

AEROSPACE PROPULSION

MATLAB[®] CODES

T.-W. Lee

Arizona State University, USA

2.6 MATLAB® Program

MCE29

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%MCE29: Basic Aircraft Propulsion Parameters
% Specific thrust, TSFC as a function of flight Mach no and altitude
%
% Fs=specific thrust[ lbf/(lbm/s)] (Eq.2.14c)
% TSFC=TSFC[ (lbm/hr)/lbf] (Eq.2.22)
% H= altitude[ ft]
% Temperature model for standard atmosphere
% T=Tref-0.0036H; Tref=518.67 oR
Tref=518.67;
%
% a= speed of sound=sqrt(gamma*R*T); R=gas constant=1716.2[ ft^2/(s^2oR)]
% gamma=cp/cv=1.4
gamma=1.4;
R=1716.2;
%
% Start of calculations
H=0;
T=Tref-0.0036*H;
a=sqrt(gamma*R*T);
%
%1=turbojet (Ue=3000); 2=low bypass ratio turbofan (Ue=2250)
%3=high bypass ratio turbofan (Ue =1500); 4=turboprop (Ue=1000)
Ue1=3000; Ue2=2250; Ue3=1100; Ue4=280;
%
%hT=thermal efficiency; hPR=fuel heating value[ kJ/kg]
hT=0.38; hPR=18400;
for i=1:100;
    %
    % Mo from 0 to 2.5;
    Mo(i)=(i-1)*(2.5/100);

    Fs1(i)=(1/32.174)*(Ue1-a*Mo(i));
    Fs2(i)=(1/32.174)*(Ue2-a*Mo(i));
    Fs3(i)=(1/32.174)*(Ue3-a*Mo(i));
    Fs4(i)=(1/32.174)*(Ue4-a*Mo(i));

    TSFC1(i)=(Fs1(i)+(1/32.174)*2*a*Mo(i))/(2*hT*hPR*778.16)*3600*32.174;
    TSFC2(i)=(Fs2(i)+(1/32.174)*2*a*Mo(i))/(2*hT*hPR*778.16)*3600*32.174;
    TSFC3(i)=(Fs3(i)+(1/32.174)*2*a*Mo(i))/(2*hT*hPR*778.16)*3600*32.174;
    TSFC4(i)=(Fs4(i)+(1/32.174)*2*a*Mo(i))/(2*hT*hPR*778.16)*3600*32.174;

end
%
%Altitude effect
H1=0; H2=5000; H3=10000; H4=33000;
T1=Tref-0.0036*H1
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T2=Tref-0.0036* H2
T3=Tref-0.0036* H3
T4=Tref-0.0036* H4
a1=sqrt(gamma*R*T1);
a2=sqrt(gamma*R*T2);
a3=sqrt(gamma*R*T3);
a4=sqrt(gamma*R*T4);
for i=1:100;
    % Mo from 0 to 2.5;
    Mo(i)=(i-1)*(2.5/100);

Fs11(i)=(1/32.174)*(Ue3-a1*Mo(i));
Fs12(i)=(1/32.174)*(Ue3-a2*Mo(i));
Fs13(i)=(1/32.174)*(Ue3-a3*Mo(i));
Fs14(i)=(1/32.174)*(Ue3-a4*Mo(i));

TSFC11(i)=(Fs11(i)+(1/32.174)*2*a1*Mo(i))/(2*hT*hPR*778.16)*3600*32.174;
TSFC12(i)=(Fs12(i)+(1/32.174)*2*a2*Mo(i))/(2*hT*hPR*778.16)*3600*32.174;
TSFC13(i)=(Fs13(i)+(1/32.174)*2*a3*Mo(i))/(2*hT*hPR*778.16)*3600*32.174;
TSFC14(i)=(Fs14(i)+(1/32.174)*2*a4*Mo(i))/(2*hT*hPR*778.16)*3600*32.174;

end
plot(Mo,Fs1,Mo,Fs2,Mo,Fs3,Mo,Fs4)
plot(Mo,TSFC1,Mo,TSFC2,Mo,TSFC3,Mo,TSFC4)
plot(Mo,Fs11,Mo,Fs12,Mo,Fs13,Mo,Fs14)
plot(Mo,TSFC11,Mo,TSFC12,Mo,TSFC13,Mo,TSFC14)

```

3.6 MATLAB[®] Program

```
% MCE 34: Calculates the turbofan performance based on the following inputs:  
% Mo, To, gamma, cp, hPR, T4o, pc, pf (fan pressure ratio), alpha (bypass ratio).  
% OUTPUT PARAMETERS: U7, U9, Fs, TSFC, hP, hT, ho.  
% Other variations such as turbojets can be calculated, e.g. simply by setting  
% alpha = 0.  
  
