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Air Turbo Rocket Ramjet

Aerospace Propulsion Final Project - Part 2

```
clear, clc, close all
run('startup')

phis = [1 2 10];
%  Properties Override
%phis = 2;
```

Initialize Constants

```
% Load the standard atmosphere
atm = readtable('std_atm.csv');

% gamma
g = 1.4;

% Universal gas constant
RR = 3.406*1000; % % lb ft/(kmol*R)

% Molar masses
M_DryAir = 1.9850755; % slugs/kmol (28.97 kg/kmol)
O2.MM  = 2.1927; % slugs/kmol (32)
N2.MM  = 1.92984701; % slugs/kmol (28.164)
H2.MM  = 0.137044; % slugs/kmol (2)

% Mass fraction of air constituents:
O2.m_frac = 0.232;
N2.m_frac = 0.768;

% Mixture properties: air.prop
R_dryair  = RR/M_DryAir; % lb ft / (slug*R)
cp_dryair = R_dryair*g/(g-1);

% DEBUG OVERRIDE
% R_dryair = 1716;
% cp_dryair = 6007;
```

Run the Simulation

```
% Iterator Variable
```

```
PIs_fan = 1.1:0.01:4;

% Properties Override
%PIs_fan = 2;

% Turbomachinery Efficiencies
etaF = 0.95; % Fan
etaT = 0.90; % Turbine
etaS = 0.99; % Shaft


% Specify flight condition values
% Cruise (flight condition 2)
h1 = 60000; % 60000 ft
M1 = 4;
pid = 0.669;
Cd = 0.4;
FN_g = 5000; % required thrust


% Freestream conditions (station 0) (flight condition 1)
Ttrto = M_Tt_T_inv(M1,g);
Ptrto = M_Pt_P_inv(M1,g);

Tt0 = Ttrto * interp1(atm.h,atm.t,h1);
Pt0 = Ptrto * interp1(atm.h,atm.P,h1);

T0  = Tt0/Ttrto;
P0  = Pt0/Ptrto;

% DEBUG OVERRIDE
% P0 = 151;
% Pt0 = 22927;
% T0 = 390;
% Tt0 = 1638;

u0 = M1*sqrt(g*R_dryair*T0);
rho0 = P0/(R_dryair*T0);

mft0 = mft_calc(M1,g);


% Begin Iteration
for m = 1:length(phis)
    for n = 1:length(PIs_fan)

        % Select specific phi and PIfan
        phi = phis(m);
        pif = PIs_fan(n);

        % Inlet (Pressure Recovery and Isenthalpic Assumption)
        Pt12 = pid*Pt0;
        Tt12 = Tt0;
```

```
        % Station 13 (Fan pressure rise)
        Pt13 = pif*Pt12;

        % Station 15 (Isentropic flow)
        Pt15 = Pt13;
        M15  = 0.2; % Given
        P15  = Pt15/M_Pt_P_inv(M15,g);

        % Station X
        Mx  = 1; % Given
        Px  = P15;
        Ptx = Px*M_Pt_P_inv(Mx,g);
        mftx = mft_calc(Mx,g); % Choaked throat

        % Station C (The Combustion Problem)
        Ptc = 2E5; % psf total chamber pressure

        % Turbine
        pit  = Ptx/Ptc; % Turbine pressure ratio (Ptx = Pt5 by
isentropic flow)
        g1   = (g-1)/g;
        taut = 1 - etaT*(1-pit^g1); % Turbine temperature ratio

        % Mass Fractions
        yO = 32/(4*phi+32);
        yH = 4*phi/(4*phi+32);
        yN = 0;

        % Compute Ttc.
        CpH = g*(RR/H2.MM)/(g-1);
        CpO = g*(RR/O2.MM)/(g-1);

        T_inject = 540;
        hc = (yH*CpH*T_inject + yO*CpO*T_inject);
        Ttc = Ttbrn_yHyOyNhi(yH,yO,yN,hc,g);

        MWT = MWT_yHyOyN(yH,yO,yN);
        R_mix = 49710/MWT;                % CL
        Cp_mix = R_mix*g/(g-1);

        % Calculate Specific Work
        wt = Cp_mix*Ttc*(1-taut);

        % Find A0 by regula falsi
        A0_l = 0.001;  % m^2
        A0_h = 1000; % m^2
        A0_g = (A0_l+A0_h)/2;

        % DEBUG OVERRIDE
        % A0_g = 2.11;

        exit = false;
        while exit == false
```

```
                % Rubber Inlet
                A1 = A0_g;

                % Fan Airflow
                mdot0  = Pt0*A0_g*mft0 / sqrt(R_dryair*Tt0);
                tauf   = (-1+pif^g1)/etaF + 1; % Fan Temperature Ratio
                Tt13   = tauf*Tt12;
                WdotF  = mdot0*cp_dryair*(Tt13-Tt12); % Fan Power

                % Turbine
                mdott = WdotF/(etaS*wt); % Turbine mass flow
                Tt5 = taut*Ttc;

                % Station X
                mdotx = mdott;
                Ttx   = Tt5;
                Ax    = mdotx*sqrt(Ttx*R_mix)/(Ptx*mftx);
                Tx    = Ttx/M_Tt_T_inv(Mx,g);
                ux    = Mx*sqrt(g*R_mix*Tx);
                Ix    = mdotx*ux+Px*Ax;

                % Station 15
                mdot15 = mdot0;
                mft15  = mft_calc(M15,g);
                Tt15   = Tt13;
                T15    = Tt15/M_Tt_T_inv(M15,g);
                A15    = mdot15*sqrt(R_dryair*Tt15)/(mft15*Pt15);
                u15    = M15 * sqrt(g*R_dryair*T15);
                I15    = mdot15*u15 + P15*A15;

                % Mass Flow Accounting
                mdotO = yO*mdotx;
                mdotH = yH*mdotx;

                % Mixer Flow
                Amixer = A15 + Ax;
                mdot_mixer = mdotx + mdot15;
                Imixer = Ix + I15;
                hi = (mdotH*CpH*T_inject    + mdotO*CpO*T_inject...
                   +  mdot15*cp_dryair*Tt12 - mdott*wt*(1-etaS))/
mdot_mixer;

                % Station 7 (Mixer Combustion Propagation)
                % Find Cp7
                mdot7   = mdot_mixer;

                yO15    = O2.m_frac;
                yN15    = N2.m_frac;

                mdotO15 = mdot15*yO15;
                mdotN15 = mdot15*yN15;

                yO7     = (mdotO15 + mdotO)/mdot7; % combine the oxygen
 species
```

