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```
%Aero 402 Homework 4: 10/27/25
```

Workspace Prep

```
warning off
format long      %Allows for more accurate decimals
close all;       %Clears all
clear all;       %Clears Workspace
clc;             %Clears Command Window
```

Question 2: Non-Ideal Conditions

```
g2 = 1.4;
r2 = 297;
tc2 = 298;

g = 1.2;
R = 260; %J/kg-k
Tc = 1650; %combustion temp
tb = 10000;
F = 40; %N
g0 = 9.81; %at sea level

PcPe = linspace(1,100);
PePc = linspace(0,1);

CF = C_f(g,PePc, 1, 0);
Cstar = 1009.945158;
mdotv = F./(Cstar.*CF);
Isp = F./(mdotv.*g0);

eps = expansionRatio(g,PcPe);

Vtank = linspace(0,1);
Ptank = 1./Vtank; %make all constants = 1 for simplicity

% non ideal
```

```matlab
mdot = F/(Cstar*1.4); %1.4 is the C_f chosen from the knee of the plot
disp(num2str(mdot));
ISP = F/(mdot*g0);
disp(num2str(ISP));
tb = 40000/F;
mp = mdot*tb;
disp(num2str(mp));

% Plots

% % This first plot is not what the question asks for (that ones next) but
% % this makes much more sense, especially because as the Pe/Pc ratio
% % approaches zero the C_f approaches the ideal case
% figure
% grid on
% hold on
% plot(PePc,CF)
% title('C_F vs Pe/Pc')
% xlabel('C_F')
% ylabel('Pe/Pc')

figure
grid on
hold on
plot(PcPe, C_f(g,1./PcPe, 1, 0))
plot(PcPe, C_f(g2,1./PcPe, 1, 0))
title('C_F vs Pc/Pe')
xlabel('C_F')
ylabel('Pc/Pe')
legend('Hydrazine','Cold Gas')

figure
grid on
hold on
plot(Isp,eps)
title('Isp vs \epsilon')
xlabel('Isp (s)')
ylabel('\epsilon')

figure
grid on
hold on
plot(Vtank,Ptank)
title('Tank Volume vs Tank Pressure')
xlabel('Tank Volume (m^3)')
ylabel('Tank Pressure (Pa)')

