Template 4EB00

Special Topic: The Jet Engine

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**Groep**

## Assignment 1 The adiabatic flame temperature

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| --- |
| clear all;close all;clc;  %%  warning off  abspath\_to\_generalfolder='C:\Users\s137280\Documents\tue leerjaar 2\Thermodynamics\Jet\_Engine\Matlab\General'; % absolute reference to General folder  addpath(abspath\_to\_generalfolder);  %% Load Nasadatabase  TdataBase=fullfile('General','NasaThermalDatabase');  load(TdataBase);  %% Some easy units  kJ=1e3;kmol=1e3;dm=0.1;bara=1e5;  %% Used by Nasa pols  global Runiv pref  Runiv=8.314472;  pref=1.01235e5; % Reference pressure, 1 atm!  Tref=298.15; % Reference Temperature  %% Nasa is ready  TA=300; % Initial temperature  cFuel='Gasoline'; % Proper indices to database  iSp = myfind({Sp.Name},{cFuel,'O2','CO2','H2O','N2'});    %% Determine compositions Yi of initial and final mixture and do your stuff  SpS=Sp(iSp); %% Subselection of the database in the order according to {'Gasoline','O2','CO2','H2O','N2'}  NSp = length(SpS);  Mi = [SpS.Mass];    %% determine Aircomp and Fuelcomp  Xair = [0 0.21 0 0 0.79] ; %% mole fraction  Mair = Xair\*Mi';  Yair = Xair.\*Mi/Mair;  Yfuel = [1 0 0 0 0];    x = Sp(iSp(1)).Elcomp(3); %% line 33  y = Sp(iSp(1)).Elcomp(2); %% line 34  a = (x+(y/4)); %% line 35    MO2 = Sp(iSp(2)).Mass;  MN2= Sp(iSp(5)).Mass;  MF= Sp(iSp(1)).Mass;  MCO2= Sp(iSp(3)).Mass;  MH2O= Sp(iSp(4)).Mass;    MA=a\*(MO2+(Xair(5)/Xair(2))\*MN2); %% line 43  phi = [0.125:0.025:1];  %%AFstoi = (11.035\*Mair/0.21)/Mi(1);  AF = (MA/MF)./phi; %% line 46    %% determine compositions mix AFstoi at beginning  YF = 1./(1+AF); %% line 49  YA = 1-YF; %% line 50  YO\_before = 1/(1+(Xair(5)\*MN2)/(Xair(2)\*MO2)).\*YA; %% line 51  YN2 = 1/(1+(Xair(2)\*MO2)/(Xair(5)\*MN2)).\*YA; %% line 52    %% determine compostions mix AFstoi at end  YCO2 = (YF./MF).\*x.\*MCO2; %% line 55  YH2O = (YF./MF).\*y/2.\*MH2O; %% line 56  YO2after = 1-YCO2-YH2O-YN2; %% line 57    h1 = YF.\*HNasa(TA,Sp(55))+YO\_before.\*HNasa(TA,Sp(4))+YN2.\*HNasa(TA,Sp(48)); %% line 59    %% h2 for every temperature and mixture  i=1;  for T=200:1:3000  for j = 1:length(AF)  h2(i,j) = YCO2(j)\*HNasa(T,Sp(16))+YH2O(j)\*HNasa(T,Sp(6))+YN2(j)\*HNasa(T,Sp(48))+YO2after(j)\*HNasa(T,Sp(4)); %% line 65  end  i=i+1;  end    T\_i = [200:1:3000];  for i=1:length(AF) % Compute properties for all species for TR temperature range  T\_ad(i) = interp1(h2(:,i),T\_i,h1(i)); %%line 72  end    figure(1);  plot(phi,T\_ad);  grid on;  xlabel('Equivalence ratio [-]');  ylabel('Temperature [K]');  title('Adiabatic temperature v.s. Equivalence ratio');    figure(2);  plot(AF,T\_ad);  grid on;  xlabel('Air Fuel ratio [-]');  ylabel('Temperature [K]');  title('Adiabatic flame temperature v.s. Air Fuel ratio'); |
| Code snippet |

## Explanation code snippet (formulas solved and connection with code snippet)

For a hydrocarbon fuel given by CxHy a stoichiometric reaction is expressed as (line 33-35):

Where:

This relation is used to determine the mass of each component, the total fuel and total air used (line 46)

This relation together with the previous two are used to compute the mass fractions before and after the reaction.