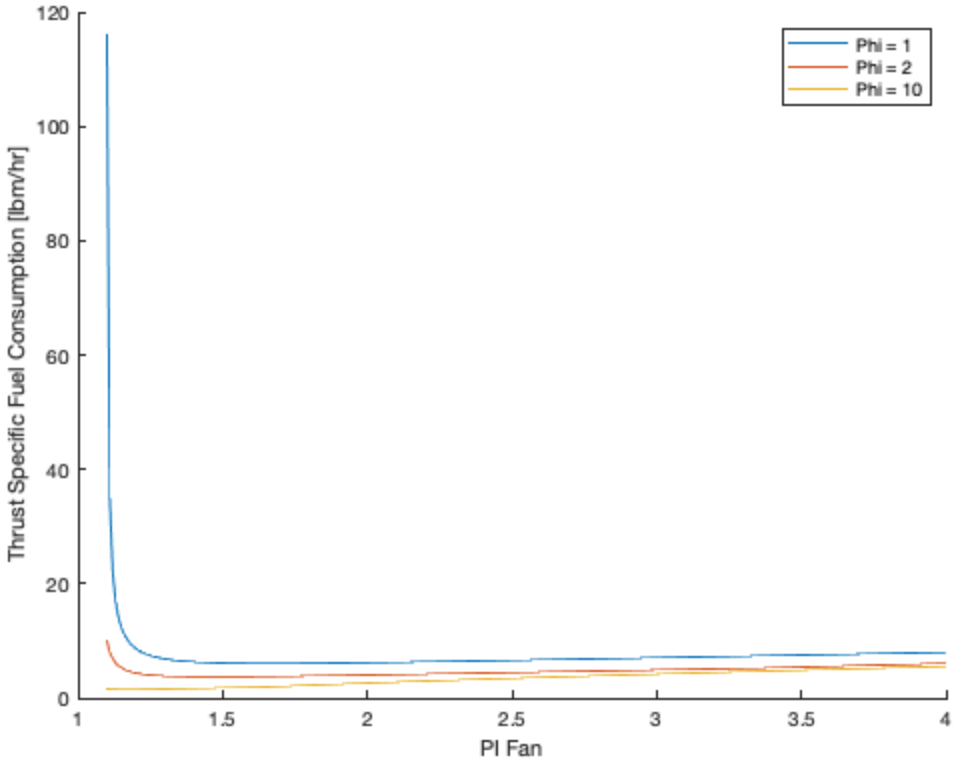
```
yN7     = mdotN15/mdot7;           % only comes from air
yH7     = mdotH/mdot7;             % only comes from fuel

MWT = MWT_yHyOyN(yH7,yO7,yN7);
R7  = 49710/MWT; % CL
Cp7 = R7*g/(g-1);

% Find Station 7 Properties
Tt7 = Ttbrn_yHyOyNhi(yH7,yO7,yN7,hi,g);

ht7  = Cp7*Tt7;
I7   = Imixer;
mfi7 = ht7*(mdot7/I7)^2;
M7   = m_sub_mfi(mfi7,g);
A7   = Amixer;

T7 = Tt7/M_Tt_T_inv(M7,g);
u7   = M7*sqrt(g*R7*T7);
rho7 = mdot7/(u7*Amixer);
P7   = rho7*R7*T7;
Pt7  = P7*M_Pt_P_inv(M7,g);

% Station 8 Properties
M8  = 1; % Given
R8  = R7;
A8  = A7*mft_calc(M7,g)/mft_calc(M8,g);
Tt8 = Tt7;
Pt8 = Pt7;
P8  = Pt8/M_Pt_P_inv(M8,g);
T8  = Tt8/M_Tt_T_inv(M8,g);
u8  = M8*sqrt(g*R8*T8);

% Station 9 Properties
P9    = interp1(atm.h,atm.P,h1); % ambient pressure BC
mdot9 = mdot_mixer;
Tt9   = Tt7;
Pt9   = Pt8;
M9    = M_Pt_P(Pt9/P9,g);
T9    = Tt9/M_Tt_T_inv(M9,g);
u9    = M9*sqrt(g*R7*T9);
A9    = A8*mft_calc(M8,g)/mft_calc(M9,g);

% Gross Thrust
Cfg = 0.96;         % Given
Fg  = Cfg*mdot9*u9; % Pressures equal and cancel out

% Subtract ram drag and cowl drag to get net thrust, FN.
Acowl = 0.1*A0_g;
Dram = mdot0*u0;
Dcowl = .5*rho0*u0^2*Cd*Acowl;
FN = Fg-Dram-Dcowl; % Last equation on slide 5 on slide
set d.
```

