

# Scilab Textbook Companion for Aircraft Propulsion

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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

```
1 clear;
2 clc;
3 close;
4 disp("Example 2.1")
5 p=3*10^6; //pressure in Pa
6 t=298; //temperatuue 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 temperature 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 velocity 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-  
      component 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

```
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

```
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
        inlet mach no. <1
22         M2=z
23     end
24 end
25
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 //Fxwalls=I2-I1=A1p1(1+gm*M1^2)-A2p2(1+gm*M2^2)
36 //Let , u=Fxwall/(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
        ratio ()
30         M2=z
31     end
32 end
33
34 i=i+1
35 end
36 disp(M2,"(a)The exit Mach no. M2:")
37 //p2/p0=1/(1+(gm-1)/2*M2^2)^(gm/(gm-1))
38 //p0=(p2/Pth)*(Pth/p1)*(p1/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
    ambient pressure p2/p0")//Fxwall=-Fxliquid=I1-I2
43
44 //let r=A1/Ath
45 r=(f)*(1/M1)*(((1+((gm-1)/2)*(M1)^2)/((gm+1)/2))^((gm+1)/(2*(gm-1))))
46 //disp(r)
47 //Psth is throat static pressure.
48 //z1=Psth/p1=f/((gm+1)/2)^(gm/(gm-1))
49 z1=f/((gm+1)/2)^(gm/(gm-1))
50 //disp(z1)
51 //p1 is static pressure at inlet
52 //s1=p1/p0
53 s1=1/(1+((gm-1)/2)*(M1)^2)^(gm/(gm-1))
54 //disp(s1)
55 //let y=Fxwall/(Ath*p1), 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*p1

```

```

60 // f1=p2/p1
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. turbione 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

```

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

```
1 clear;
2 clc;
3 close;
4 disp("Example 4.2")
5 m=50 //mass flow rate in kg/s
6 ec=0.9 //compressor 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) Compressor 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 eng

```

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 in adiabatic nozzle
12 //let p=pt9/p9
13 p=tpr*NPR*1 //p=pt9/p9; p0=p9 for 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 t1=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 t1AB=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 tempeaure:")
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:")

```

---

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

```

1 clear;
2 clc;

```

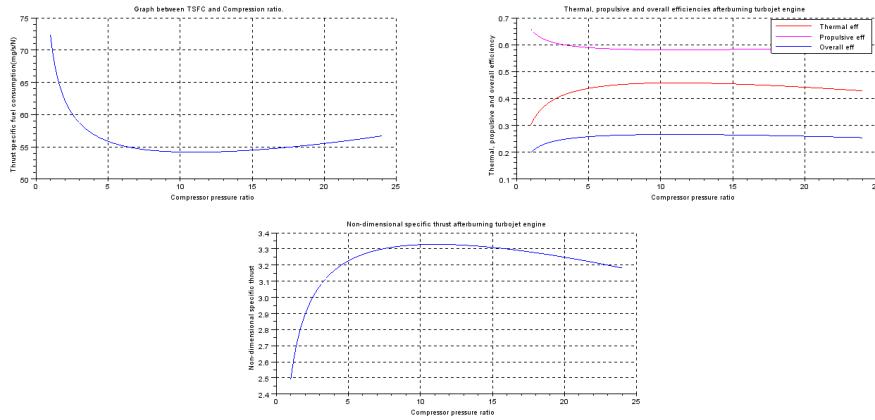


Figure 4.1: Effect of compressor pressure ratio on an afterburner turbojet engine