First is solved the mass fraction of the fuel using (line 49):

Than is solved the mass fraction of the air using (line 50):

Solving the mass fraction of Oxygen before combustion (line 51):

Solving the mass fraction of Nitrogen before/after combustion (this one stays the same) (line 52) :

Solving the mass fraction of CO2 (line 55):

Solving the mas fraction of H2O (line 56)

Mixture properties before combustion determined using f.i. (line 59)



*Yi* at the beginning consists of Ymix1.

Mixture properties at temperature range of 200-3000K after combustion determined using f.i. (line 65)



*Yi* at the end consists of Ymix2

Knowing the mass fractions before and after and due to definition of adiabatic flame temperature (line 72) :

The adiabatic flame temperatures can be determined, using the NASA tables and interpolation

## Answer

Provide the following

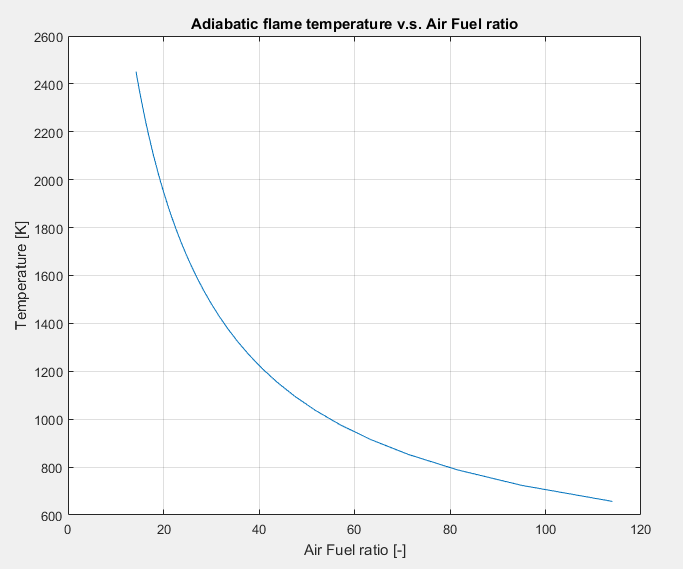
1. Figure 1 Tb vs AF and Tb vs equivalence ratio. AF range AFstoi to 8\*AFstoi .

Figure 1. Adiabatic flame temperature versus. Air Fuel ratio

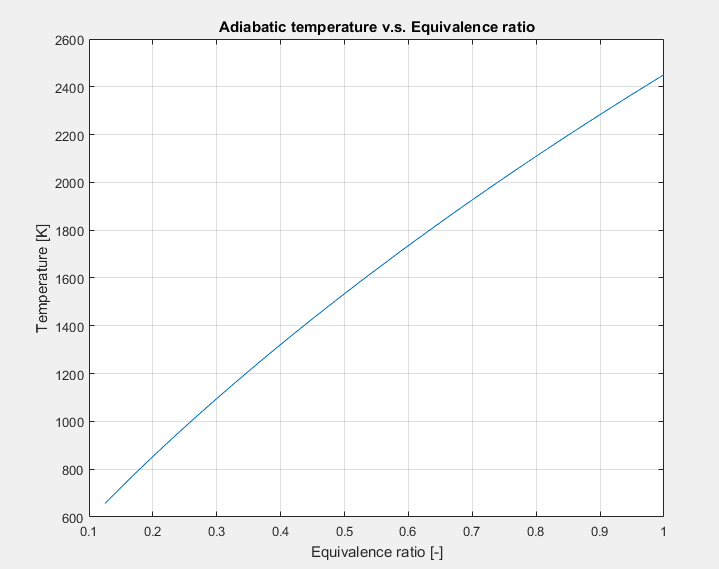


Figure 2. Adiabatic flame temperature versus Equivalence ratio

1. Tabel 1.1. ***Include the value for AFstoi (stoichiometric Air Fuel ratio) in the table header!***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | AF=AFstoi **AFstoi =14.2483** | | AF=8\*AFstoi | |
| **Mass fractions** | Initial | Final | Initial | Final |
| Fuel | 0,065581192716704 | 0 | 0.008696696343635 | 0 |
| O2 | 0,217642503251585 | 0 | 0,230891898587318 | 0.202029486095615 |
| N2 | 0,716776304031711 | 0,716776304031711 | 0,760411405069047 | 0.760411405069047 |
| CO2 | 0 | 0.210499356595360 | 0 | 0.027914237436155 |
| H2O | 0 | 0.072731316003760 | 0 | 0.009644871399183 |
| **Temp** | 298.15 | 2451.04 | 298.15 | 656.85 |
| **Table 1.1: Mixture composition and Temperature before and after combustion** | | | | |