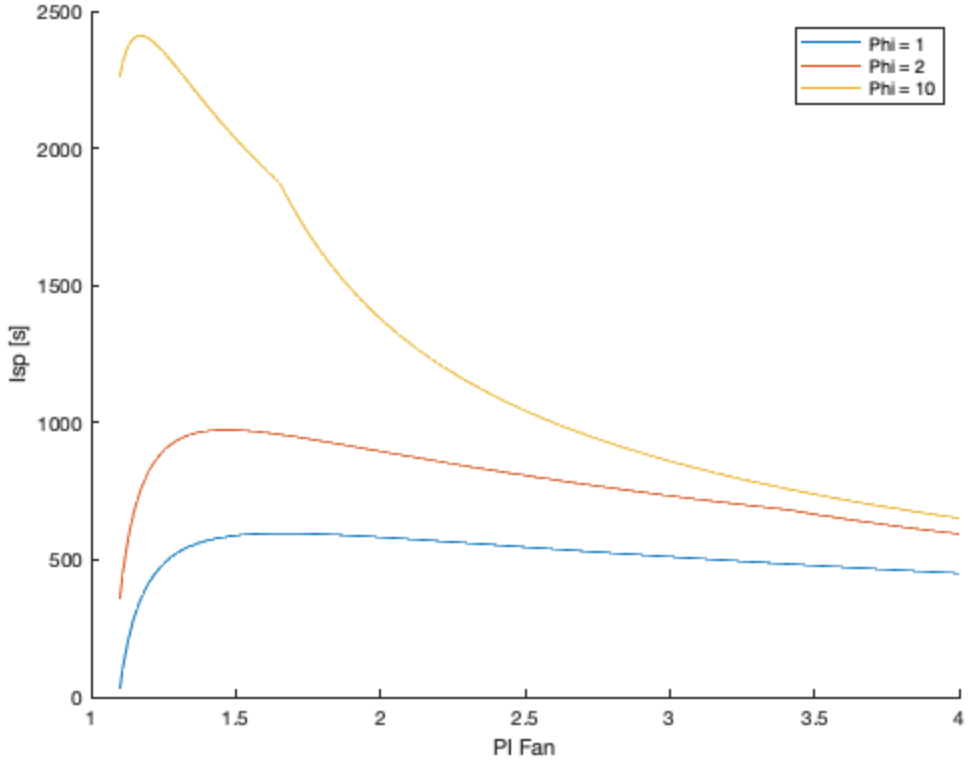
```
            % If FN does not match required for the flight condition,
 update A0.
            if FN < FN_g - 0.001 || FN > FN_g + 0.001
                if FN < FN_g
                    A0_l = A0_g;
                else
                    A0_h = A0_g;
                end

                A0_g = (A0_h+A0_l)/2;

            else
                exit = true;
            end

        end

        % Data Collection
        % mc is now known, get outputs
        A0s(m,n)  = A0_g;
        mdotxs(m,n) = mdotx;
        TSFC(m,n) = mdotx*32.174*3600/FN; % --> lbm/hr
        Isp(m,n)  = 3600/TSFC(m,n);
        ST(m,n)   = FN/mdot0;
    end
end
```