```

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));
        //total flight pressure
45     Tt0=T0*(1+(((gmc-1)*(M0)^2)/2)); //total flight
        temp
46     Tt2=Tt0 ;//Adiabatic inlets
47     pt2=pt0*pd; // in kPa
48     pt3=pt2*pc; //compressor exit total pressure
49     k2=((gmc-1)/(gmc*ec));
        //disp(k2)
50     tc=pc^k2; //relation between temp and pressure
        ratios
        //disp(tc)
51     Tt3=Tt2*tc; //total temp at compressor exit
52     Tt4=Cpc*T0*t1/Cpt; //combustor exit total temp.
53     pt4=pt3*pb; //combustor exit pressure
54     f=(Cpt*Tt4-Cpc*Tt3)/(Qr*eb*1000-Cpt*Tt4); //fuel
        -to-air ratio in burner
        //disp(f)
55     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 //temperatuue 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 tl=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*(ndsf+ndsc)*(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(Tt19," 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

```

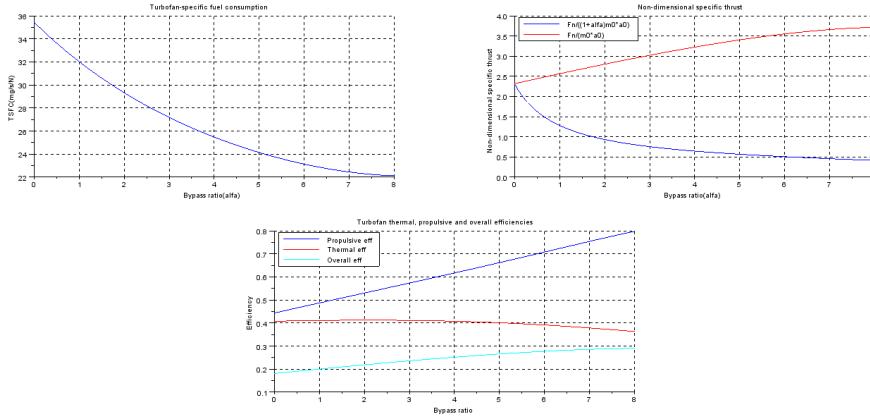


Figure 4.2: Graph of the performance of separate exhaust turbofan engine for a range of bypass ratios from 0 to 8

```

    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

```

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 //temperatuue 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 pfn=0.95 //compression ratio of convergent fan
    nozzle
14 pc=40 //compression ratio of compressor
15 ec=0.9 //compressor efficiency
16 tl=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=pf*pd/(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*pd
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=(pd*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 gmt6M=(((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 af**

```

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=pf*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=(pf*d*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("Compressure pressure ratio")
167 ylabel("f+fAB")
168 title("f+fAB")

```

---

**Scilab code Exa 4.17** The turboprop engine performance parameter