## Assignment 2 Cycle Analysis of the Jet Engine based on Nasa tables

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| State | **1** | **2** | **3** | **4** | **5** | **6** |
| P (kPa) | 55.00 | 71.84 | 502.88 | 502.88 | 236.02 | 55.00 |
| T (K) | 250.00 | 269.88 | 468.32 | 1002.81 | 830.38 | 566.57 |
| v (m/s) | 200.00 | 0.00 | 0.00 | 0.00 | 0.00 | 761.91 |
| ***Table 2.1: Thermodynamic state summary*** | | | | | | |

Applying conservation equations and the Nasa tables fill out table 2.1. The code and approach should be explained in detail in the following pages. As an example a worked-out part is given for the diffusor (page 5)

## Diffusor

|  |
| --- |
| clear all;close all;clc;  %%  warning off  abspath\_to\_generalfolder='C:\Users\s137280\Documents\tue leerjaar 2\Thermodynamics\Jet\_Engine\Matlab\General'; % absolute reference to General folder  addpath(abspath\_to\_generalfolder);  %% Load Nasadatabase  TdataBase=fullfile('General','NasaThermalDatabase');  load(TdataBase);  %% Some convenient units  kJ=1e3;kmol=1e3;dm=0.1;bara=1e5;kPa = 1000;kN=1000;kg=1;s=1;  %% Used by Nasa pols should not be changed  global Runiv Pref  Runiv=8.314472;  Pref=1.01235e5; % Reference pressure, 1 atm!  Tref=298.15; % Reference Temperature  %% Given conditions. Take the ones from your specific case  v1=200;Tamb=250;P3overP2=7;Pamb=55\*kPa;mfurate=0.68\*kg/s;AF=71.25; % These are the ones from group 138  cFuel='Gasoline';  %% Select all species  iSp = myfind({Sp.Name},{cFuel,'O2','CO2','H2O','N2'});  SpS=Sp(iSp); % Subselection of the database in the order according to {'Gasoline','O2','CO2','H2O','N2'}  NSp = length(SpS);  Mi = [SpS.Mass];  %% Air comp  Xair = [0 0.21 0 0 0.79]; %%line 25 % Order is important  MAir = Xair\*Mi';  Yair = Xair.\*Mi/MAir; %%line 27  %% Fuel comp  Yfuel = [1 0 0 0 0]; % Only fuel  %% Range of enthalpies/thermal part of entropy of species  TR = [200:1:3000];  for i=1:NSp % Compute properties for all species for TR temperature range  hia(:,i) = HNasa(TR,SpS(i));  sia(:,i) = SNasa(TR,SpS(i));  end  hair\_a= Yair\*hia'; % enthalpy of air for range of T  sair\_a= Yair\*sia'; % thermal part of entropy of air for range of T  %% [1-2] Diffusor  sPart = 'Diffusor';  T1 = Tamb;  P1 = Pamb;  Rg = Runiv/MAir;  for i=1:NSp  hi(i) = HNasa(T1,SpS(i));  end  h1 = Yair\*hi';  v2=0; %% line 47  h2 = h1+0.5\*v1^2-0.5\*v2^2; %% line 48  T2 = interp1(hair\_a,TR,h2); %% line 49 % Not exactly correct but nearly. Why??? can also do a search  for i=1:NSp  hi2(i) = HNasa(T2,SpS(i));  si1(i) = SNasa(T1,SpS(i));  si2(i) = SNasa(T2,SpS(i));  end  h2check = Yair\*hi2'; %% line 55 % Why do I do compute this h2check value? Any ideas?  s1thermal = Yair\*si1';  s2thermal = Yair\*si2';  lnPr = (s2thermal-s1thermal)/Rg;  Pr = exp(lnPr);  P2 = P1\*Pr; %% line 60  S1 = s1thermal - Rg\*log(P1/Pref);  S2 = s2thermal - Rg\*log(P2/Pref); |
| Code snippet diffusor [1-2] |

### Procedure

**Determine**

Because of energy conservation, solved is first (line 48)



to determine *T2*

Applying isentropic compression to solve for the pressure (line 60)

.