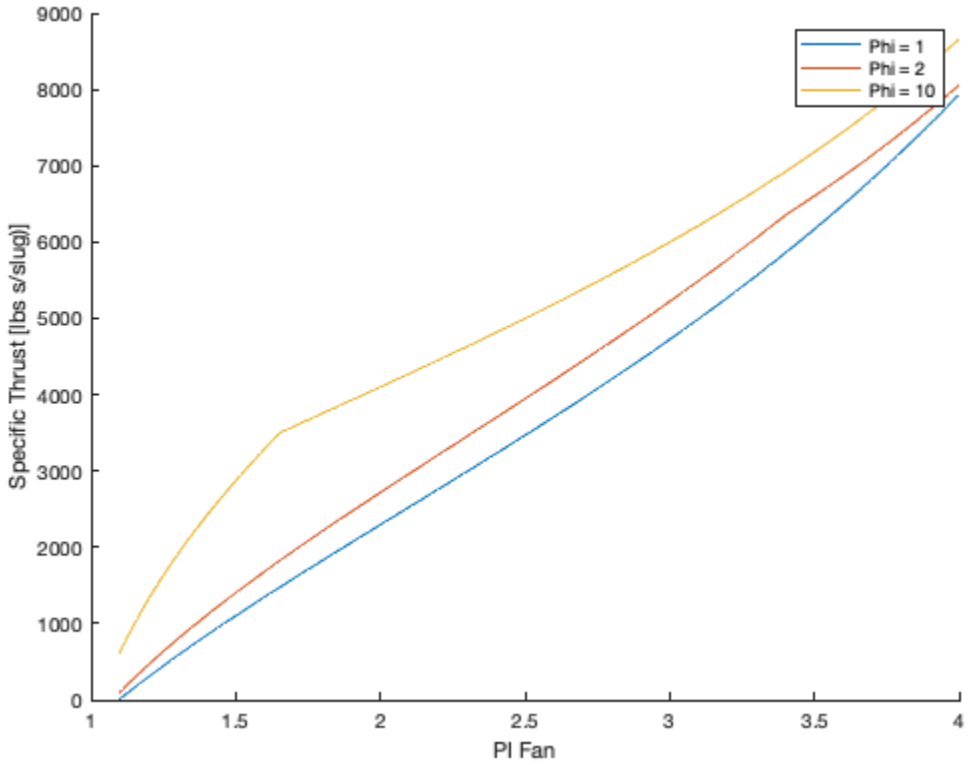
Plotting

```
for i = 1:length(phis)
    figure(1); hold on
    plot(PIs_fan,TSFC(i,:),'DisplayName',['Phi = ', num2str(phis(i))])
    legend('show')

    figure(2); hold on
    plot(PIs_fan,Isp(i,:), 'DisplayName',['Phi = ', num2str(phis(i))])
    legend('show')

    figure(3); hold on
    plot(PIs_fan,ST(i,:), 'DisplayName',['Phi = ', num2str(phis(i))])
    legend('show')
end

figure(1)
xlabel('PI Fan')
ylabel('Thrust Specific Fuel Consumption [lbm/hr]')

figure(2)
xlabel('PI Fan')
ylabel('Isp [s]')

figure(3)
xlabel('PI Fan')
```

```
ylabel('Specific Thrust [lbs s/slug)]')
```

