 pc=30 //compressor pressurer ratio
12 ec=0.92 //thermal efficiency of compressor
13 Tt4=1600 //in K
14 Qr=42000000 //in kJ/kg
15 eb=0.99 //thermal efficiency of burner
16 pb=0.96 //burner pressure ratio
17 etHPT=0.82
18 emHPT=0.99
19 alfa=0.85
20 emLPT=0.99
21 eLPT=0.88
22 egb=0.995
23 en=0.95
24 gmc=1.4 //gamma of compressor
25 Cpc=1004 // in J/kg.K
26 gmt=1.33 //gamma of turbine
27 Cpt=1152 // in J/kg.K
28 Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
29 pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
30 a0=((gmc-1)*Cpc*T0)^(1/2);
31 V0=a0*M0
32 pt2=pt0*pd
33 Tt2=Tt0 //Adiabatic
34 pt3=pt2*pc
35 tc=pc^((gmc-1)/(ec*gmc))
36 Tt3=Tt2*tc
37 f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
38 pt4=pt3*pb
39 ht45=Cpt*Tt4-(Cpc*Tt3-Cpc*Tt2)/((1+f)*emHPT)
40 Tt45=ht45/Cpt
41 pt45=pt4*(Tt45/Tt4)^(gmt/((gmt-1)*etHPT))
42 m9=(1+f)*m

```

```

43 sp=(1+f)*m*eLPT*alfa*ht45*(1-(p0/pt45)^((gmt-1)/gmt)
    )/10^6
44 Tt5=(ht45-sp*10^6/((1+f)*m))/Cpt
45 tt=Tt5/Tt45
46 et=log(tt)/(log(1-((1-tt)/eLPT)))
47 pt=tt^(gmt/(et*(gmt-1)))
48 pt5=pt45*pt
49 p9=p0 //assumption
50 pi=p9/pt5
51 ti=pi^((gmt-1)/gmt)
52 T9i=Tt5*ti
53 T9=Tt5-en*(Tt5-T9i)
54 V9=(2*Cpt*(Tt5-T9))^(1/2)
55 Fprop=eprop*egb*emLPT*sp*10^3/V0
56 a9=((gmt-1)*Cpt*T9)^(1/2)
57 M9=V9/a9
58 pt9=p9*(1+((gmt-1)*M9^2)/2)^(gmt/(gmt-1))
59 pn=pt9/pt5
60 Fncore=m*((1+f)*V9-V0)/1000
61 spp=egb*emLPT*sp
62 Ft=Fprop+Fncore
63 mp=((m9*V9^2)/2-m*(V0^2)/2)/10^3
64 mf=m9-m
65 PSFC=mf*10^6/((spp*10^3)+mp)
66 TSFC=mf*10^3/(Ft)
67 eth=(spp*10^3+mp)*10^3/(mf*Qr)
68 ep=(Ft*V0)/(spp*10^3+mp)
69 eo=eth*ep
70 disp("a(1) Total pressures throughout the engine in
    kPa:")
71 disp(pt0," Total pressure of flight:")
72 disp(pt2," Total pressure at engine face:")
73 //disp(p19," Static pressure at nozzle exit:")
74 disp(pt3," Total pressure at compressor exit:")
75 disp(pt4," Total pressure at burner exit:")
76 disp(pt45," Total pressure across HPT :")
77 disp(pt5," Total pressure at turbine exit:")
78 disp(pt9," Total pressure at nozzle exit:")

```

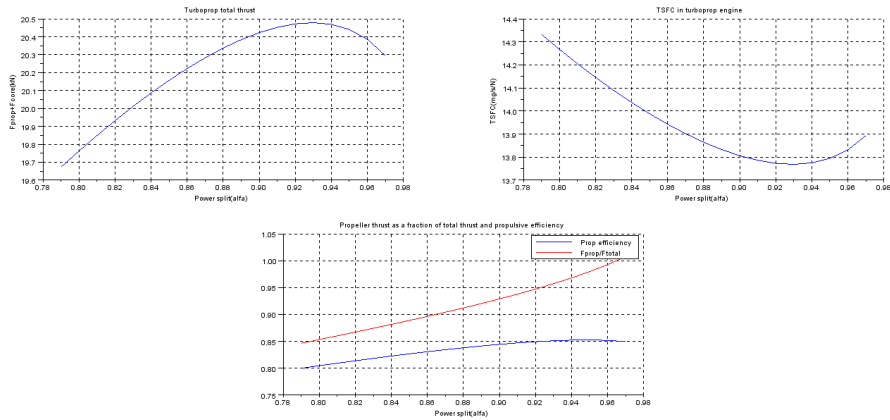


Figure 4.5: Graph of the performance parameters of the engine in above example with power split varying over a range

```

79
80 disp(" a(2) Total temperatures across the engine in K:
      ")
81 disp(Tt0," Total temperature of flight:")
82 disp(Tt2," Total temperature at engine face:") //Tt0=
      Tt2, since adiabatic!
83 disp(Tt3," Total temperature at compressor exit:")
84 disp(Tt4," Total temperature at burner exit:")
85 disp(Tt45," Total temperature across HPT :")
86 disp(Tt5," Total temperature at turbine exit:")
87 disp(f," a(3) fuel-to-air ratio in burner :")
88 disp(Fncore," (b) Engine core thrust in kN :")
89 disp(Fprop," (c) Propeller thrust in kN :")
90 disp(PSFC," (d) Power-specific fuel consumption in mg/
      s/kW :")
91 disp(TSFC," (e) TSFC in mg/s/N :")
92 disp(ep," f(1) Propulsive efficiency :")
93 disp(eth," f(2) Thermal efficiency :")
94 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

```
1 clear;
2 clc;
3 close;
4 disp("Example 4.17")
5 M0=0.7
6 T0=228 //in K
7 p0=16 //kPa
8 eprop=0.85 //efficiency of prop
9 m=10 //Kg/s
10 pd=0.98
11 pc=30
12 ec=0.92
13 Tt4=1600
14 Qr=42000000 // in kJ/kg
15 eb=0.99
16 pb=0.96
17 etHPT=0.82
18 emHPT=0.99
19 alfa=0.79
20 emLPT=0.99
21 eLPT=0.88
22 egb=0.995
23 en=0.95
24 gmc=1.4
25 Cpc=1004
26 gmt=1.33
27 Cpt=1152
28 z0=[0.79:0.01:0.97]
29 g1=[]
30 gc1=1
31 g2=[]
```

```

32 gc2=1
33 g3=[]
34 gc3=1
35 g4=[]
36 gc4=1
37 for alfa=0.79:0.01:0.97
38 Tt0=T0*(1+((gmc-1)*(M0)^2)/2)
39 pt0=p0*(1+((gmc-1)*(M0)^2)/2)^(gmc/(gmc-1))
40 a0=((gmc-1)*Cpc*T0)^(1/2);
41 V0=a0*M0
42 pt2=pt0*pd
43 Tt2=Tt0 // Adiabatic
44 pt3=pt2*pc
45 tc=pc^((gmc-1)/(ec*gmc))
46 Tt3=Tt2*tc
47 f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
48 pt4=pt3*pb
49 ht45=Cpt*Tt4-(Cpc*Tt3-Cpc*Tt2)/((1+f)*emHPT)
50 Tt45=ht45/Cpt
51 pt45=pt4*(Tt45/Tt4)^(gmt/((gmt-1)*etHPT))
52 m9=(1+f)*m
53 sp=(1+f)*m*eLPT*alfa*ht45*(1-(p0/pt45)^((gmt-1)/gmt)
    )/10^6
54 Tt5=(ht45-sp*10^6/((1+f)*m))/Cpt
55 tt=Tt5/Tt45
56 et=log(tt)/(log(1-((1-tt)/eLPT)))
57 pt=tt^(gmt/(et*(gmt-1)))
58 pt5=pt45*pt
59 p9=p0 // assumption
60 pi=p9/pt5
61 ti=pi^((gmt-1)/gmt)
62 T9i=Tt5*ti
63 T9=Tt5-en*(Tt5-T9i)
64 V9=(2*Cpt*(Tt5-T9))^(1/2)
65 Fprop=eprop*egb*emLPT*sp*10^3/V0
66 a9=((gmt-1)*Cpt*T9)^(1/2)
67 M9=V9/a9
68 pt9=p9*(1+((gmt-1)*M9^2)/2)^(gmt/(gmt-1))