% English units are used in this example.  
G=32.174; % conversion factor  
  
% INPUT PARAMETERS  
Mo = 0.8; To = 411.8; po= 629.5; ao= 995;  
gamma = 1.4; cp =0.24; hPR =18400;  
T4o =1850;; pc =15; pf = 1.75; alpha =6.5;  
mo=1125;  
  
%Start of calculations  
  
%Options to vary X(i) = Mo, To, etc.  
  
N = 25;  
Xmax=1; Xmin=0; dX=(Xmax-Xmin)/N;  
for i = 1:N;  
    X(i)= Xmin+dX*(i-1);  
    Mo=X(i);  
  
    Uo=Mo* ao  
  
    tr=1+ (gamma-1)/2* Mo^2; T2o=tr* To  
  
    tc=pc^ ((gamma-1)/gamma)  
    tf=pf^ ((gamma-1)/gamma)  
  
    tL=T4o/To  
  
    tt=1-tr/tL* (tc-1+alpha* (tf-1))  
  
    % Exit velocities: U2=(U7/ao)^2; V2=(U9/ao)^2  
  
    U2=2/ (gamma-1)* tL/ (tr* tc)* (tr* tc* tt-1)  
  
    U7=sqrt (U2)* ao  
  
    V2=2/ (gamma-1)* (tr* tf-1);  
  
    U9=sqrt (V2)* ao  
  
    % Mass flow rates  
  
    mc=mo/ (1+alpha); mF=mo* alpha/ (1+alpha);  
  
    % Thrust  
  
    F1=mc* (U7-Uo)+mF* (U9-Uo);  
  
    F=F1/G  
  
    Fs (i) = F/mo  
  
    % TSFC
```

```
f = cp* To/hPR* (tL-tr* tc) ;  
TSFC(i)=f/((1+alpha)* Fs(i))* 3600  
% Efficiencies  
hT(i) = 1-1/(tr* tc)  
N1=U7/Uo-1+alpha* (U9/Uo-1);  
D1=(U7/Uo)^2-1+alpha* ((U9/Uo)^2-1);  
hP(i)=N1/D1  
ho(i)=hT(i)* hP(i)  
end  
plot(X,Fs)
```

5.7 MATLAB® Programs

```
% MCE 53: Stage analysis using area-weighted average for three blade
% segments.

%Input parameters
Tao=350;
pao=195;
g=1.4; R =287;
cp=1040;
hst=0.9;
rm = 0.75;
z=0.8;
RPM = 3000;
cza = 150;
aa = 35*pi/180;
bb=10*pi/180;

u=RPM*2*pi*rm/60

Ta=Tao-cza^2/(2*cp);
ssa=sqrt(g*R*Ta);
%Calculation of the mid-radius

cqa=cza*sin(aa);
wqa=u-cqa;
wqb=cza*sin(bb);
cqgb=u-wqb;
delc=cqgb-cqa;

wsm=u*delc;
prm=(1+hst*u*delc/(cp*Tao))^(g/(g-1))

wa2=wqa^2+cza^2;
wb2=wqb^2+cza^2;

Rm=(wa2-wb2)/(2*u*delc)
Cpm=1-wb2/wa2
Mm=sqrt(wa2)/ssa
% Hub parameters
rmrh=0.5*(1/z+1);
rh=rm/rmrh
uh=u/rmrh;
cqah=cqa*rmrh;
cqbh=cqgb*rmrh;
delch=cqbh-cqah;

wsh=uh*delch;
prh=(1+hst*uh*delch/(cp*Tao))^(g/(g-1))
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wqah=uh-cqah;
wqbh=uh-cqbh;
wah2=wqah^2+cza^2;
wbh2=wqbh^2+cza^2;

Rh=(wah2-wbh2) / (2*uh*delch)
Cph=1-wbh2/wah2
Mh=sqrt(wah2) / ssa
% Tip parameters
rmrt=0.5*(z+1);
rt=rm/rmrt
ut=u/rmrt;
cqat=cqa*rmrt;
cqbt=cqb*rmrt;
delct=cqbt-cqat;

wst=ut*delct;
prt=(1+hst*ut*delct/(cp*Tao))^(g/(g-1))

wqat=ut-cqat;
wqbt=ut-cqbt;
wat2=wqat^2+cza^2;
wbt2=wqbt^2+cza^2;
Rt=(wat2-wbt2)/(2*ut*delct)
Cpt=1-wbt2/wat2
Mt=sqrt(wat2) / ssa

% Average parameters with 2:1:1=m:t:h
prA=0.5*prm+0.25*prh+0.25*prt
RA=0.5*Rm+0.25*Rh+0.25*Rt
CpA=0.5*Cpm+0.25*Cph+0.25*Cpt

```

```

% MCE 64: Calculation of the adiabatic flame temperature
% using specific heats

%Input parameters
To=298.15;

CpCO2=50.16;
CpH2O=38.90;
CpO2=33.35;
CpN2=31.5;

hfCO2=-393522;
hfH2O=-241827;
hfOct=-249952;

mairs=12.5* 32+12.5* 3.75* 28.014;
fs=114.23/mairs;

for i = 1:25;
g(i)= 1+0.2* (i-1);
mair=f(i)* (12.5* 32+12.5* 3.76* 28.014);
phi(i)=114.23/mair/fs;

nO2=12.5* g(i)-12.5;
nN2=12.5* 3.76* g(i);