```

1 clear;
2 clc;
3 close;

```

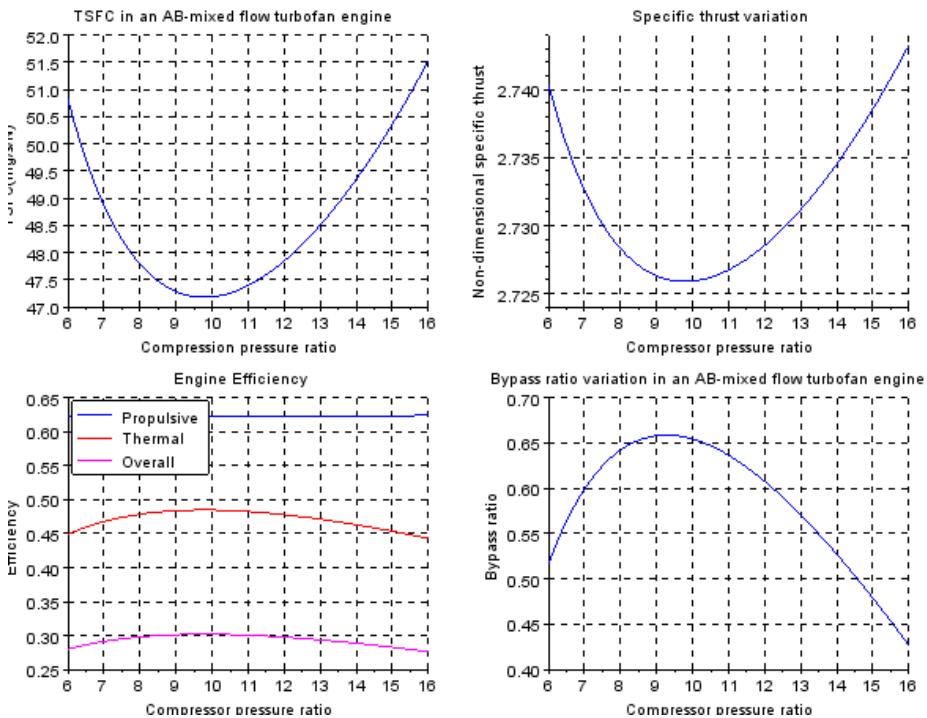


Figure 4.3: Engine performance of a mixed exhaust turbofan engine with afterburner having same parameters as in previous example for a range of compressor pressure ratios from 6 to 16

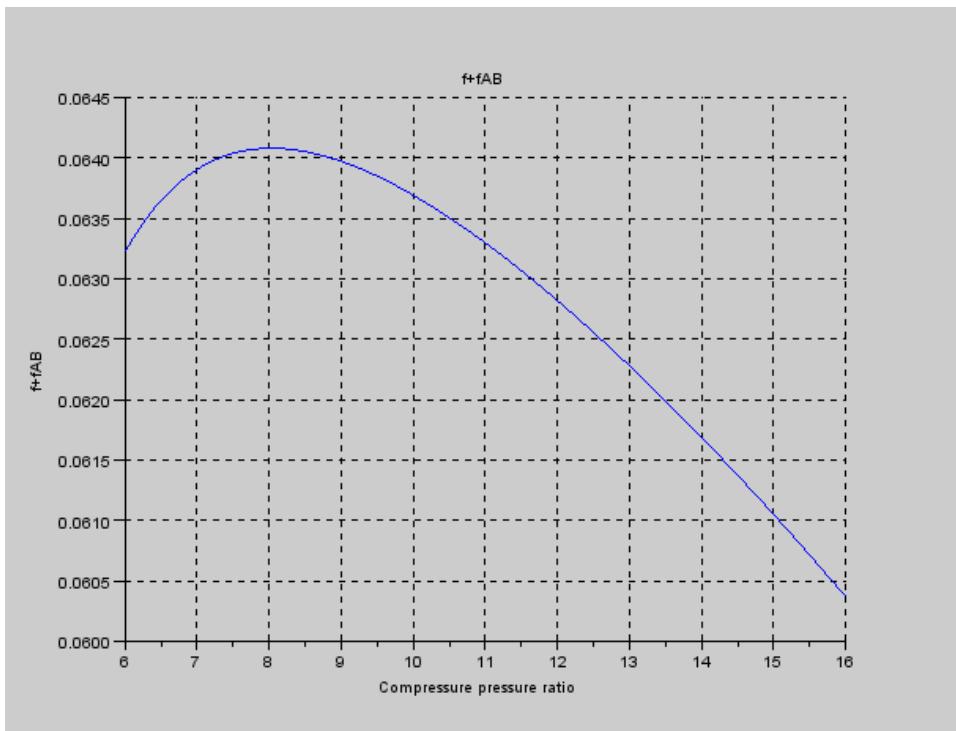


Figure 4.4: Engine performance of a mixed exhaust turbofan engine with afterburner having same parameters as in previous example for a range of compressor pressure ratios from 6 to 16

```

4 disp("Example 4.17")
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:")
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 ex

```

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

```

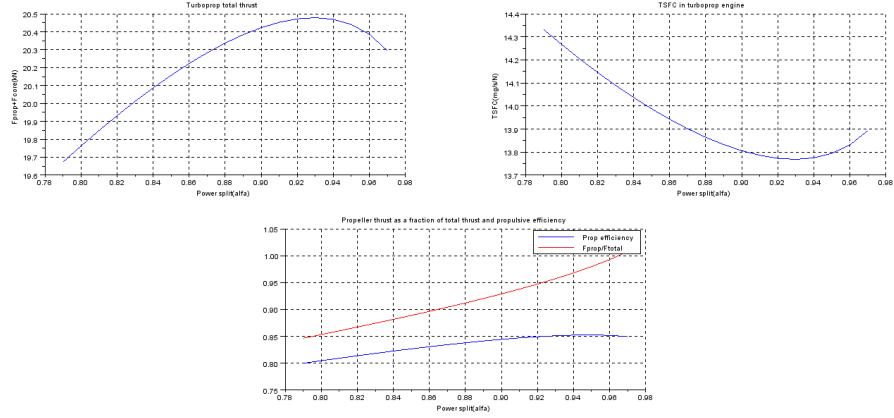


Figure 4.5: Graph of the performance parameters of the engine in above example with power split varying over a range

```

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 isentropioc 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 Ca for a conical nozzle with exit