```

```

69 pn=pt9/pt5
70 Fncore=m*((1+f)*V9-V0)/1000
71 spp=egb*emLPT*sp
72 Ft=Fprop+Fncore
73 Fr=Fprop/Ft
74
75 mp=((m9*V9^2)/2-m*(V0^2)/2)/10^3
76 mf=m9-m
77 PSFC=mf*10^6/((spp*10^3)+mp)
78 TSFC=mf*10^3/(Ft)
79 eth=(spp*10^3+mp)*10^3/(mf*Qr)
80 ep=(Ft*V0)/(spp*10^3+mp)
81 eo=eth*ep
82 g1(gc1)=Ft;
83 gc1=gc1+1;
84 g2(gc2)=TSFC;
85 gc2=gc2+1
86 g3(gc3)=ep
87 gc3=gc3+1
88 g4(gc4)=Fr
89 gc4=gc4+1
90
91 end
92 subplot(2,2,1)
93 plot2d(z0,g1,2)
94 xgrid
95 title("Turboprop total thrust")
96 xlabel("Power split(alfa)")
97 ylabel("Fprop+Fcore(kN)")
98 subplot(2,2,2)
99 plot2d(z0,g2,2)
100 xgrid
101 title("TSFC in turboprop engine")
102 xlabel("Power split(alfa)")
103 ylabel("TSFC(mg/s/N)")
104 subplot(2,2,3.5)
105 plot2d(z0,g3,2)
106 plot2d(z0,g4,5)

```

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

Chapter 5

Aircraft engine inlet and nozzles

Scilab code Exa 5.1 Overspeed Mach no

```
1 clear;
2 clc;
3 close;
4 disp(" Example 5.1")
5 Md=1.5
6 //From isentropic table ,
7 gm=1.4 //gamma
8 A=1.176 //A=A1/Ath=A1/Acr
9 //for same A, from isentropic table for M<1
10 My=0.61
11 //for My=0.61, from normal shock table
12 Mx=1.8
13 Mos=Mx
14 disp(Mos," Overspeed Mach no.")
```

Scilab code Exa 5.2 Kantrowitz Donaldson inlet

```

1  clear;
2  clc;
3  close;
4  disp("Example 5.2")
5  Md=2.65
6  Mx=Md
7  //for Mx=2.65, from normal shock table
8  My=0.4996
9  M1=My
10 //from isentropic table for M1=0.5,
11 A=1.34
12 //for Md=2.65, from isentropic table (A=A1/Acr)
13 A1=3.036
14 Af=A1/A
15 //from isentropic table Af,
16 Mth=2.35
17 //for Mth=2.35, from normal shock table
18 p=0.5615 //p=pty/ptx
19 disp(p,"Maximum total pressure recovery:")

```

Scilab code Exa 5.3 Variable throat isentropic C D nozzle

```

1  clear;
2  clc;
3  close;
4  disp("Example 5.3")
5  Md=3.3 //from isentropic table
6  A=5.629 // A=A1/Acr=A1/Ath
7  Mx=Md //from normal shock table
8  My=0.4596
9  M1=My
10 //from isentropic table
11 A11=1.425
12 pt=((1/A11 - 1/A)/(1/A))*100
13 Af=A/A11

```

```

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

```

Scilab code Exa 5.4 Normal shock inlet

```

1 clear;
2 clc;
3 close;
4 disp("Example 5.4")
5 M0=1.4
6 //from normal shock table
7 p=0.9582 //p=pt2/pt0
8 M1=M0
9 //from isentropic table:
10 A=1.115 //A=A1/Acr
11 A11=1.1 //A11=Ax/A1
12 Af=A11*A
13 //from normal shock table for M>1
14 Mx=1.56
15 //from normal table
16 p1=0.91 //p=pt2/pt0
17 p2=p
18 disp(p,"(a)The best backpressure :")
19 disp(p1,"(b)The supercritical mode inlet total
    pressure recovery:")
20 disp(p2,"(c)Inlet pressure recovery in subcritical
    mode with 10% spillage:")

```

Scilab code Exa 5.5 External compression inlets

```

1 clear;
2 clc;
3 close;
4 disp("Example 5.5")
5 //th=theta and b=beta.
6 gm=1.4 //gamma
7 //OBLIQUE SHOCK 1
8 M0=2
9 th=8 //degree
10 //from theta-beta-M chart,
11 b1=37 //degree
12 Mn1=M0*sind(b1)
13 p1=0.993 //p=pt2/pt1
14 Mn2=((2+(gm-1)*Mn1^2)/(2*gm*Mn1^2-(gm-1)))^(1/2)
15 M2=Mn2/sind(b1-th)
16 //OBLIQUE SHOCK 2
17 M0=M2
18 th=12
19 //from oblique shock chart,
20 b2=48.7
21 Mn1=M0*sind(b2)
22 p2=0.978
23 Mn2=((2+(gm-1)*Mn1^2)/(2*gm*Mn1^2-(gm-1)))^(1/2)
24 M3=Mn2/sind(b1-th)
25 //NORMAL SHOCK
26 M0=M3
27 b3=90
28 pNS=0.977
29
30 Po=p1*p2*pNS
31 disp(Po,"Total pressure recovery:")

```

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

```

1 clear;

```



```

2  clc;
3  close;
4  disp("Example 5.6")
5  M9=1 // Mach no.
6  p=1/8 //p=p0/pt7
7  gm=1.3 //gamma
8  V9cd=(2*(1-p^((gm-1)/gm)))^(1/2)
9  px=p*((gm+1)/2)^(gm/(gm-1))
10 V9c=(2*(gm-1)/(gm+1))^(1/2)
11 FR=(V9cd/V9c)/(1+(1-px)/gm)
12 pr=(FR-1)*100/1
13 disp(pr,"% increase in gross thrust:")

```

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

```

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

```

```

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

```

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

```

1 clear;
2 clc;
3 close;
4 disp("Example 5.8")
5 alfa=0 //alfa=cone half angle
6 dx=[0:0.03:44]
7 x=[]
8 count=1
9 for alfa=0:0.03:44
10 Ca=(1+cosd(alfa))/2 //Flow angularity loss
    coefficient
11 x(count)=Ca
12 count=count+1
13 //disp(Ca,"Divergence correction factor Ca:")
14 end
15 plot2d(dx,x,2)
16 xgrid
17 title("Flow convergence loss in a conical nozzle")

```

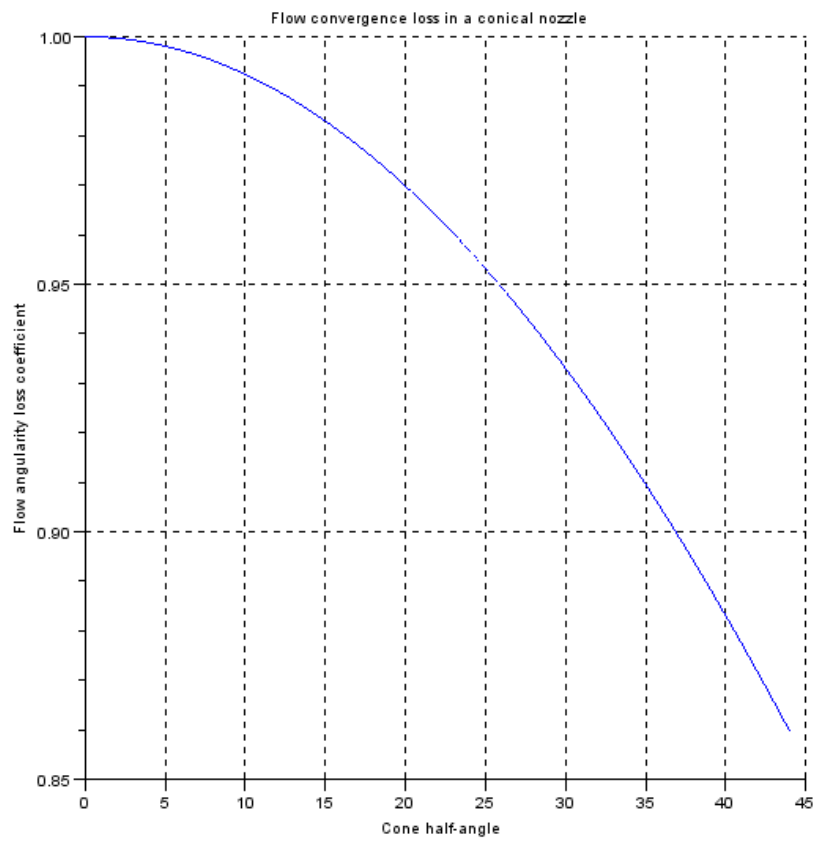


Figure 5.1: Divergence correction factor C_a for a conical nozzle with exit flow angles varying over a range