figure
grid on
hold on
plot(PcPe,eps)
title('Ae/At (\epsilon) vs Pc')
xlabel('\epsilon')
ylabel('Pc (Pa)')
```
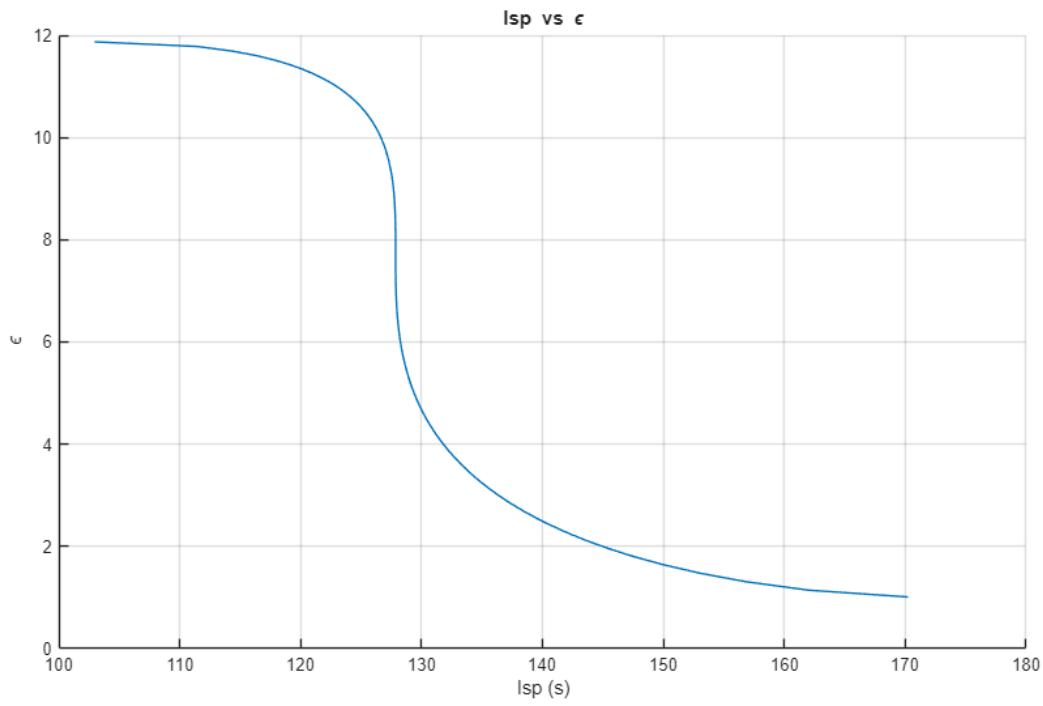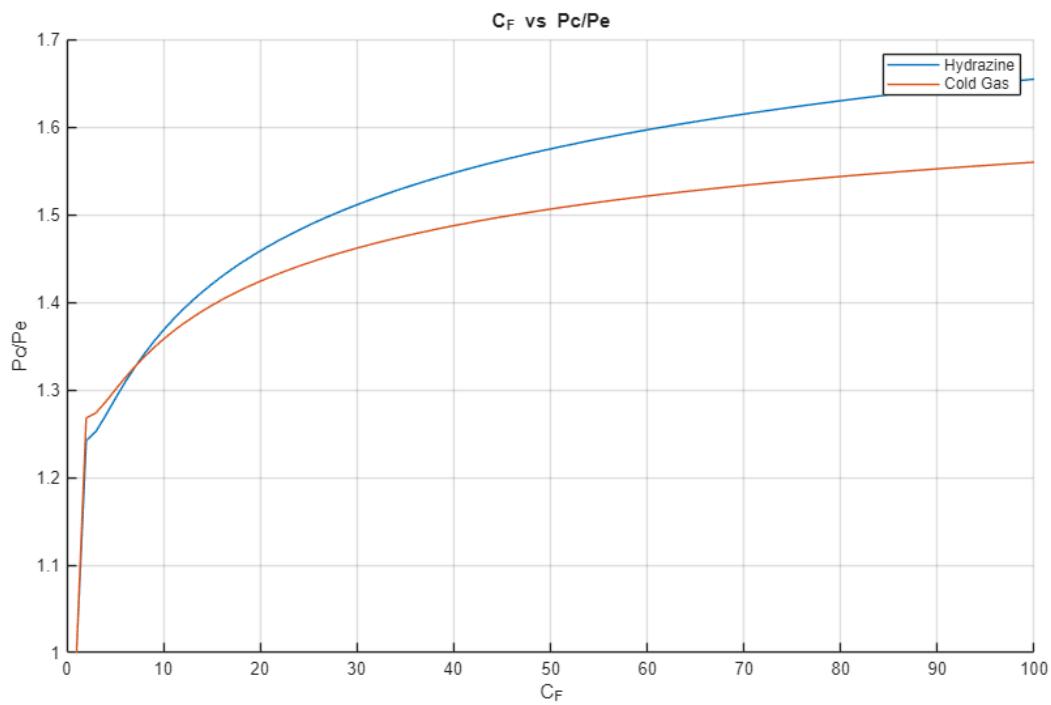