```

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

```

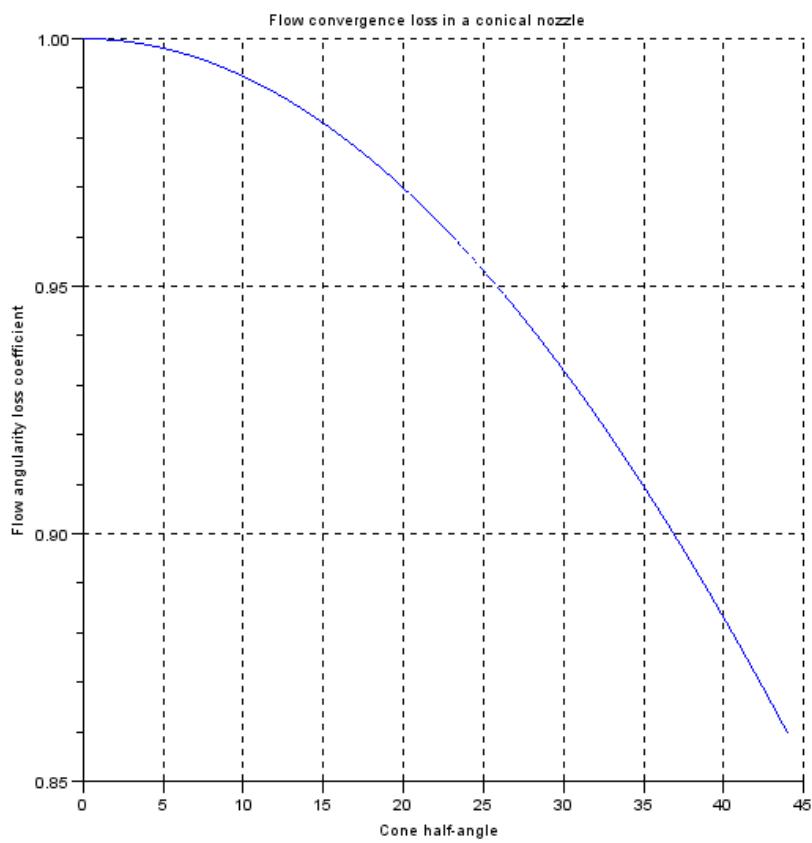


Figure 5.1: Divergence correction factor  $Ca$  for a conical nozzle with exit flow angles varying over a range

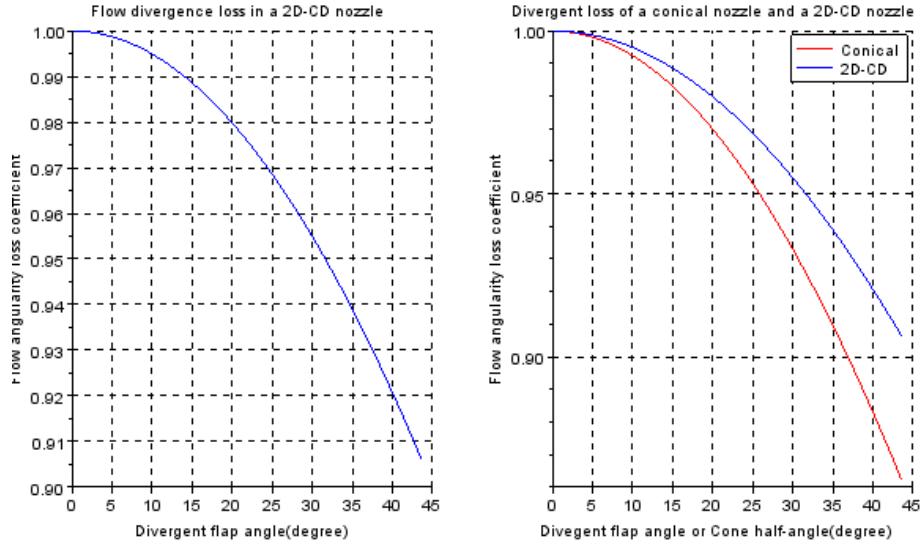


Figure 5.2: Graph of divergence correction factor for a two dimensional nozzle with exit flow angles varying over a range

---

**Scilab code Exa 5.9 Graph of divergence correction factor for a two dimensional nozzle**

```

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("Divegent 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**

```

1
2 clear;
3 clc;
4 close;