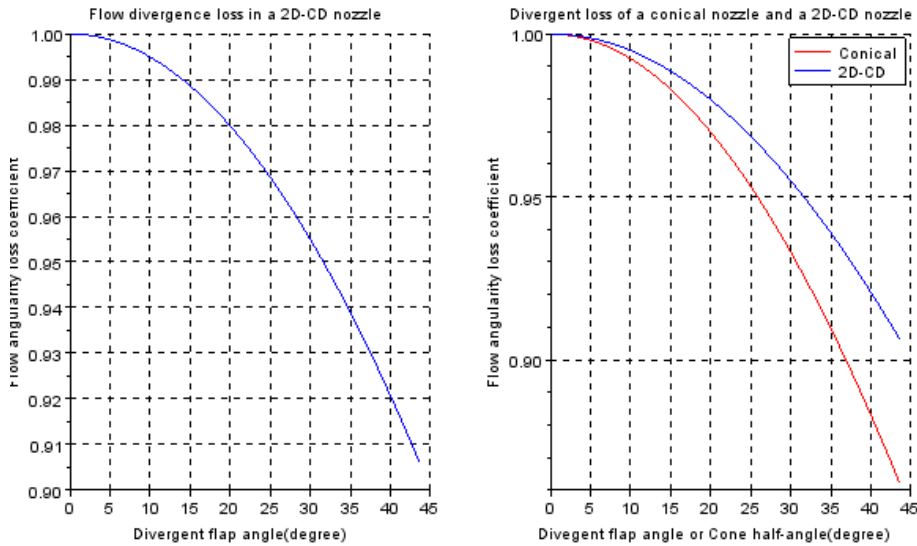


Figure 5.2: Graph of divergence correction factor for a two dimensional nozzle with exit flow angles varying over a range

```
18 xlabel("Cone half-angle")
19 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

```
1 clear;
2 clc;
3 close;
4 disp("Example 5.9")
5 alfa=0.1
6 dx=[0.1:0.5:44]
7 x=[]
```

```

8 g1=[]
9 g1=1
10 count=1
11 g2=[]
12 gc1=1
13 for alfa=0.1:0.5:44
14 Ca=(sind(alfa))/(alfa*%pi/180)
15 Cac=(1+cosd(alfa))/2
16 x(count)=Ca
17 count=count+1
18 g1(gc1)=Cac
19 gc1=gc1+1
20 end
21 subplot(1,2,1)
22 plot2d(dx,x,2)
23 xgrid
24 title("Flow divergence loss in a 2D-CD nozzle")
25 xlabel("Divergent flap angle(degree)")
26 ylabel("Flow angularity loss coefficient")
27 subplot(1,2,2)
28 plot2d(dx,g1,5)
29 plot2d(dx,x,2)
30 xgrid
31 legend(["Conical", "2D-CD"])
32 xlabel("Divergent flap angle or Cone half-angle(
    degree)")
33 ylabel("Flow angularity loss coefficient")
34 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

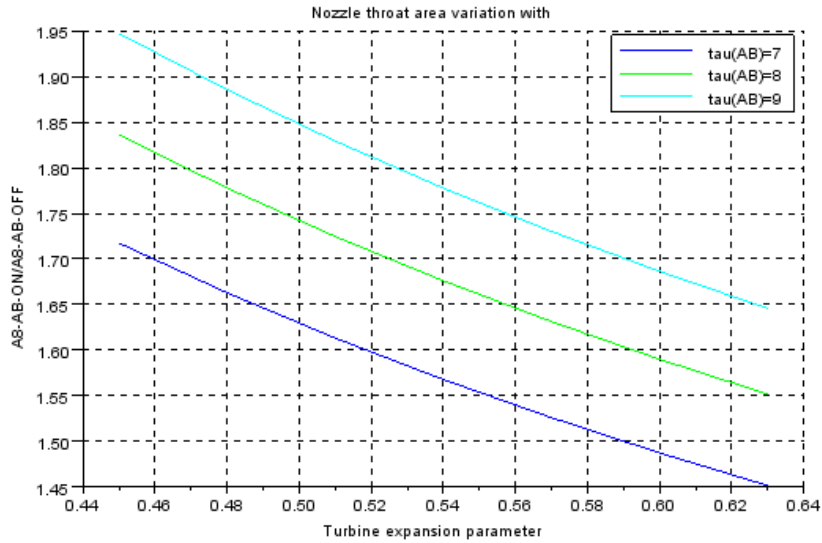


Figure 5.3: Graph of the ratio of nozzle throat area with the afterburner on and off for a range of turbine expansion parameter

```

1
2 clear;
3 clc;
4 close;
5 disp(" Example 5.10")
6 p=0.96 //p=p't8/pt8
7 f=0.02
8 fAB=0.04
9
10 z0=[0.45:0.03:0.65]
11 gmr=1.3/1.33 //gm=gm/gm' gm=gamma
12 gm=1.33
13 gm1=1.3
14 t1AB=7
15 t1=6
16 i=2
17 for t1AB=7:1:9
18     tt=6.5

```

```

19     g1=[]
20     gc1=1
21
22     for tt=0.45:0.03:0.65
23         A=(1+f+fAB)/(1+f)*((gmr)^(1/2))*1/p*((t1AB/(
                t1*tt))^(1/2))*(((gm1+1)/2)^((gm1+1)
                /(2*(gm1-1))))/(((gm+1)/2)^((gm+1)/(2*(gm
                -1))))))
24         g1(gc1)=A
25         gc1=gc1+1
26     end
27
28     plot2d(z0,g1,i)
29     xgrid
30     i=i+1
31     xlabel("Turbine expansion parameter")
32     ylabel("A8-AB-ON/A8-AB-OFF")
33     title("Nozzle throat area variation with ")
34     legend(["tau(AB)=7", "tau(AB)=8", "tau(AB)=9"])
35 end

```

Scilab code Exa 5.12 Hypersonic nozzle

```

1 clear;
2 clc;
3 close;
4 disp("Example 5.12")
5 gm=1.1
6 M0=2.5
7 g1=[]
8
9 z0=[0:0.1:4]
10 i=2

```

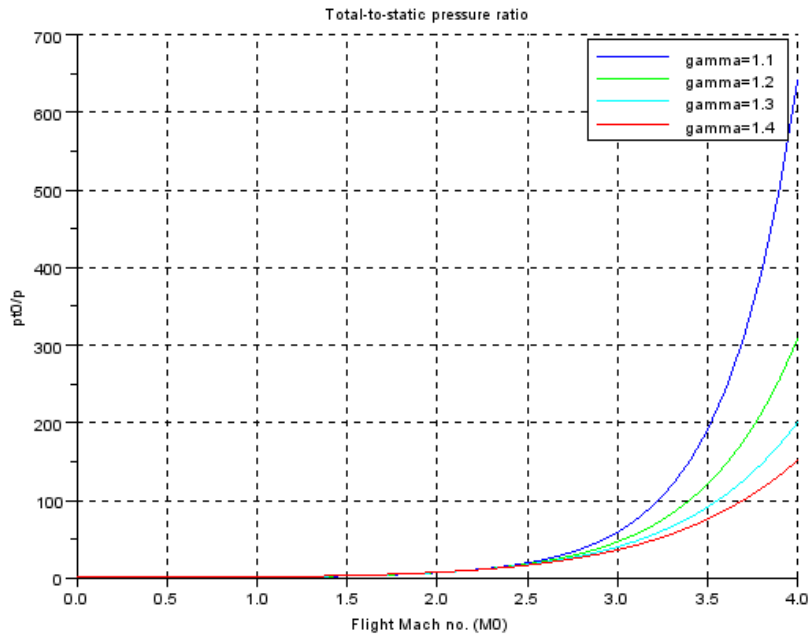


Figure 5.4: Hypersonic nozzle


```

11 for gm=1.1:0.1:1.4
12     gc1=1
13 for M=0:0.1:4
14 p0=(1+(gm-1)/2*(M^2))^(gm/(gm-1))
15 p20=.4*p0-.5*p0
16 M=3
17 p42=0.37
18 NPR=p20*p42
19 g1(gc1)=p0
20 gc1=gc1+1
21 end
22
23 plot2d(z0,g1,i)
24 xgrid
25 title("Total-to-static pressure ratio")
26 xlabel("Flight Mach no. (M0)")
27 ylabel("pt0/p")
28 legend(["gamma=1.1", "gamma=1.2", "gamma=1.3", "gamma
        =1.4"])
29 i=i+1
30
31 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