Mixture properties determined using f.i. (line 55)



The composition *Yi* is taken equal to that of normal air.

Because of isentropic process:

S1=S2 (fig 8.19)

Also is equal to zero according to energy conservation (line 47).

## Compressor

|  |
| --- |
| %% determining fractions of the mix at the beginning.    x = Sp(iSp(1)).Elcomp(3); %% line 72  y = Sp(iSp(1)).Elcomp(2); %% line 73  a = (x+(y/4)); %% line 74    MO2 = Sp(iSp(2)).Mass; %% line 76  MN2= Sp(iSp(5)).Mass;  MF= Sp(iSp(1)).Mass;  MCO2= Sp(iSp(3)).Mass;  MH2O= Sp(iSp(4)).Mass; %% line 80    YF = 1./(1+AF); %% line 82  YA = 1-YF; %% line 83  YO\_before = 1/(1+Xair(5)\*MN2/(Xair(2)\*MO2)).\*YA; %% line 84  YN2 = 1/(1+(Xair(2)\*MO2)/(Xair(5)\*MN2)).\*YA; %% line 85    Ymix1 = [YF YO\_before 0 0 YN2]; %% line 87  Nmix1 = Ymix1./Mi;  Xmix1 = Nmix1./sum(Nmix1);  Mmix1 = Xmix1\*Mi';    Xair = [0 0.21 0 0 0.79]; % Order is important  MAir = Xair\*Mi';  Yair = Xair.\*Mi/MAir;    %%determining fractions of the mix at the end  YCO2 = (YF./MF).\*x.\*MCO2; %% line 97  YH2O = (YF./MF).\*(y/2).\*MH2O; %% line 98  YO2after = 1-YCO2-YH2O-YN2; %% line 99    Yafter = [0 YO2after YCO2 YH2O YN2]; %% line 100  Nafter = Yafter./Mi;  Xafter = Nafter./sum(Nafter);  Mafter = Xafter\*Mi';  %%[2-3 compressor]  sPart='Compressor';  P3 = P2\*P3overP2; %% line 108  s\_druk3 = Rg\*log(P3/Pref); %%s3 can be found since S2=S3 and P3 is known  s3thermal = S2+s\_druk3; %% line 110    T3 = interp1(sair\_a,TR,s3thermal); %% line 112 because we now s3thermal we can find T3.  v3=0; %%conservation of energy line 113    for i=1:NSp  hl(i) = HNasa(T3,SpS(i));  end  h3 = Yair\*hl'; %% line 118  mairflow=mfurate\*AF; %% line 121  Wincomp = mairflow\*(h3-h2); %% line 122 |
| Code snippet Compressor [2-3] |

### Procedure

Line nr. (72 till 74):

For a hydrocarbon fuel given by CxHy a stoichiometric reaction is expressed as:

Where: (line 74)

This relation is used to determine the mass of each component, the total fuel and total air used.

First is solved the mass fraction of the fuel using (line 82):

Than is solved the mass fraction of the air using (line 83):

Solving the mass fraction of Oxygen before combustion (line 84):

Solving the mass fraction of Nitrogen before/after combustion (this one stays the same) (line 85) :

The total mass fraction before combustion (line 87)

Solving the mass fraction of CO2 (line 97):

Solving the mas fraction of H2O (line 98)

Solving the mass fraction of Oxygen after combustion (line 99):

The total mass fraction after combustion (line 100):

**Determine**

Compressor ratio is given so P3 can be calculated using: (line 108):

No according to energy conservation (line113)

Because of reversible (isentropic) compression and knowing P3 , T3 can be determined using (with SNasa and interpolation) (line 112):



Mixture properties determined using f.i. (line 118)



The composition *Yi* is taken equal to that of normal air.