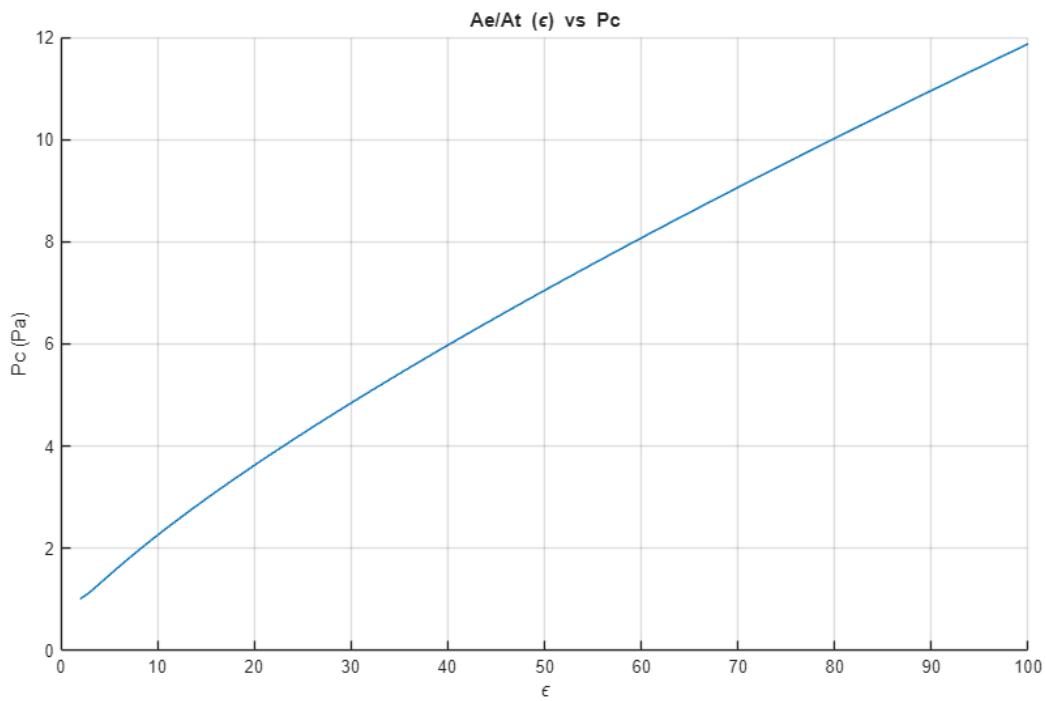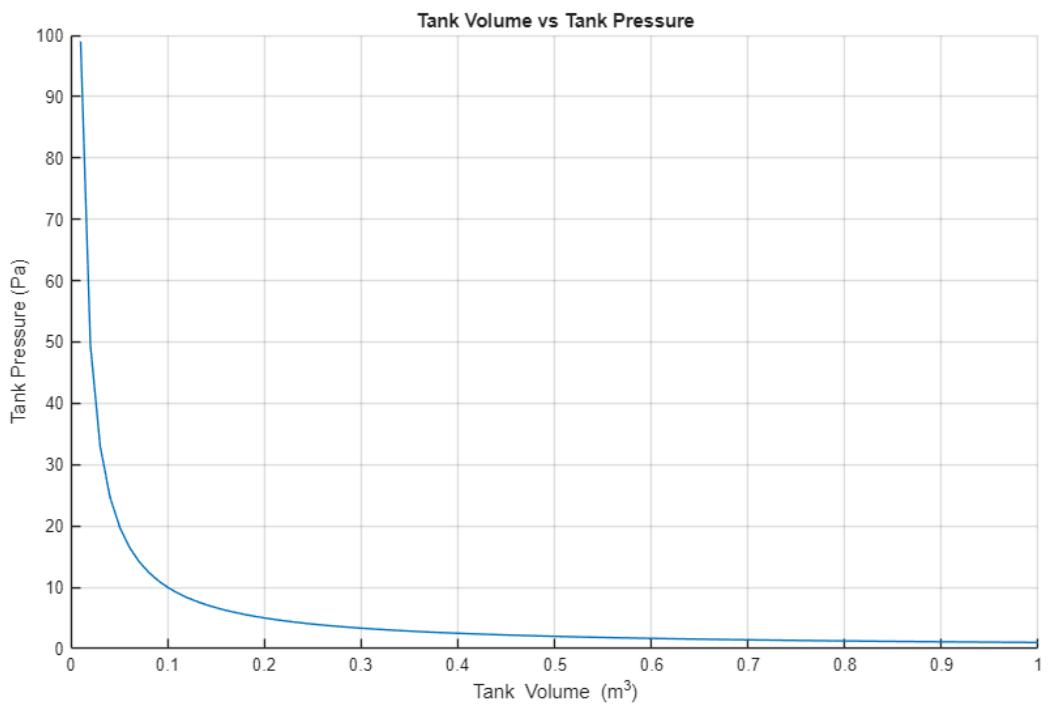
Figure: C_F vs Pc/Pe

Figure: Isp vs ϵ

Tank Volume vs Tank Pressure

Ae/At (ε) vs Pc

Question 3:

```
mdot = 0.05; %nitrogen, h2o2, hydrazine
```

```matlab
gamman2 = 1.4;
gammah2 = 1.25;
gammahy = 1.2;

Tcn2 = 300;
Tch2 = 1300;
Tchy = 1650;

Rn2 = 297;
Rh2 = 290;
Rhy = 260;

epsilon = 20;

[PcPen2, cstarn2, cfn2, Ispn2, thrustn2] = performance(gamman2, Rn2, Tcn2,
epsilon, mdot);
[PcPeh2, cstarh2, cfh2, Isph2, thrusth2] = performance(gammah2, Rh2, Tch2,
epsilon, mdot);
[PcPehy, cstarhy, cfhy, Isphy, thrusthy] = performance(gammahy, Rhy, Tchy,
epsilon, mdot);

Propellant = {'Nitrogen (N2)'; 'Hydrogen (H2)'; 'Hydrazine (Hy)'};
Gamma = [gamman2; gammah2; gammahy];
Tc = [Tcn2; Tch2; Tchy];
R = [Rn2; Rh2; Rhy];
PcPe = [PcPen2; PcPeh2; PcPehy];
cstar = [cstarn2; cstarh2; cstarhy];
cf = [cfn2; cfh2; cfhy];
Isp = [Ispn2; Isph2; Isphy];
Thrust = [thrustn2; thrusth2; thrusthy];

results = table(Propellant, Gamma, Tc, R, PcPe, cstar, cf, Isp, Thrust);

disp('----------------------------------------------');
disp(' Propellant Performance Comparison ');
disp('----------------------------------------------');
disp(results);

%c = cStar(1.4,297,298)
```

Question 4:

```matlab
% a) CEA Printout:
%
******************************************************************************
**
%
%        NASA-GLENN CHEMICAL EQUILIBRIUM PROGRAM CEA2, FEBRUARY 5, 2004
%               BY  BONNIE MCBRIDE AND SANFORD GORDON
%     REFS: NASA RP-1311, PART I, 1994 AND NASA RP-1311, PART II, 1996
%
%
******************************************************************************
```

```
**
 %
 %
 %
 %
 % ### CEA analysis performed on Tue 28-Oct-2025 01:12:05
 %
 % # Problem Type: "Rocket" (Infinite Area Combustor)
 %
 % prob case = _____8869 ro equilibrium
 %
 % # Pressure (1 value):
 % p,atm= 2
 % # Supersonic Area Ratio (1 value):
 % supar= 20
 %
 % # You selected the following reactants:
 % reac
 % name H2O2(L)              wt%=100.0000
 %
 % # You selected these options for output:
 % # short version of output
 % output short
 % # Proportions of any products will be expressed as Mass Fractions.
 % output massf
 % # Heat will be expressed as siunits
 % output siunits
 %
 % # Input prepared by this script:/var/www/sites/cearun/cgi-bin/CEARUN/
prepareInpu
 % tFile.cgi
 %
 % ### IMPORTANT:  The following line is the end of your CEA input file!
 % end
 %
 %
 %
 %
 %
 %             THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM
 %
 %          COMPOSITION DURING EXPANSION FROM INFINITE AREA COMBUSTOR
 %
 % Pin =    29.4 PSIA
 % CASE = _____
 %
 %            REACTANT                    WT FRACTION     ENERGY      TEMP
 %                                        (SEE NOTE)     KJ/KG-MOL      K
 % NAME        H2O2(L)                     1.0000000    -187780.000
272.740
 %
 % O/F=     0.00000   %FUEL=  0.000000  R,EQ.RATIO= 0.500000  PHI,EQ.RATIO=
0.000000
 %
```

6