```

1
2 clear;
3 clc;
4 close;
5 disp("Example 5.13")
6 //T=Th/Tc

```

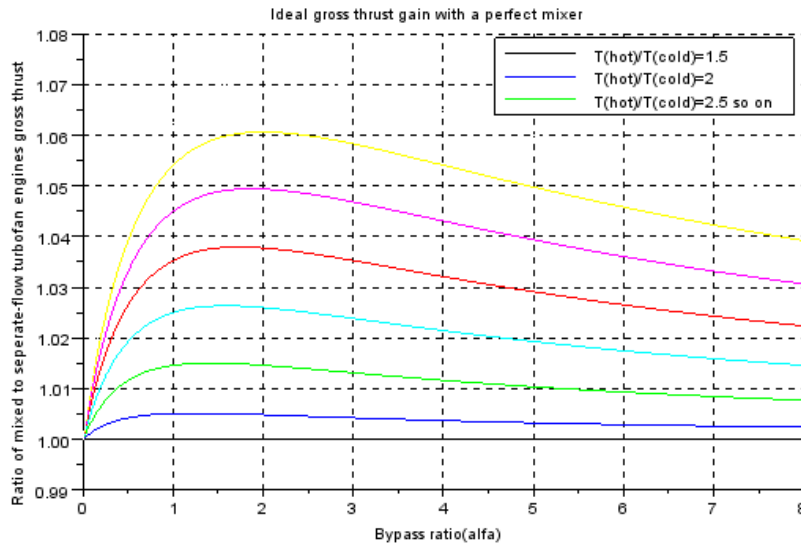


Figure 5.5: Graph of the ratio of mixed to separate flow turbofan engine for a range of hot to cold temperature ratio and a varying bypass ratio upto 8

```

7 z0=[0:0.05:8]
8 i=1
9 for T=1:0.5:4.5
10 g1=[]
11 gc1=1
12 for alfa=0:0.05:8
13
14 FR=((1+alfa)^(1/2)*(T+alfa)^(1/2))/(T^(1/2)+alfa)
15 g1(gc1)=FR
16 gc1=gc1+1
17 end
18
19 //a.data_bounds=[0,1;8,1.08]
20 plot2d(z0,g1,i)
21 xgrid
22 i=i+1
23 xlabel("Bypass ratio(alfa)")
24 ylabel("Ratio of mixed to seperate-flow turbofan

```

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

Chapter 6

Combustion chambers and afterburners

Scilab code Exa 6.1 Moles in a mixture

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

Scilab code Exa 6.3 Heating values of hydrogen

```
1 clear;
2 clc;
3 close;
4 disp(" Example 6.3")
5 T=298.16 //in K
```

```

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

```

Scilab code Exa 6.5 Chemical reaction and flame temperature

```

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

```

Scilab code Exa 6.6 Mole fraction at equilibrium

```

1 clear;
2 clc;
3 close;
4 disp("Example 6.6")
5 Kp=0.1
6 x=poly(0,"x")
7 pm=1
8 y=4*(x)^2*pm-Kp+Kp*(x)^2
9 d=roots(y)
10 for i=1:1:2
11
12 if real(d(i))>0 then
13     disp(d(i),"(a)Mole fraction of N2 at equilibrium
14         when pm is 1 atm:")
15 end
16 //part (b)
17 Kp=0.1
18 x=poly(0,"x")
19 pm=10
20 y=4*(x)^2*pm-Kp+Kp*(x)^2
21 d=roots(y)
22 for i=1:1:2
23
24 if real(d(i))>0 then
25     disp(d(i),"(b)Mole fraction of N2 at equilibrium
26         when pm is 10 atm:")
27 end

```

Chapter 7

Axial compressor aerodynamics

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

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

Scilab code Exa 7.2 Stage parameters

```

1 clear;
2 clc;
3 close;
4 disp("Example 7.2")
5 rm=0.5
6 Um=212 //m/s
7 Czm=155 //m/s
8 Ct1m=28 //m/s
9 Rm=0.6
10 alfar=1 //alfar=alfa3/alfa1.
11 w=Um*60/(rm*2*pi)
12 disp(w,"(a)Rotor angular speed w in rpm")
13 Ct2m=2*Um*(1-Rm)-Ct1m
14 disp(Ct2m,"(b)Rotor exit swirl in m/s:")
15 wcm=Um*(Ct2m-Ct1m)/1000
16 disp(wcm,"(c)Rotor specific work at pitchline Wcm in
kJ/kg :")
17 Wt2m=Ct2m-Um
18 disp(Wt2m,"(d)Rotor relative velocity vector at
rotor exit in m/s:")
19 disp("Hence vector is 155k-70.4e")
20 //Since alfa3=alfa1, rotor and stator torques are
equal and opposite each other.
21 trm=rm*(Ct2m-Ct1m)
22 tsm=-1*trm
23 disp(trm,"(e)Rotor torque per unit mass flow rate in
m^2/s:")
24 disp(tsm,"stator torque per unit mass flow rate in m
^2/s")
25 pshm=(Ct2m-Ct1m)/Um
26 phm=Czm/Um
27 disp(pshm,"(f)Stage loading parameter at pitchline :
")
28 disp(phm,"(g)Flow coefficient :")

```

Scilab code Exa 7.3 Stage parameters

```
1 clear;
2 clc;
3 close;
4 disp("Example 7.3")
5 Um1=200 // in m/s
6 Um2=Um1
7 Cz1=150 //in m/s
8 Cz2=Cz1
9 b2=-35 //in degree
10 Cm=7 //in cm
11 Sm=7 //in cm
12 W1m=((Um1^2)+Cz1^2)^(1/2)
13 Wt2m=Cz2*tand(-35)
14 W2m=((Cz1)^2+(Wt2m)^2)^(1/2)
15 disp(W1m,"(a)W1m in m/s:")
16 disp(W2m,"W2m in m/s :")
17 sigma=Cm/Sm
18 Wt1m=-1*Um1
19 Dm=1-(W2m/W1m)+(abs(Wt2m-Wt1m))/(2*sigma*W1m)
20 disp(Dm,"(b)D-factor Dm :")
21 Tm=Sm/100*abs(Wt1m-Wt2m)
22 disp(Tm,"(c) Circulation Tm in m^2/s:")
```

Scilab code Exa 7.4 de Haller criterion

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

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

Scilab code Exa 7.5 Stage parameters

```
1 clear;
2 clc;
3 close;
4 disp(" Example 7.5")
5 ps=1.5
6 es=0.9
7 gm=1.4
8 ts=1+(1/es)*(ps^((gm-1)/gm)-1)
9 ec=(gm-1)/gm*(log(ps))/log(ts)
10 disp(ts," Total temperature ratio :")
11 disp(ec," Compressor polytropic efficiency :")
```

Scilab code Exa 7.6 Stage parameters

```
1 clear;
2 clc;
3 close;
4 disp(" Example 7.6")
5 W1=460 //in m/s
6 b1=45 //degrees
7 W2=376
8 b2=30
9 c=5.25
10 w=0.05
11 s=3.5
12 Wt1=W1*sind(45)
13 Wt2=W2*sind(30)
14 Wtm=(Wt1+Wt2)/2
```

```

15 Wz1=W1*cosd(45)
16 Wz2=W2*cosd(30)
17 Wz=(Wz1+Wz2)/2
18 bm=(atan(Wtm/Wz))*180/%pi
19 sigma=c/s
20 Cd=w/sigma*cosd(bm)
21 T=s/100*(abs(Wt1-Wt2))
22 Wm=(Wz^2+Wtm^2)^(1/2)
23 C1=2*T/(Wm*(c/100))-Cd*tand(bm)
24 disp(bm,"(a)mean relative flow angle :")
25 disp(Cd,"(b)The rotor section (2D) drag coefficient
      :")
26 disp(T,"(c)The rotor circulation in m^2/s :")
27 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

```

1 clear;
2 clc;
3 close;
4 disp("Example 7.7")
5 Rm=0.5
6 b=0 //b=b/w
7 i=1
8 for b=0:0.1:0.5
9 r=0.5
10 vr=[]
11 x=[]
12 count=1
13     for r=0.5:0.05:1.5