```

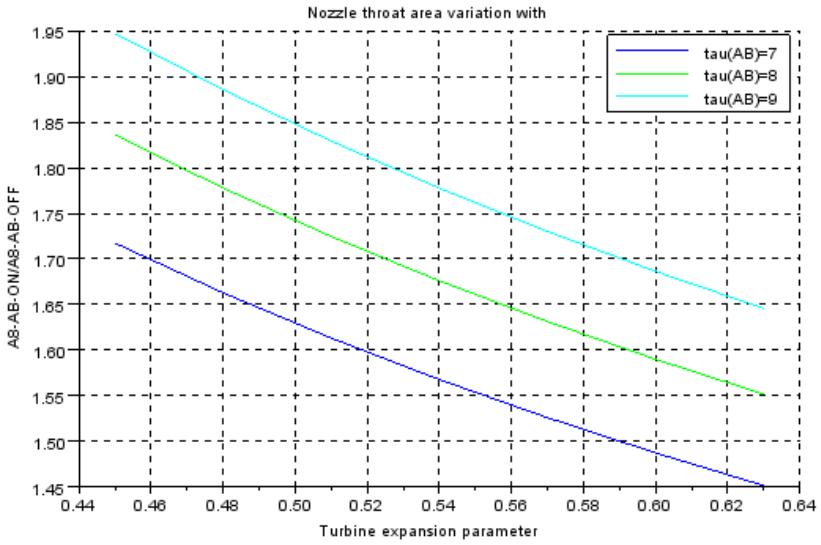


Figure 5.3: Graph of the ratio of nozzle throat area with the afterburner on and off for a range of turbine expansion parameter

```

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/
24          t1*tt))^(1/2))*(((gm1+1)/2)^(gm1+1)
25          /(2*(gm1-1))))/(((gm+1)/2)^(gm+1)/(2*(gm
26          -1))))
27      g1(gc1)=A
28      gc1=gc1+1
29      end
30
31      plot2d(z0,g1,i)
32      xgrid
33      i=i+1
34      xlabel("Turbine expansion parameter")
35      ylabel("A8-AB-ON/A8-AB-OFF")
36      title("Nozzle throat area variation with ")
37      legend(["tau(AB)=7","tau(AB)=8","tau(AB)=9"])
38      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
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))

```

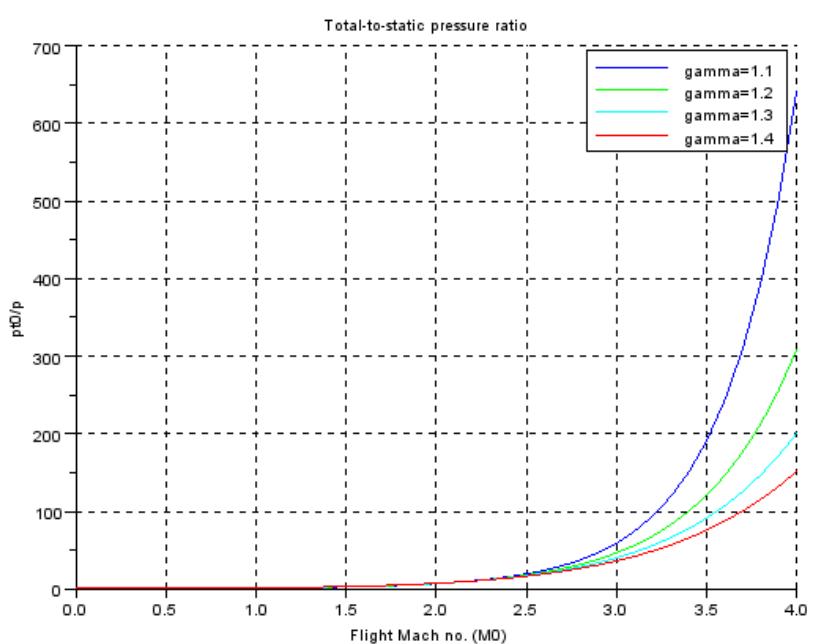


Figure 5.4: Hypersonic nozzle

```

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**