```
%                    CHAMBER   THROAT    EXIT
% Pinf/P             1.0000    1.8079   284.05
% P, BAR             2.0265    1.1209   0.00713
% T, K               1274.54   1130.83  347.32
% RHO, KG/CU M       4.3364-1  2.7034-1 5.6024-3
% H, KJ/KG          -5520.56  -5781.47 -7039.39
% U, KJ/KG          -5987.88  -6196.10 -7166.74
% G, KJ/KG          -19324.1  -18028.6 -10800.9
% S, KJ/(KG)(K)      10.8302   10.8302  10.8302
%
% M, (1/n)           22.676    22.676   22.676
% (dLV/dLP)t        -1.00000  -1.00000 -1.00000
% (dLV/dLT)p         1.0001    1.0000   1.0000
% Cp, KJ/(KG)(K)     1.8460    1.7848   1.4318
% GAMMAs             1.2479    1.2586   1.3442
% SON VEL,M/SEC      763.7     722.4    413.7
% MACH NUMBER        0.000     1.000    4.213
%
% PERFORMANCE PARAMETERS
%
% Ae/At                        1.0000   20.000
% CSTAR, M/SEC                 1037.7   1037.7
% CF                           0.6961   1.6796
% Ivac, M/SEC                  1296.4   1816.0
% Isp, M/SEC                   722.4    1742.9
%
%
% MASS FRACTIONS
%
% H2O                0.52962   0.52963  0.52963
% *OH                0.00002   0.00000  0.00000
% *O2                0.47036   0.47037  0.47037
%
%  * THERMODYNAMIC PROPERTIES FITTED TO 20000.K
%
% NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL
OXIDANTS

% b)
% The results partially match my results from the previous question. It is
% possible they mismatch because CEA specifically calculates and accounts
% for a 2atm input pressure where my calcs do not. CEA also includes more
% advanced/specific chemistry that my method ignores. But the Cf values are
% extremely close (i got 1.78 and CEA got 1.67). The Cstar values are also
% close, i got 933 and cea got 1037.

% c)
%
******************************************************************************
**
%
%        NASA-GLENN CHEMICAL EQUILIBRIUM PROGRAM CEA2, FEBRUARY 5, 2004
%                  BY  BONNIE MCBRIDE AND SANFORD GORDON
%      REFS: NASA RP-1311, PART I, 1994 AND NASA RP-1311, PART II, 1996
```

```
 %
 %
*******************************************************************
**
 %
 %
 %
 %
 % ### CEA analysis performed on Tue 28-Oct-2025 01:10:32
 %
 % # Problem Type: "Rocket" (Infinite Area Combustor)
 %
 % prob case = _____6230 ro equilibrium
 %
 % # Pressure (1 value):
 % p,atm= 2
 % # Supersonic Area Ratio (1 value):
 % supar= 20
 %
 % # You selected the following reactants:
 % reac
 % name CH6N2(L),MMH        wt%=100.0000
 %
 % # You selected these options for output:
 % # short version of output
 % output short
 % # Proportions of any products will be expressed as Mass Fractions.
 % output massf
 % # Heat will be expressed as siunits
 % output siunits
 %
 % # Input prepared by this script:/var/www/sites/cearun/cgi-bin/CEARUN/
prepareInpu
 % tFile.cgi
 %
 % ### IMPORTANT:  The following line is the end of your CEA input file!
 % end
 %
 %
 %
 %
 %
 %              THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM
 %
 %            COMPOSITION DURING EXPANSION FROM INFINITE AREA COMBUSTOR
 %
 % Pin =    29.4 PSIA
 % CASE = _____
 %
 %              REACTANT                    WT FRACTION      ENERGY      TEMP
 %                                          (SEE NOTE)    KJ/KG-MOL       K
 % NAME         CH6N2(L),MMH                1.0000000     54200.000
298.150
 %
```