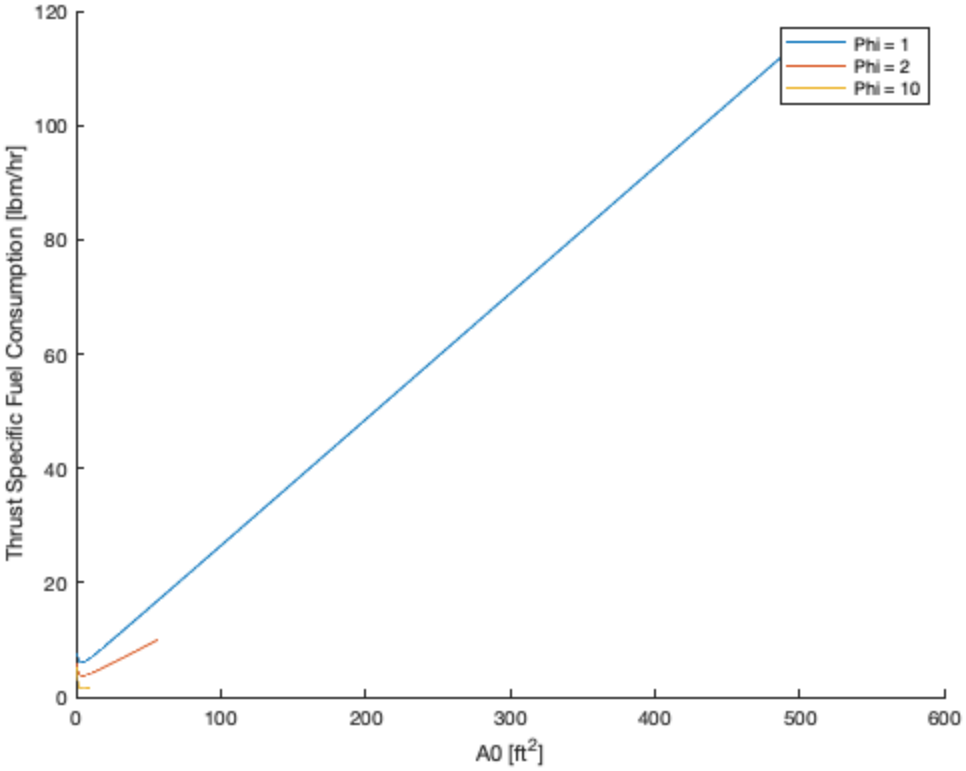


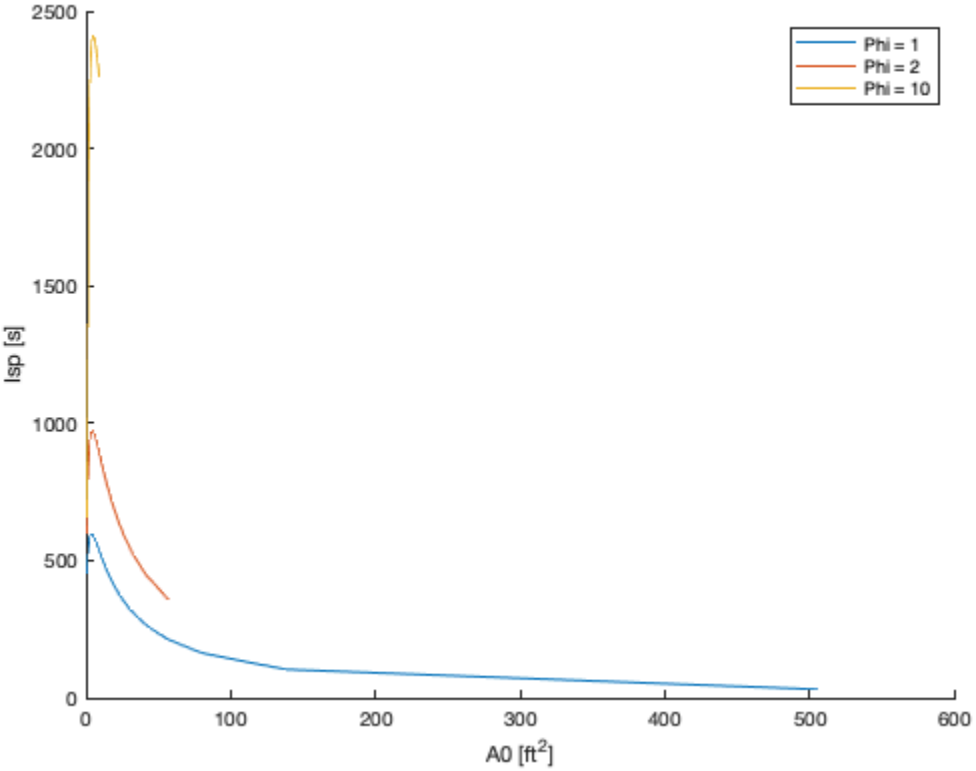

Phi = 1
Phi = 2
Phi = 10
Isp [s]
PI Fan
0
500
1000
1500
2000
2500
1
1.5
2
2.5
3
3.5
4