The mass rate of air can be calculated because the mass rate of the fuel is known (line 121)

With can be calculated. (line 122)

## Combustor

|  |
| --- |
| sPart='Combustor';  %% h3 = h4 line 132  P4=P3; %% line 133 the pressure is constant    %% T4 is adiabaticflame temperature  h\_4= Ymix1\*hl'; %% line 136  h4 = Yafter\*hia'; %% line 137  T4 = interp1(h4,TR,h\_4); %% line 138  for i=1:NSp  hl2(i) = HNasa(T4,SpS(i)); %% line 140  end  h4check = Yafter\*hl2';    for i=1:NSp  si4(i) = SNasa(T4,SpS(i));  end  s4thermal = Yafter\*si4';  s4thermal = sum(s4thermal);    %% Rg2 = Runiv/Mafter    S4 = s4thermal - Rg\*log(P4/Pref) ; %% line 152    v4 = 0; %% line energy conversation %% line 154 |
| Code snippet Combustor [3-4] |

### Procedure

**Determine and complete table 2.2**

Because of definition of adiabatic combustion h4 = h3

The mass fraction before changes from complete air to air with fuel, because fuel is added (=mix1), the temperature isn’t changed yet.

Mixture properties determined using f.i. (line 136)



The composition *Yi* is taken equal to that of normal air with the fuel (mix1).

Mix1 becomes mix2 after combustion.

Because it is an isobaric process (line 133):

Mixture properties determined at a range for T=200-3000 K using f.i. (line 137)



The composition *Yi* is taken equal to that of normal air with CO2 and H2O (mix2).

T4 can be determined by interpolation (line 138).

Energy conservation (line 154):

So equals zero

Because T4 and P4 are known, determining the entropy at stage 4 using (line 152):

The composition *Yi* is taken equal to that of normal air with CO2 and H2O (mix2).

|  |  |  |
| --- | --- | --- |
|  | **AF=71.25** | |
| **Mass fractions** | Initial | Final |
| Fuel | 0,013840830449827 | 0 |
| O2 | 0,229693739672700 | 0,183759083351967 |
| N2 | 0,756465429877473 | 0,756465429877473 |
| CO2 | 0 | 0,044425631552931 |
| H2O | 0 | 0,015349855217629 |
| **Table 2.2: Mixture composition before and after the combustor** | | |

## Turbine

|  |
| --- |
| sPart = 'Turbine';    h5 = h4check-(mairflow\*(h3-h2)/(mairflow+mfurate)); %% line 163 conservation of energy  v5 = 0; %% line 164    h\_5 = Yafter\*hia'; %% line 166  T5 = interp1(h\_5,TR,h5); %% line 167  for i=1:NSp  hi5(i) = HNasa(T5,SpS(i));  end  h5check = Yafter\*hi5';    for i=1:NSp  si5(i) = SNasa(T5,SpS(i));  end  s5thermal = Yafter\*si5';    lnPr2 = (s5thermal-s4thermal)/Rg;  Pr2 = exp(lnPr2);  P5 = P4\*Pr2; %% line 180  S4 = s4thermal - Rg\*log(P4/Pref);  S5 = s5thermal - Rg\*log(P5/Pref); |
| Code snippet Turbine [4-5] |

### Procedure

Determine

According to conservation of energy:

The total mass in and out are the same. However the mass rate which causes : is only the mass rate of air

And since: we can write (line 163):

Mixture properties determined at a range for T=200-3000 K using f.i. (line 166)



The composition *Yi* is taken equal to that of normal air with CO2 and H2O (mix2).

T5 can be determined by interpolation. (line 167).

Because of isentropic process (fig 8. 19) the pressure at stage 5 can be determined using: (line 180)



No according to energy conservation so equals zero (line 164)

## Nozzle

|  |
| --- |
| sPart = 'Nozzle';    P6 = Pamb; %%line 191  s\_druk6 = Rg\*log(P6/Pref);  s6thermal = S5+s\_druk6;  s\_6= Yafter\*sia';    T6 = interp1(s\_6,TR,s6thermal); %%line 196  for i=1:NSp  hi6(i) = HNasa(T6,SpS(i));  end  h6 = Yafter\*hi6';  v6 = (2\*(h5-h6))^0.5; %%line 201 |
| Code snippet Nozzle [5-6] |

### Procedure

**Determine**

P6 is given (line 191)

Because it’s an isentropic process, using (line 196):

To find the temperature at stage 6

Mixture properties determined using f.i. (line 200)



The composition *Yi* is taken equal to that of normal air with CO2 and H2O (mix2).

According to energy conservation:

Now it is also possible to calculate (line 201)