Cp=8* CpCO2+9* CpH2O+nO2* CpO2+nN2* CpN2;
RHS=hfOct-8* hfCO2-9* hfH2O+Cp* To;
Tf(i)=RHS/Cp;

end
plot(phi,Tf)

```

7.3 MATLAB® Program

```
% MCE 73: Calculates the turbofan performance based on the following inputs:  
% Comparison of ideal and real cycle performance  
% Mo, To, gamma, cp, hPR, T4o, pc, pf (fan pressure ratio), alpha (bypass  
ratio).  
% gc, gt, cpc, cpt, ec, ef, pid, pifn, hb, hm, pib  
% p0p7, p0p9  
% OUTPUT PARAMETERS: U7, U9, Fs, TSFC, hP, hT, ho.  
% Other variations such as turbojets can be calculated, e.g. simply by  
setting  
% alpha = 0.  
  
% English units are used in this example.  
G=32.174; FL=778.16 % conversion factor  
  
% INPUT PARAMETERS  
Mo = 0.8; To = 390; po= 629.5;  
gc = 1.4; cpc =0.24; gt = 1.33; cpt = 0.276; hPR = 18400;  
T4o = 3000;; pc =36; pf = 1.65; alpha = 10;  
mo=1125;  
  
ec = 0.9; ef=0.89; et = 0.89; pid = 0.99; pin = 0.99; pifn = 0.99;  
hb=0.99; hm=0.99; pib = 0.96; pop7=0.9; pop9=0.9;  
  
Rc=(gc-1)*cpc*FL/gc; Rt=(gt-1)*cpt*FL/gc;  
ao=sqrt(gc*Rc*G*To); gamma = gc; cp = cpc;  
  
%Start of calculations  
  
% Ideal Cycle  
% Options to vary X(i) = Mo, To, etc.  
  
N = 25;  
Xmax=1; Xmin=0; dX= (Xmax-Xmin)/N;  
for i = 1:N;  
    X(i)= Xmin+dX*(i-1);  
    Mo=X(i);  
  
    Uo=Mo* ao  
  
    tr=1+ (gamma-1)/2*Mo^2; T2o=tr* To  
  
    tc=pc^((gamma-1)/gamma)  
    tf=pf^((gamma-1)/gamma)  
  
    tL=T4o/To
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tt=1-tr/tL*(tc-1+alpha*(tf-1))

% Exit velocities: U2=(U7/ao)^2; V2=(U9/ao)^2

U2=2/(gamma-1)*tL/(tr*tc)*(tr*tc*tt-1)

U7=sqrt(U2)*ao

V2=2/(gamma-1)*(tr*tf-1);

U9=sqrt(V2)*ao

% Mass flow rates

mc=mo/(1+alpha); mF=mo*alpha/(1+alpha);

% Thrust

F1=mc*(U7-Uo)+mF*(U9-Uo);

F=F1/G

Fs(i)=F/mo;
```

8.3 MATLAB® Programs

```
% MCE 82: Calculation of Hmax using Equation 8.17.  
clear all  
%Input parameters  
go=9.81;  
  
Umin=750; Umax= 2500; Rmin=5; Rmax=100; tmin=30; tmax =600;  
Rm=50;  
Ueq=1500;  
tb=180;  
for i = 1:25;  
    U(i)=Umin+(Umax-Umin)*(i-1)/25;  
    R(i)=Rmin+(Rmax-Rmin)*(i-1)/25;  
    t(i)=tmin+(tmax-tmin)*(i-1)/25;  
    HU(i)=(U(i)*log(Rm))^2/(2*go)-U(i)*tb*(Rm*log(Rm)/(Rm-1)-1);  
    HR(i)=(Ueq*log(R(i)))^2/(2*go)-Ueq*tb*(R(i)*log(R(i))/(R(i)-1)-1);  
    Ht(i)=(Ueq*log(Rm))^2/(2*go)-Ueq*t(i)*(Rm*log(Rm)/(Rm-1)-1);  
  
end  
  
plot(U/Ueq,HU,R/Rm,HR,t/tb,Ht)
```

10.5 MATLAB® Program

```
%MCE101: Plot of normalized exit velocity
R=8314;
g1=1.15; g2=1.25; g3=1.35;
% Start of calculations
for i=1:50;
%
pr(i)=1/(2.5+(i-1)*(25-2.5)/50);
prr(i)=1/pr(i);

A1=1-pr(i)^((g1-1)/g1);
A2=1-pr(i)^((g2-1)/g2);
A3=1-pr(i)^((g3-1)/g3);

U1(i)=sqrt(A1);
U2(i)=sqrt(A2);
U3(i)=sqrt(A3);
end
plot(prr,U1,prr,U2,prr,U3)
```