```

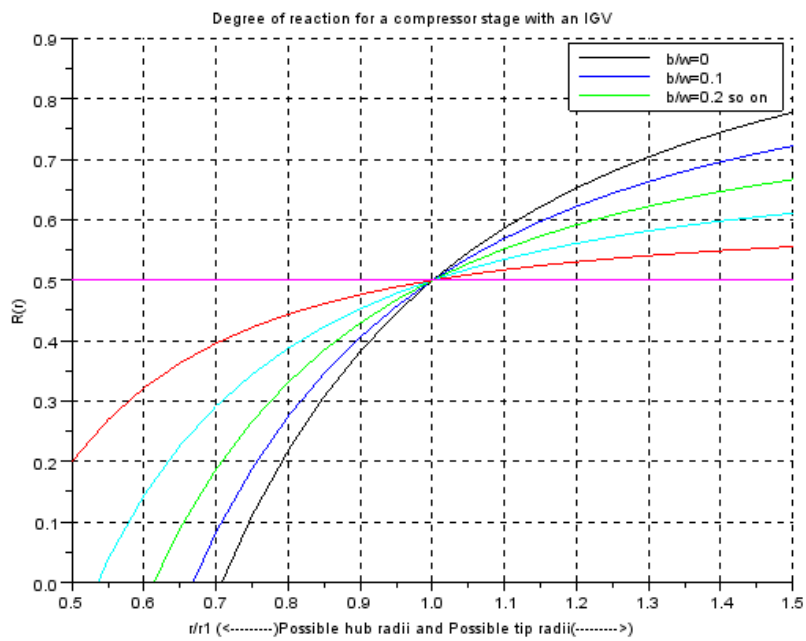


Figure 7.1: Comparison of the degree of reaction profile of a compressor stage with and without an IVG for a range of hub tip radii that result in a positive degree of reaction

```

14
15 R=(1-b)-((1-b)-Rm)/(r)^2
16 x(count)=R
17 count=count+1
18 end
19 vr=[0.5:0.05:1.5]
20 a=gca();
21 a.data_bounds=[0.5,0;1.5,0.9]
22
23 plot2d(vr,x,i)
24 i=i+1
25 xgrid
26 xlabel("r/r1 (<-----)Possible hub radii and
    Possible tip radii(----->)")
27 ylabel("R(r)")
28 title("Degree of reaction for a compressor stage
    with an IGV")
29 legend("b/w=0","b/w=0.1","b/w=0.2 so on")
30 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

```
1 clear;
2 clc;
3 close;
4 disp("Example 8.1")
5 z0=[0.2:0.05:0.6]
6 g1=[]
7 gc1=1
8 gm=1.4
9 for M1=0.2:0.05:0.6
10
11 y=1/((1+((gm-1)/2)*M1^2)^(1/2))
12
13 g1(gc1)=y
14 gc1=gc1+1
15 end
16 a=gca()
```

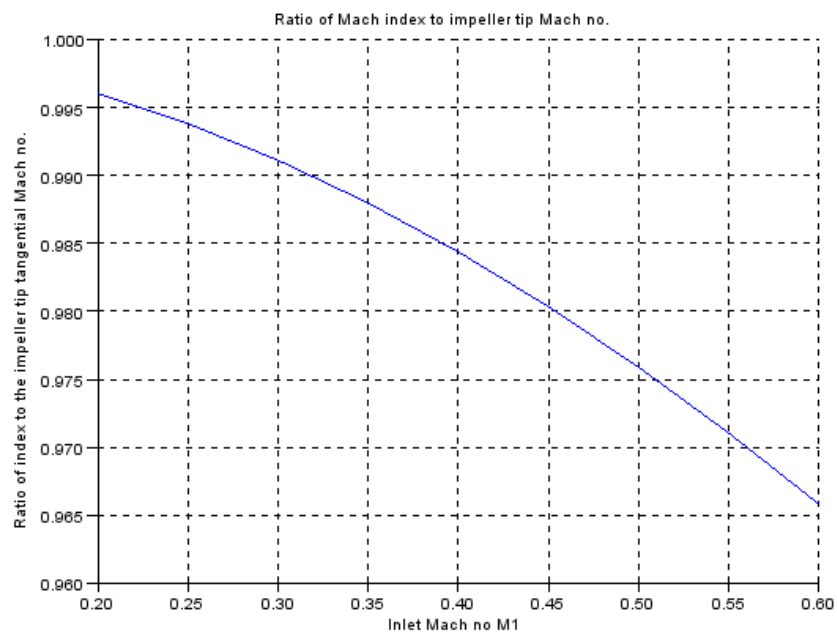


Figure 8.1: Graph of the ratio of Mach index to the impeller tip tangential Mach no for a range of inlet Mach no

```

17 a.data_bounds=[0.2,0.96;0.6,1]
18
19 plot2d(z0,g1,2)
20 xgrid
21 xlabel("Inlet Mach no M1")
22 ylabel("Ratio of index to the impeller tip
        tangential Mach no.")
23 title("Ratio of Mach index to impeller tip Mach no."
        )

```

Scilab code Exa 8.3 Radial diffuser

```

1 clear;
2 clc;
3 close;
4 disp("Example 8.3")
5 M1=1.2 //Mach no at impeller tip
6 gm=1.4 //gamma
7 p31=(1+(gm-1)*M1^2)^(gm/(gm-1)) //p=p3/p1
8 p32=p31^(1/2) //p31=p3/p2
9 Cp=(2/(gm*M1^2))*(2.2-1) //static pressure rise in
        radial diffuser
10 disp(p31,"(a)The static pressure the rotor and
        diffuser p3/p1 :")
11 disp(p32,"The static pressure ratio across the
        diffuser p3/p2")
12 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

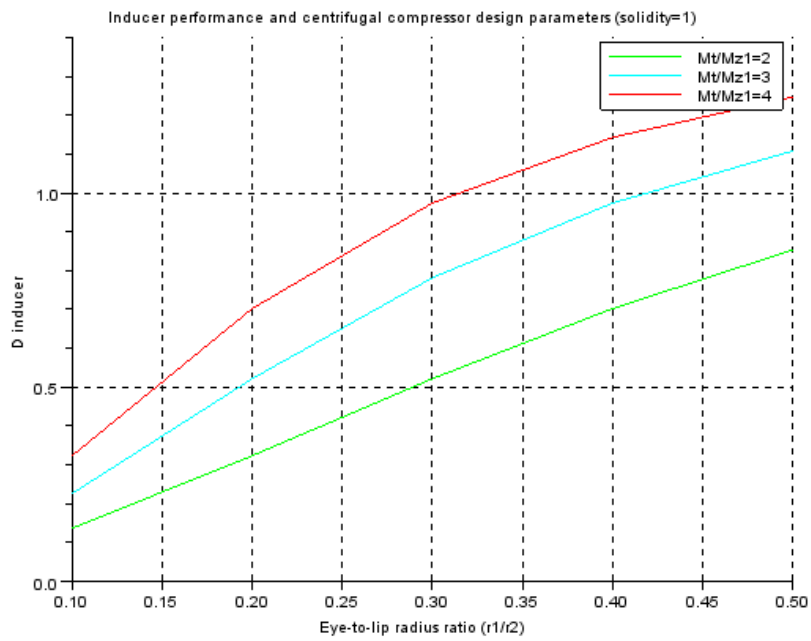


Figure 8.2: Graph of the inducer D factor for solidity of one and over a range of impeller tip Mach numbers and radius ratios

```

1 clear;
2 clc;
3 close;
4 disp("Example 8.4")
5 M=2
6 i=2
7 sigma=1
8 z0=[0.1:0.1:0.5]
9 gm=1.4
10
11 for M=2:4
12     g1=[]
13     gc1=1
14     for r=[0.1:0.1:0.5]
15         y=1-(1/(1+(r^2)*(M^2)))+(M*r)/(2*sigma*(1+(r^2)*(M
            ^2))^(1/2)))
16         g1(gc1)=y
17         gc1=gc1+1
18     end
19     i=i+1
20     plot2d(z0,g1,i)
21     xgrid
22     xlabel("Eye-to-lip radius ratio (r1/r2)")
23     ylabel("D inducer")
24     title("Inducer performance and centrifugal
            compressor design parameters (solidity=1)")
25     legend("Mt/Mz1=2", "Mt/Mz1=3", "Mt/Mz1=4")
26 end