```

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

```

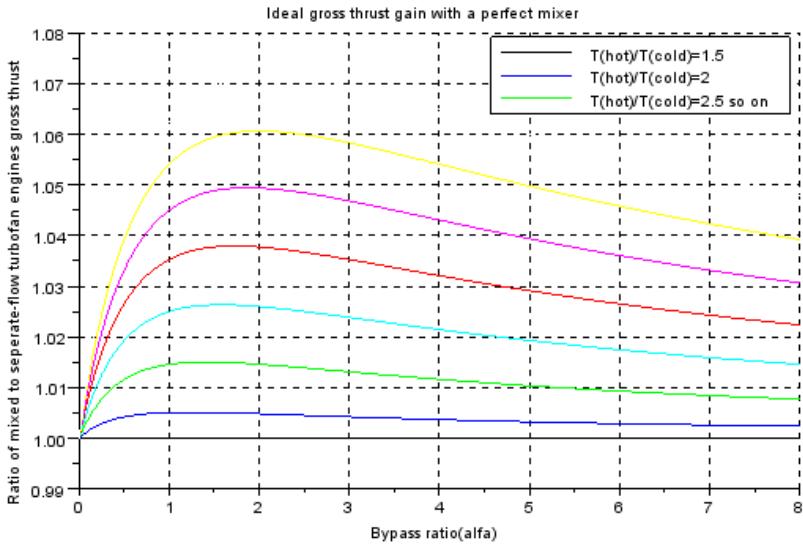


Figure 5.5: Graph of the ratio of mixed to separate flow turbofan engine for a range of hot to cold temperature ratio and a varying bypass ratio upto 8

```

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 sepearte-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 stoichiometric 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
   stoichiometric 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

```
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,"stotor 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)+(|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

```

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
14
15 R=(1-b)-((1-b)-Rm)/(r)^2

```

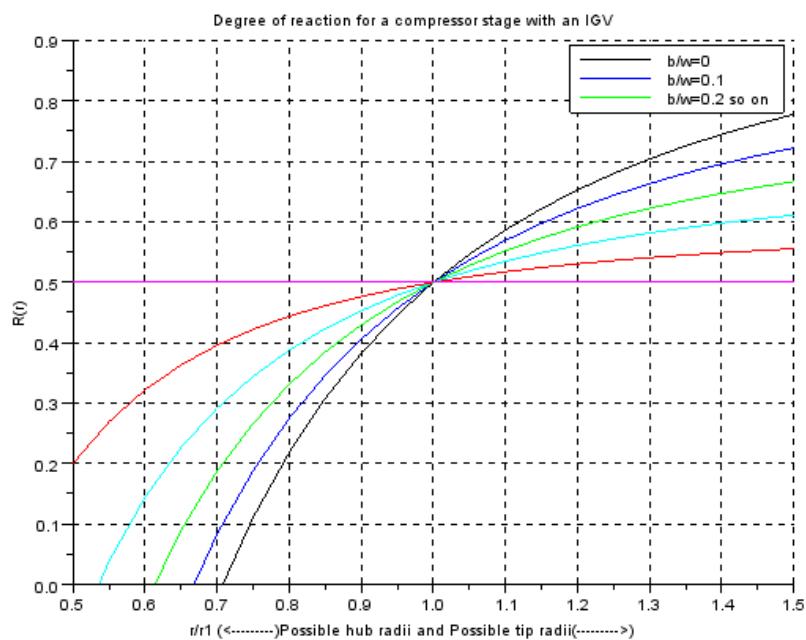


Figure 7.1: Comparison of the degree of reaction profile of a compressor stage with and without an IVG for a range of hub tip radii that result in a positive degree of reaction