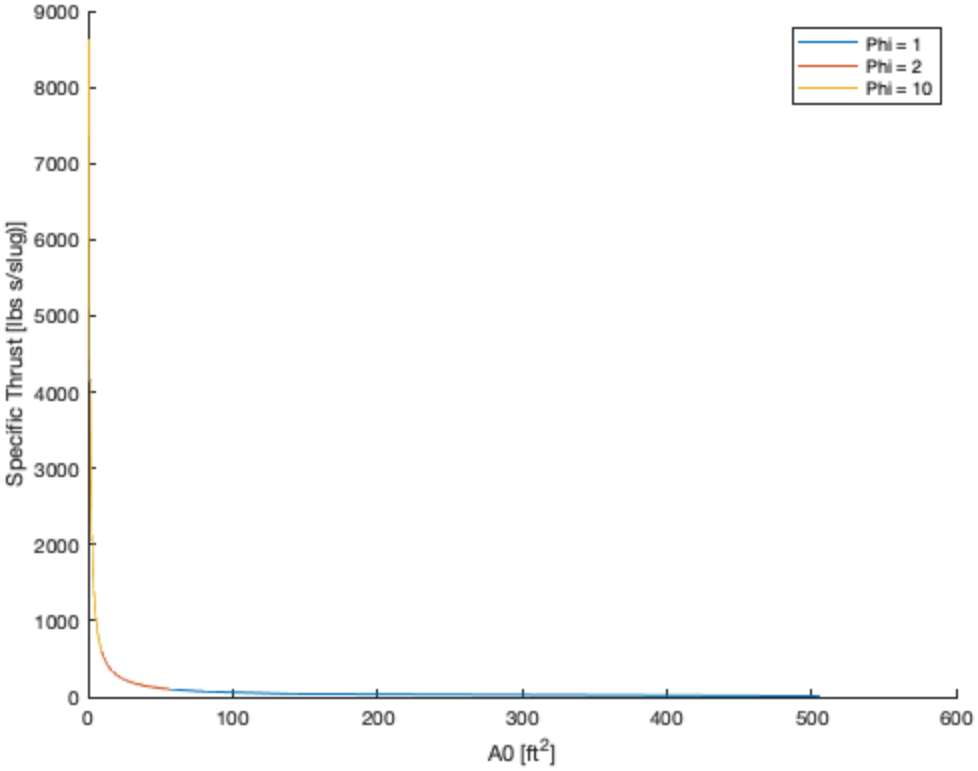

Phi = 1
Phi = 2
Phi = 10
Specific Thrust [lbs s/slug)]
PI Fan
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1
1.5
2
2.5
3
3.5
4

Test Plots

```
for i = 1:length(phis)
    figure(4); hold on
    plot(A0s(i,:),TSFC(i,:),'DisplayName',['Phi = ',
 num2str(phis(i))])
    legend('show')

    figure(5); hold on
    plot(A0s(i,:),Isp(i,:), 'DisplayName',['Phi = ',
 num2str(phis(i))])
    legend('show')

    figure(6); hold on
    plot(A0s(i,:),ST(i,:), 'DisplayName',['Phi = ', num2str(phis(i))])
    legend('show')
end

figure(4)
xlabel('A0 [ft^2]')
ylabel('Thrust Specific Fuel Consumption [lbm/hr]')

figure(5)
xlabel('A0 [ft^2]')
ylabel('Isp [s]')

figure(6)
xlabel('A0 [ft^2]')
ylabel('Specific Thrust [lbs s/slug)]')
```


Thrust Specific Fuel Consumption [lbm/hr]
A0 [ft^2]
Phi = 1
Phi = 2
Phi = 10
0
20
40
60
80
100
120
0
100
200
300
400
500
600


Isp [s]
A0 [ft^2]
Phi = 1
Phi = 2
Phi = 10
0
500
1000
1500
2000
2500
0
100
200
300
400
500
600



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