```

Scilab code Exa 8.6 Performance parameters of a centrifugal compressor

```

1 clear;
2 clc;
3 close;
4 disp("Example 8.6")

```

```
5
6 Tt1=288
7 Cp=1004
8 gm=1.4
9 ett=0.8
10 p=6.8 //pt3/pt1
11 C1=200
12 pt1=101
13 Tt3=Tt1*(1+(1/ett)*(p^((gm-1)/gm)-1))
14 Tt2s=Tt1*p^((gm-1)/gm)
15 T1=Tt1-C1^2/(2*Cp)
16 ets=(Tt2s-T1)/(Tt3-T1)
17 disp(ets,"Compressor total-to-static efficiency :")
```

Chapter 9

Aerothermodynamics of Gas Turbines

Scilab code Exa 9.1 Axial flow turbine

```
1 clear;
2 clc;
3 close;
4 disp(" Example 9.1")
5 Tt1=1800
6 M1=0.55
7 alfa1=0
8 gm=1.33
9 Cp=1157
10 alfa2=60
11 T1=Tt1/(1+(gm-1)*M1^2/2)
12 a1=((gm-1)*Cp*T1)^(1/2)
13 C1=a1*M1
14 C2=C1/cosd(alfa2)
15 Tt2=Tt1
16 T2=Tt2-C2^2/(2*Cp)
17 a2=((gm-1)*Cp*T2)^(1/2)
18 M2=C2/a2
19 Ct2=C1*tand(alfa2)
```

```

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

```

Scilab code Exa 9.2 Axial flow turbine

```

1  clear;
2  clc;
3  close;
4  disp("Example 9.2")
5  M2=1.0 //i.e choked
6  Tt2=1800
7  gm=1.33
8  C1=445
9  Cp=1157
10 T2=Tt2/(1+(gm-1)*M2^2/2)
11 a2=((gm-1)*Cp*T2)^(1/2)
12 M2=1
13 C2=M2*a2
14 alfa2=acos(C1/C2)*180/%pi
15 disp(alfa2,"Nozzle exit flow angle if M2=1 in
      degrees:")

```

Scilab code Exa 9.3 Axial flow turbine

```

1  clear;
2  clc;
3  close;
4  disp("Example 9.3")
5  C1=411

```

```

6  alfa2=60
7  C2=800
8  W2=450
9  alfa3=13
10 C3=411
11 Cz2=C2*cosd(60)
12 Cz3=C3*cosd(13)
13 Ct2m=Cz3*tand(60)
14 Wt2m=(450^2-400^2)^(1/2)
15 Um=Ct2m-Wt2m
16 Ct3=C3*sind(13)
17 Rm=1-(Ct2m+Ct3)/(2*Um)
18 disp(Cz2,"(a)The axial velocities up- and downstream
      of the rotor in m/s:")
19 disp(Cz3)
20 disp(Um,"(b)The rotor velocity Um in m/s:")
21 disp(Rm,"(c)The degree of reaction at this radius :")
    )

```

Scilab code Exa 9.4 Loss of turbine efficiency

```

1  clear;
2  clc;
3  close;
4  disp("Exmple 9.4")
5  Cd=0.5
6  bm=-20
7  r=1.25
8  phi=0.5
9  chi=1
10 t=0.02
11
12 De=Cd*t*r*(1-(chi/phi)*tand(bm))^(1/2)
13 disp(De,"Loss of the turbine efficiency (eta0 times)
      :")

```

Scilab code Exa 9.5 Turbine cooling

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

Scilab code Exa 9.6 Convective cooling

```
1 clear;
2 clc;
```

```

3  close;
4  disp(" Example 9.6")
5  T0=288 //in K
6  p0=100 //in kPa
7  Tt3=800 //in K
8  gm=1.4
9  Cpc=1.0045 //kJ/Kg.K
10 pc=25
11 ec=0.9
12 Tt4=2000 //in K
13 gmc=1.33
14 Cpg=1.188 //kJ/Kg.K
15 Stg=0.005 //Gas-side Stanton no.
16 Taw=2000 //in K
17 ptg=2.5 //in Mpa
18 Tawd=1200 // desired temp. in K
19 d=2 //thickness of internally cooled wall in mm
20 bms=2 //blade mean solidity in HPT
21 kw=14.9 //in W/m.K
22 Twc=870 //in K
23 S=1/2 //S=Stc/Stg
24 e=(Cpc/Cpg)*S*(Twc-Tt3)/(Tt4-Tawd)
25 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

```
1 clear;
2 clc;
3 close;
4 disp(" Example 10.1")
5 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

6 disp(cmap," Compressor map data in table:")
7 Cpc=1004
8 Cpt=1156
9 f=0.03 //fuel-to-air ratio
10 em=0.995 //efficiency
11 T=6 //T=Tt4/Tt2
12 pb=0.95 //burner pressure ratio
```

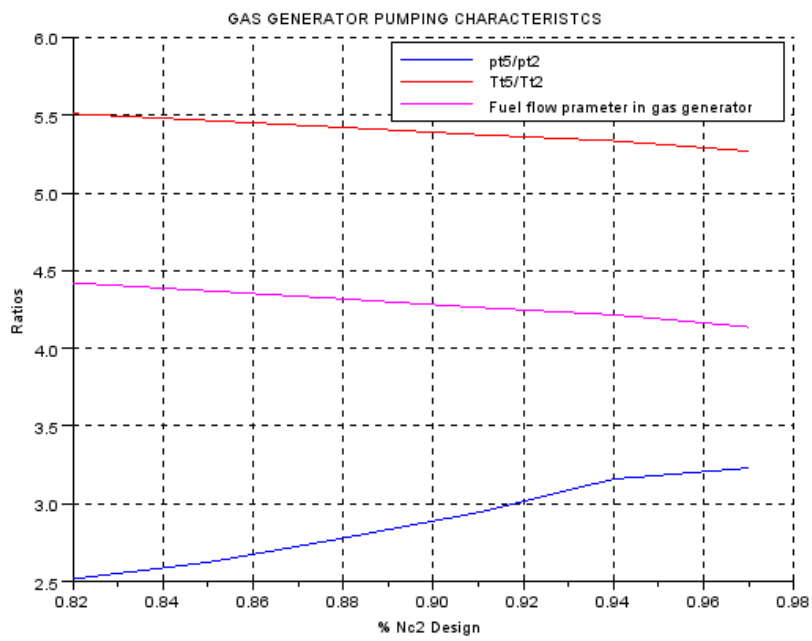


Figure 10.1: Graph of graph generator pumping characteristics verses percent Nc2 design

```

13 gmt=1.33 //gamma turbine
14 gmc=1.4
15 i=6
16 b=1
17 g1=[]
18 gc1=1
19 g2=[]
20 gc2=1
21 g3=[]
22 gc3=1
23 g4=[]
24 gc4=1
25 z0=[0.82:0.03:0.97]
26 for b=1:6
27     Nc2=cmap(i,1)
28     pc=cmap(i,2)
29     mc2=cmap(i,3)
30     ec=cmap(i,4)
31     i=i-1
32     tc=1+(1/ec)*(pc^((gmc-1)/gmc)-1)
33     ffp=T-tc
34     tt=1-(Cpc/Cpt)*((tc-1)/(em*(1+f)*(T)))
35     Nc4=Nc2/T^(1/2)
36     mc4=mc2*((1+f)*(T)^(1/2))/(pb*pc)
37     pt=(1-(1-tt)/ec)^(gmt/(gmt-1)) //Assuming et=ec i.e.
        same efficiency
38     var=T-tc //fuel flow parameter in gas generator
39     p52=pb*pc*pt
40     T52=T-(Cpc/Cpt)*(tc-1)/(em*(1+f))
41     g1(gc1)=p52
42     gc1=gc1+1
43     g3(gc3)=T52
44     gc3=gc3+1
45     g4(gc4)=var
46     gc4=gc4+1
47
48 end
49 plot2d(z0,g1,2)

```

```

50 xlabel("% Nc2 Design")
51 ylabel(" Ratios")
52 title("GAS GENERATOR PUMPING CHARACTERISTICS")
53 xgrid
54 plot2d(z0,g3,5)
55 plot2d(z0,g4,6)
56 legend("pt5/pt2","Tt5/Tt2","Fuel flow parameter in
        gas generator")

```

Scilab code Exa 10.2 Off design analysis of a turbojet engine