```

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

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

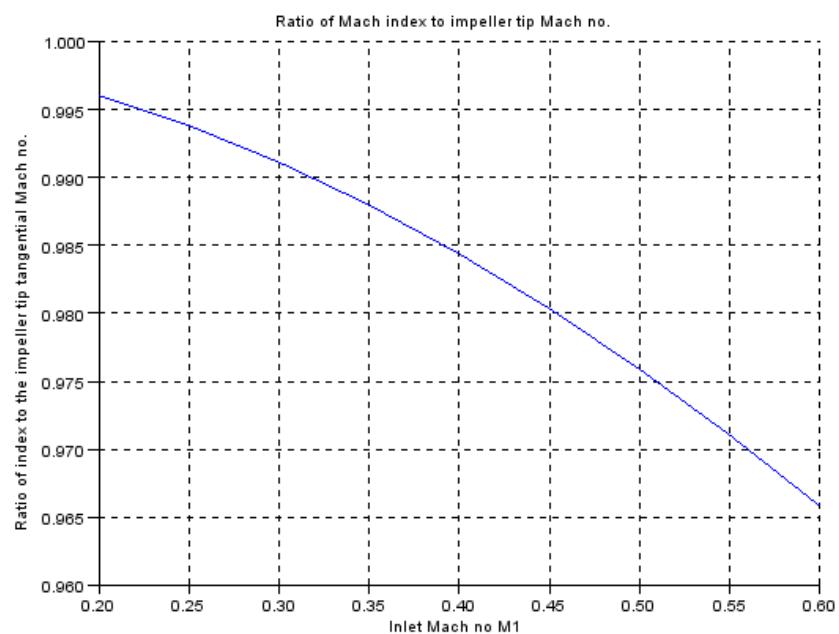


Figure 8.1: Graph of the ratio of Mach index to the impeller tip tangential Mach no for a range of inlet Mach no

```

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 r

```

1 clear;
2 clc;

```

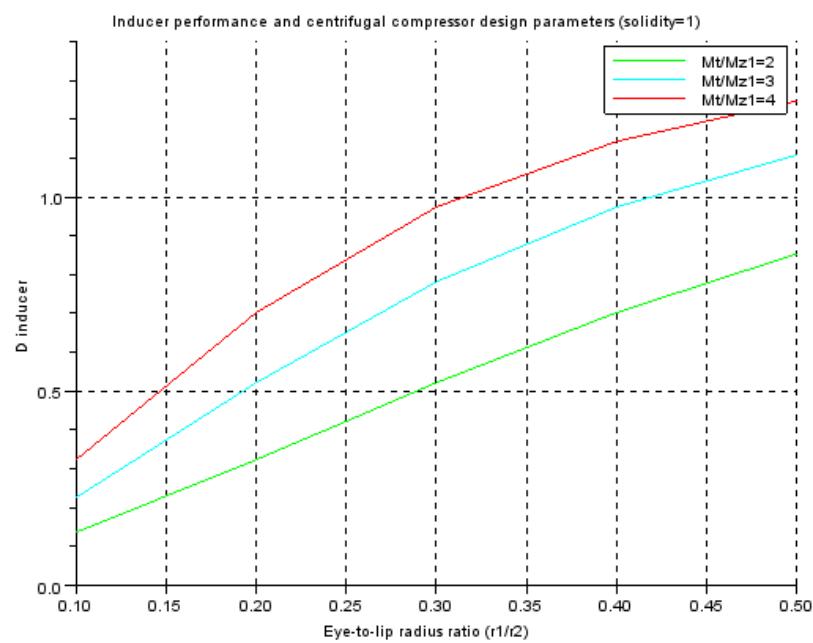


Figure 8.2: Graph of the inducer D factor for solidity of one and over a range of impeller tip Mach numbers and radius ratios

```

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
16     ^2))^(1/2)))
17     g1(gc1)=y
18     gc1=gc1+1
19     end
20     i=i+1
21     plot2d(z0,g1,i)
22     xgrid
23     xlabel("Eye-to-lip radius ratio (r1/r2)")
24     ylabel("D inducer")
25     title("Inducer performance and centrifugal
26     compressor design parameters (solidity=1)")
27     legend("Mt/Mz1=2","Mt/Mz1=3","Mt/Mz1=4")
28     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 per-

```
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;12.5,4.8,19.0,0.78;12,5.1,17.5,0.75;11.5,5.4,17.0,0.72;11,5.7,16.5,0.68;10.5,6.0,16.0,0.65;10,6.3,15.5,0.62;9.5,6.6,15.0,0.58;9,7.0,14.5,0.55;8.5,7.4,14.0,0.52;8,7.8,13.5,0.48;7.5,8.2,13.0,0.45;7,8.6,12.5,0.42;6.5,9.0,12.0,0.38;6,9.4,11.5,0.35;5.5,9.8,11.0,0.32;5,10.2,10.5,0.28;4.5,10.6,10.0,0.25;4,11.0,9.5,0.22;3.5,11.4,9.0,0.18;3,11.8,8.5,0.15;2.5,12.2,8.0,0.12;2,12.6,7.5,0.08;1.5,13.0,7.0,0.05;1,13.4,6.5,0.02];
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
13 gmt=1.33 //gamma turbine
```