```
% O/F=    0.00000  %FUEL=  0.000000  R,EQ.RATIO= 0.000000  PHI,EQ.RATIO=
0.000000
%
%                 CHAMBER   THROAT     EXIT
% Pinf/P           1.0000   1.7649    174.21
% P, BAR           2.0265   1.1482   0.01163
% T, K             961.67   893.65    548.83
% RHO, KG/CU M   3.2447-1 2.0176-1 3.9155-3
% H, KJ/KG        1176.43   837.74  -1071.71
% U, KJ/KG         551.87   268.62  -1368.81
% G, KJ/KG       -13604.2 -12897.5  -9507.06
% S, KJ/(KG)(K)   15.3698  15.3698   15.3698
%
% M, (1/n)         12.802   13.056    15.359
% MW, MOL WT       10.973   11.351    15.359
% (dLV/dLP)t      -1.06895 -1.07498 -1.00014
% (dLV/dLT)p       1.7639   1.8870    1.0016
% Cp, KJ/(KG)(K)   8.5440   9.6574    2.3681
% GAMMAs           1.2013   1.1902    1.2973
% SON VEL,M/SEC     866.2    823.0     620.8
% MACH NUMBER       0.000    1.000     3.416
%
% PERFORMANCE PARAMETERS
%
% Ae/At                     1.0000    20.000
% CSTAR, M/SEC              1220.4    1220.4
% CF                        0.6744    1.7375
% Ivac, M/SEC              1514.5    2260.6
% Isp, M/SEC                823.0    2120.4
%
%
% MASS FRACTIONS
%
% CH4              0.13924  0.16362   0.34821
% C2H6             0.00001  0.00000   0.00000
% *H2              0.09618  0.09006   0.04373
% NH3              0.00052  0.00045   0.00016
% *N2              0.60761  0.60766   0.60791
% C(gr)            0.15644  0.13819   0.00000
%
%  * THERMODYNAMIC PROPERTIES FITTED TO 20000.K
%
% NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL
OXIDANTS

% i)
% MMH has a higher exhaust velocity and Isp than H2O2. This is because the
% molecular weight of the products of MMH are much smaller than H2O2,
% which then scales with exit velocity. Even though H2O2 burns hotter it
% is too heavy to accelerate fast enough & exit vel matters more

% ii)
% hydrazine may perform better but its reactants are very toxic compared
```

```
% to H2O2. H2O2 can decompose into water vapor and oxygen and H2O2 can
% also be cheaper.
```

Functions

```
function CF = C_f(gamma, pe_pc, Ae_At, p0_pc)
CF = sqrt( (2.*gamma.^2./(gamma-1)) .* (2./(gamma+1)).^((gamma+1)./
(gamma-1)) ...
          .* (1 - pe_pc.^((gamma-1)./gamma)) ) ...
    + (pe_pc - p0_pc) .* Ae_At;
end

function epsilon = expansionRatio(gamma, PcPe)

epsilon = ((2./(gamma+1)).^(1./(gamma-1))) .* (PcPe.^(1./gamma)) .* ...
          (((gamma+1)./(gamma-1)) .* (1 - PcPe.^((1-gamma)./gamma))).^(-0.5);

end

function c = cStar(gamma, R, Tc)
    top = sqrt(gamma*R*Tc);
    base = 2/(gamma + 1);
    bottomroot = sqrt( base^((gamma+1)/(gamma-1)) );

    c = top / (gamma * bottomroot);

end

function [PcPe, cstar, cf, Isp, thrust] = performance(gamma, R, Tc, epsilon,
mdot)

    g = 9.81;
    syms PcPe
    eq1 = epsilon == ((2./(gamma+1)).^(1./(gamma-1))) .* (PcPe.^(1./
gamma)) .* ...
          (((gamma+1)./(gamma-1)) .* (1 - PcPe.^((1-gamma)./gamma))).^(-0.5);
    sol = solve(eq1, PcPe);
    PcPe = double(sol);
    PcPe = max(real(PcPe(PcPe>1 & imag(PcPe)==0)));

    cstar = cStar(gamma, R, Tc);
    cf = C_f(gamma,1/PcPe, 20, 0 );
    thrust = mdot*cstar*cf;
    Isp = thrust/(mdot*g);

end

0.02829
144.1308
28.2901
```

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