```

1 clear;
2 clc;
3 close;
4 disp(" Example 10.2")
5 M0=0
6 p0=0.1 //in MPa
7 T0=15+273
8 pd=0.98
9 pc=25
10 ec=0.9
11 Qr=42800000 //in J/kg
12 pb=0.98
13 eb=0.99
14 Tt4=1500+273
15 et=0.85
16 em=0.995
17 mc2=73
18 Nc2=6000 //in rpm
19 Mz2=0.6
20 pn=0.97
21 p=1 //p=p9/p0
22 //in this engine is operating in the following off-
    design conditions
23 Mo0=0.8

```

```

24 po0=33
25 To0=-15+273
26 Tt4o=1375+273
27 pdo=0.995
28 po=1
29 gm=1.4
30
31 td=T0/Tt4
32 tcd=pc^((gm-1)/(ec*gm))
33 tod=(To0*(1+(gm-1)*Mo0^2/2)/Tt4o)
34 tcod=1+(td/tod)*(tcd-1)
35 pcod=(tcod)^((ec*gm)/(gm-1))
36 disp(pcod,"(a)pressure ratio in combustor ,O-D :")
37 mratio=(pcod/pc)*(tod/td)^(1/2)
38 mc2od=mc2*mratio
39 disp(mc2od,"(b)mc2,O-D (in kg/s) :")
40 Nc2r=(td/tod)^(1/2)
41 Nc2od=Nc2r*Nc2
42 disp(Nc2od,"(c)Nc2,O-D (in rpm) :")
43 pref=101.33 //in kPa
44 pto0=po0*(1+(gm-1)/2*Mo0^2)^(gm/(gm-1))
45 pto2=pdo*pto0
46 Tref=288.2
47 Tto2=To0*(1+(gm-1)/2*Mo0^2)
48 the2=Tto2/Tref
49 del2=pto2/pref
50 m2=mc2od*del2/(the2)^(1/2)
51 M2od=poly(0,"M2od")
52 pol=0.6*((1+(gm-1)/2*M2od^2)/(1+(gm-1)/2*0.6^2))
    ^3-(73/64.5)*M2od
53 rr=roots(pol)
54 //disp(rr)
55 i=1
56 while i < 7
57 if imag (rr(i))==0 then
58     if real(rr(i))<1 then
59         disp(rr(i),"(d)Mz2,O-D")
60     end

```

```
61 end
62 i=i+1
63 end
```

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

```
1 clear;
2 clc;
3 close;
4 disp("Example 10.3")
5 M0=0
6 po=101.33 //in kPa
7 T0=288.2
8 gmc=1.4
9 Cpc=1004
10 pd=0.95
11 pc=20
12 ec=0.9
13 mc2=33
14 Nc2=7120
15 Mz2=0.6
16 Qr=428000000
17 pb=0.98
18 eb=0.97
19 Tt4=1850
20 gmt=1.33
21 Cpt=1156
22 et=0.8
23 em=0.995
24 QrAB=4280000
25 pAB=0.95
26 eAB=0.98
27 Tt7=2450
28 pAB=1.3
29 CpcAB=1243
```

```

30 pn=0.93
31 p=1 //p=p9/p0
32 Mo0=2
33 po0=20
34 To0=223
35 gm0=1.4
36 Cpc0=1004
37 pdo=0.8
38 ec0=0.9
39 Qr=42800000
40 pb0=0.98
41 ebo=0.97
42 Tt4o=1850
43 gmto=1.33
44 cpto=1156
45 eto=0.8
46 emo=0.995
47 QrABo=42800000
48 pABo=0.95
49 eab=0.98
50 Tt7o=2450
51 gmABo=1.3
52 Cpco=1243
53 pno=0.93
54 po=1
55 a0=276.4
56
57 Tt2=T0
58 tc=pc^((gmc-1)/(ec*gmc))
59 Tt3=tc*Tt2
60 f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb-Cpt*Tt4)
61 tt=1-(1/((1+f)*em))*(Cpc*Tt2/(Cpt*Tt4))*(tc-1)
62 disp(tt,"Turbine expansion parameter at on and off
    design :")
63 //Off-design analysis:
64 Tt2o=To0*(1+(gmc-1)/2*(Mo0^2))
65 tcOD=1+(1.036)*0.995*(1156*1850/(1004*401.4))
    *(1-0.7915)

```

```

66 pc0D=tc0D^(((gmc)*ec/((gmc-1)))
67 disp(pc0D,"New compressor pressure ratio :")
68 mc2D=pc0D/pc*((Tt4o/Tt2)/(Tt4o/Tt2o))^(1/2)
69 mc20D=mc2*mc2D
70 disp(mc20D,"Off-line mc2 rate in Kg/s :")
71 Nc2r=((Tt4o/Tt2o)/(Tt4/Tt2))^(1/2)
72 Nc20D=Nc2r*Nc2
73 disp(Nc20D,"Off-design Nc2,O-D in rpm:")
74 pref=101.33 //in kPa
75 pt0=po0*(1+(gmc-1)/2*Mo0^2)^((gmc)/(gmc-1))
76 pt2=pdo*pt0
77 del2=pt2/pref
78 Tref=288.2
79 the2=Tt2o/Tref
80 m2=mc20D*del2/(the2)^(1/2)
81 disp(m2,"Off-design mass flow in kg/s")
82 Tt3=859.2
83 Tt4=1850
84 f0D=0.03305
85 tcr=(1+f0D)/(1+f)
86 pt5=413.7 // kPa
87 pt7=393.04
88 fAB=0.0367
89 pt9=365.52
90 M9=2.524
91 T9=1253
92 V9=1725
93
94 ndst=(1+f+fAB)*V9/a0-M9
95 disp(ndst,"Nondimensional specific thrust :")
96 TSFC=55.94 //in mg/s/N
97 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

```
1 clear;
2 clc;
3 close;
4 disp(" Example 11.1 ")
5
6 Ts=470000 //in lb
7 Tv=375000 //in lb
8 A2=(Ts-Tv)/(14.7*144)
9 D=(4*A2/%pi)^(1/2)
10 disp(D,"Diameter of the SSME nozzle exit area :")
```

Scilab code Exa 11.2 Rocket thrust and exhaust velocity

```
1 clear;
2 clc;
3 close;
```

```

4 disp("Example 11.2")
5
6 m=1000 //in kg/s
7 g=9.8 //m/s^2
8 Is=340 //in s
9 F=m*g*Is
10 disp(F,"(a) Rocket thrust F in N :")
11 c=F/m
12 disp(c,"(b) Effective exhaust velocity c in m/s :")

```

Scilab code Exa 11.3 Thrust coefficient of a rocket engine

```

1 clear;
2 clc;
3 close;
4 disp("Example 11.3")
5
6 pc=200 //in atm
7 p2=1 //in atm
8 gm=1.3
9 Ath=25 //in m^2
10 Cf=((2*gm^2)/(gm-1)*(2/(gm+1))^(gm+1)/(gm-1))*(1-(
    p2/pc)^(gm-1/gm))^(1/2)
11 disp(Cf,"(a) Optimum thrust coefficient Cf, opt :")
12 pc=200*101 //converting to MPa
13 F=Ath*Cf*pc
14 disp(F,"(b) thrust F in N")
15 pc=200
16 M2=((2/(gm-1))*((pc/p2)^(gm-1/gm)-1))^(1/2)
17 disp(M2,"(c) Nozzle exit Mach no. M2 :")
18 A=1/M2*(2/(gm+1)*(1+(gm-1)/2*M2^2))^(gm+1)/(2*(gm
    -1))
19 disp(A,"(d) Nozzle area expansion ratio A2/Ath :")

```

Scilab code Exa 11.4 Characteristic velocity

```
1 clear;
2 clc;
3 close;
4 disp(" Example 11.4")
5
6 Tc=2999 //in K
7 Ccr=2432 //in m/s
8 gm=1.26
9 f=4.02
10 R=((Ccr*gm*(2/(gm+1))^(gm+1)/(2*(gm-1))))^2)/(gm*Tc
    )
11 disp(R," Combustion gas constant R in J/kg.K:")
12 RU=8314.6 //in j/kmol.K
13 MW=RU/R
14 disp(MW," Molecular weight of the mixture in kg/kmol
    :")
```