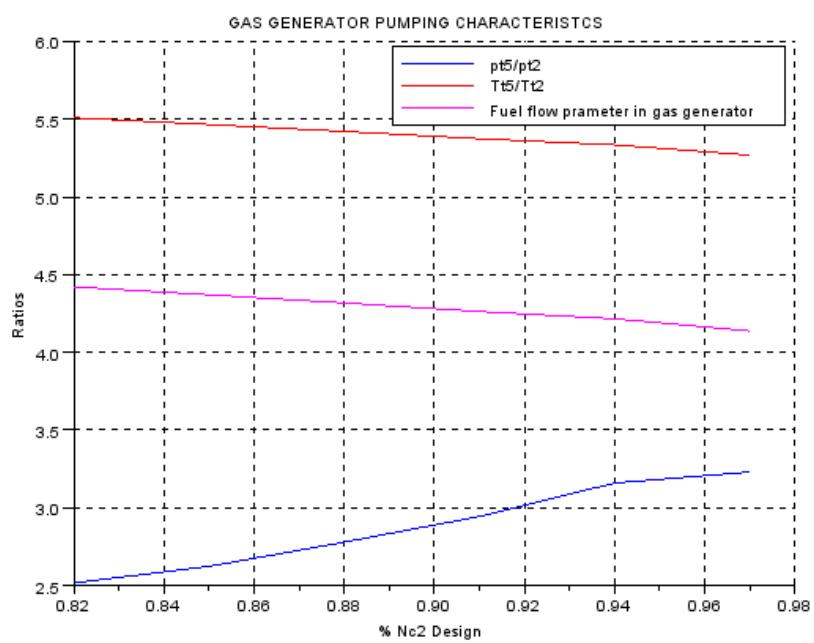


Figure 10.1: Graph of graph generator pumping characteristics verses percent Nc2 design

```

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 gmt0=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 Cpc0=1243
53 pno=0.93
54 po=1
55 a0=276.4
56
57 Tt2=T0
58 tc=p0*((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 pcOD=tcOD^((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*M0^2)^((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 vaccum 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 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 gravitatinal 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
8 Qr=120000000
```

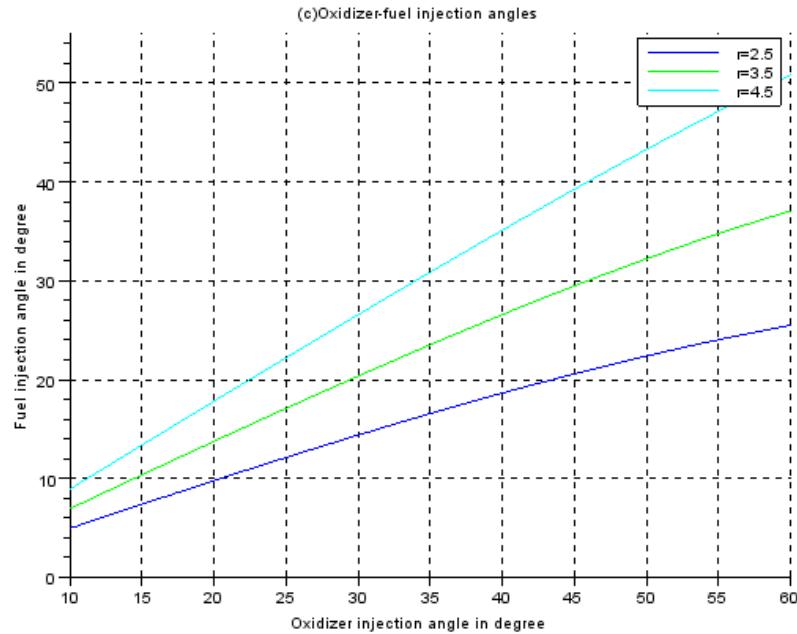


Figure 11.1: Liquid propellant combustion chambers in rocket

```

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 orifice area ratio A0/Af
   :")
15 vf=Cdf*(2*dpf/rhof)^(1/2)
16 v0=((2*dp0/rho0)^(1/2))*Cdo
17 disp(vf,"(b) Fuel orifice discharge speed in m/s:")
18 disp(v0,"Oxidizer orifice 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 i

```
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 :")
```

---