Scilab code Exa 11.5 Combustion of hydrogen and oxygen

```
1 clear;
2 clc;
3 close;
4 disp(" Example 11.5")
5
6 f=4
7 MW=(2*18+2*2)/4 //from equation
8 disp(f," (a)The oxidizer-to-fuel mixture ratio :")
9 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 vacuum flight

```
1 clear;
2 clc;
3 close;
4 disp("Example 11.6")
5
6 g=9.8 //in m/s^2
7 Is=400 //in s
8
9 delv1=g*Is*log(1/0.1) //for pmf=0.9
10 delv2=g*Is*log(1/0.05) //for pmf=0.95
11 delp=(delv2-delv1)/delv1*100
12 disp(delp,"% improvement in delv :")
```

Scilab code Exa 11.7 Rocket performance including the effect of gravity

```
1 clear;
2 clc;
3 close;
4 disp("Example 11.7")
5
6 g=9.8 //in m/s^2
7 Is=420 //in s
8 the=90 //in degree
9 tb=30 //in s
10 gavg=9.65 //in m/s^2
11 MR=0.1
12 delv1=-g*Is*log(MR) //in m/s
13 delv2=-g*Is*log(MR)-gavg*tb
14 delp=abs(delv2-delv1)/delv1*100
15 disp(delp,"% reduction in terminal speed :")
```

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

```
1 clear;
2 clc;
3 close;
4 disp("Example 11.8")
5
6 mf=0.8
7 g=9.8 //in m/s^2
8 Is=345 //in s
9 delvt=-g*Is*log(1-mf)
10 m=500000 //in kg
11 q0=100000 //in Pa
12 tb=60 //in s
13 Af=20 //in m^2
14 Cd=0.3 //mean drag coefficient
15 delvd=log(1-mf)*(Af/m)*q0*(tb/(1-mf))*Cd
16 delv=delvt+delvd
17 disp(delv,"Terminal speed of rocket vehical
    excluding gravitatal effect in m/s :")
```

Scilab code Exa 11.9 Propulsive and overall efficiencies

```
1 clear;
2 clc;
3 close;
4 disp("Example 11.9")
5
6 g=9.8 //in m/s^2
7 Is=421 //in s
```

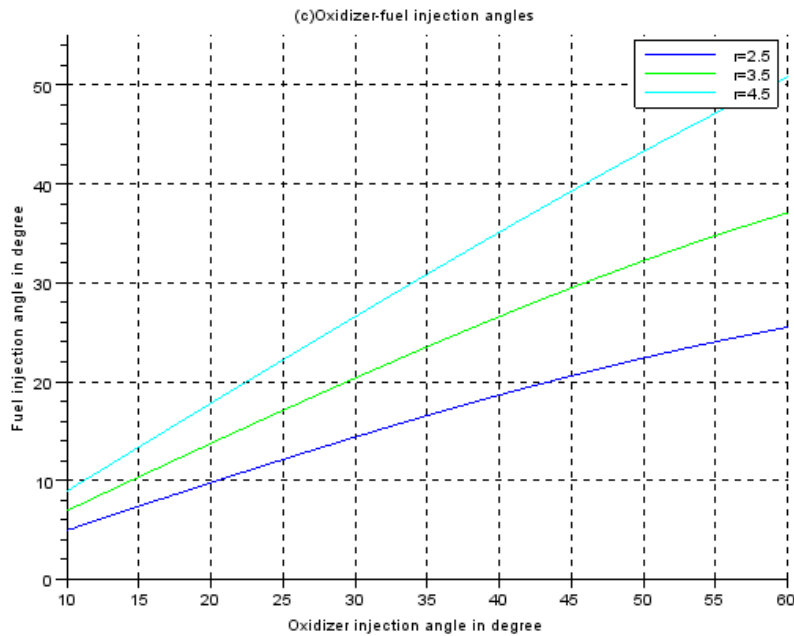


Figure 11.1: Liquid propellant combustion chambers in rocket

```

8  Qr=120000000
9  v=5000 //in m/s
10 c=g*Is
11 disp(c,"(a) Effective exhaust speed c in m/s :")
12 ep=2*(v/c)/(1+(v/c)^2)
13 disp(ep,"(b) propulsive efficiency :")
14 eo=c*v/Qr
15 disp(eo,"(c) Overall efficiency :")

```

Scilab code Exa 11.10 Liquid propellant combustion chambers in rocket

```

1  clear;
2  clc;
3  close;
4  disp(" Example 11.10")
5
6  Cdf=0.82
7  Cdo=0.65
8  dpf=200 //kPa
9  dp0=200 //in kPa
10 rhof=85 //kg/m^3
11 rho0=1350 //kg/m^3
12 r=2.5
13 A=r*Cdf/Cdo*(dpf/dp0*rhof/rho0)^(1/2)
14 disp(A,"(a) Oxidizer-to-fuel oriface aera ratio A0/Af
      :")
15 vf=Cdf*(2*dpf/rhof)^(1/2)
16 v0=((2*dp0/rho0)^(1/2))*Cdo
17 disp(vf,"(b) Fuel oriface discharge speed in m/s:")
18 disp(v0," Oxidizer oriface discharge speed in m/s:")
19 disp("(c) The graph between injection angle versus
      oxidizer injection angle for axial resultant
      stream 0 ")
20 //for graph
21
22 z0=10:0.05:60
23 i=2
24 for r=2.5:1:4.5
25     g1=[]
26     gc1=1
27
28     for gm0=10:0.05:60
29         gmf=asind((r*(v0/vf)*sind(gm0)))
30         g1(gc1)=gmf
31         gc1=gc1+1
32     end
33     plot2d(z0,g1,i)
34     xgrid
35     i=i+1

```

```

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

```

Scilab code Exa 11.11 Solid propellant combustion chamber in rockets

```

1 clear;
2 clc;
3 close;
4 disp("Example 11.11")
5
6 p=7 //in MPa,
7 n=0.5 //and
8 a=5 //cm/s
9 Tdg=15 //in degree C
10 Td=15+273 //in K
11 br=0.002 //per degree C
12 pk=0.004 //per degree C
13 t=60//s,
14
15 DT=30 // temp difference in degree C
16 pc=p*(1+pk*DT)
17 disp(pc,"(a)The new chamber pressure when the
    initial grain temp. is 45 degree C in MPa")
18 r=a*(pc/p)^n
19 r=r*(1+br*DT) //correcting for the effect of the
    grain temperature on burning rate.
20 disp(r,"Burning rate when grain temp. is 45 degree C
    ")
21 L=a*t/100
22 tb=L*100/r //time to burn 3m of end burning grain at
    5.61cm/s
23 tbn=t*(p/pc) //burn time for a constant total

```



```

        impulse
24
25 dt=t-tb
26 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

```

1 clear;
2 clc;
3 close;
4 disp("Example 11.12")
5 Tg=2750 //in K
6 Ttg=Tg
7 Tc=300 // coolant bulk temp. in K
8 tw=0.002 //Wall thickness in m
9 kw=43 //thermal conductivity of the wall in W/m.C
10 hg=657 //Gas side film coefficient in W/m^2K
11 hc=26000 //Coolant side film coefficient in W/m^2K
12 eg=0.05 //emissivity of the gas
13 sigma=5.67*10^(-8) //in W/m^2K
14 Taw=Ttg
15
16 rhf=eg*sigma*Tg^4/1000
17 disp(rhf,"(a)The radiation heat flux in kW/m^2 :")
18 qw=(Ttg-Tc+(rhf*1000/hg))/((1/hg)+(tw/kw)+(1/hc))
    /1000
19 disp(qw,"(b)The total heat flux in kW/m^2:")
20 qc=qw-rhf
21 disp(qc,"(c)The convection heat in kW/m^2:")
22 Twg=Taw-qc*1000/hg
23 disp(Twg,"(d)Wall temp. on the gas side in K:")
24 Twc=Tc+(qw*1000/hc)
25 disp(Twc,"(e)Wall temp. on the coolant side in K:")

```

Scilab code Exa 11.13 Multiphase flow in rocket nozzle

```
1 clear;
2 clc;
3 close;
4 disp("Example 11.13")
5
6 Cpg=2006 //in J/kg.K
7 Cs=903 //J/kg.K
8 X1=0.18
9 X2=0.16
10 Tr=1.057
11 Ir=(((1-X1)*Cpg+X1*Cs)*Tr/((1-X2)*Cpg+X2*Cs))^(1/2)
    //Ratio of specific impulse
12 disp(Ir,"Raio of specific impulse :")
```
