4EB00 Special Topic Thermodynamics and Combustion

Cycle analysis of a jet-engine

Lecture 2

Bart Somers (Combustion Technology)

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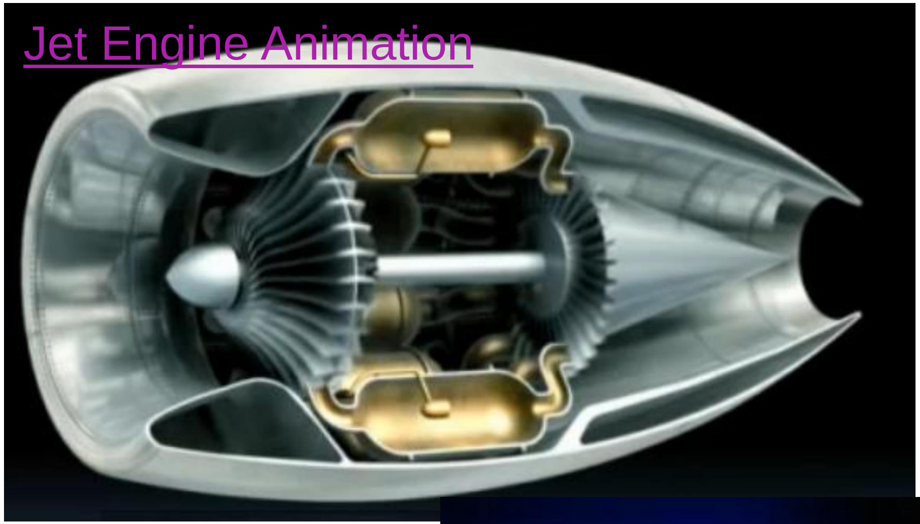
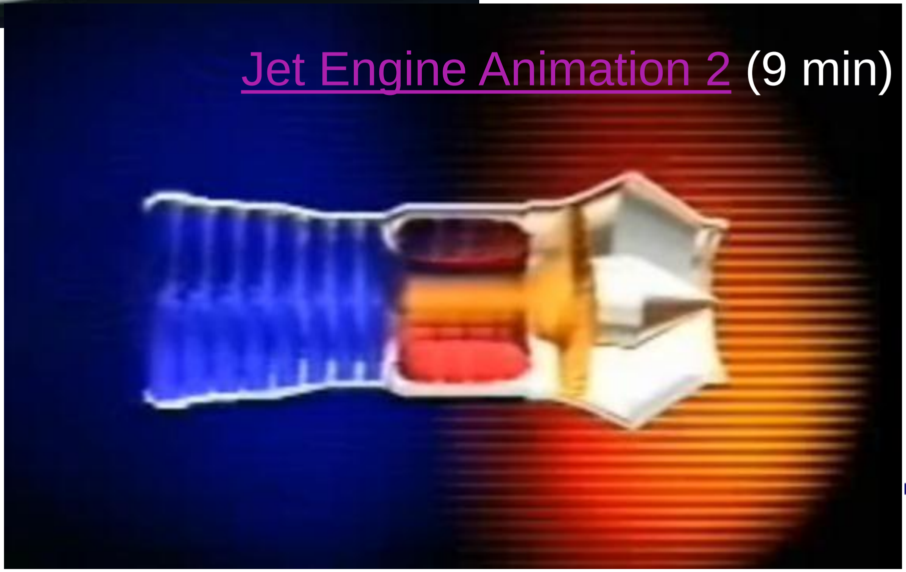
Where innovation starts

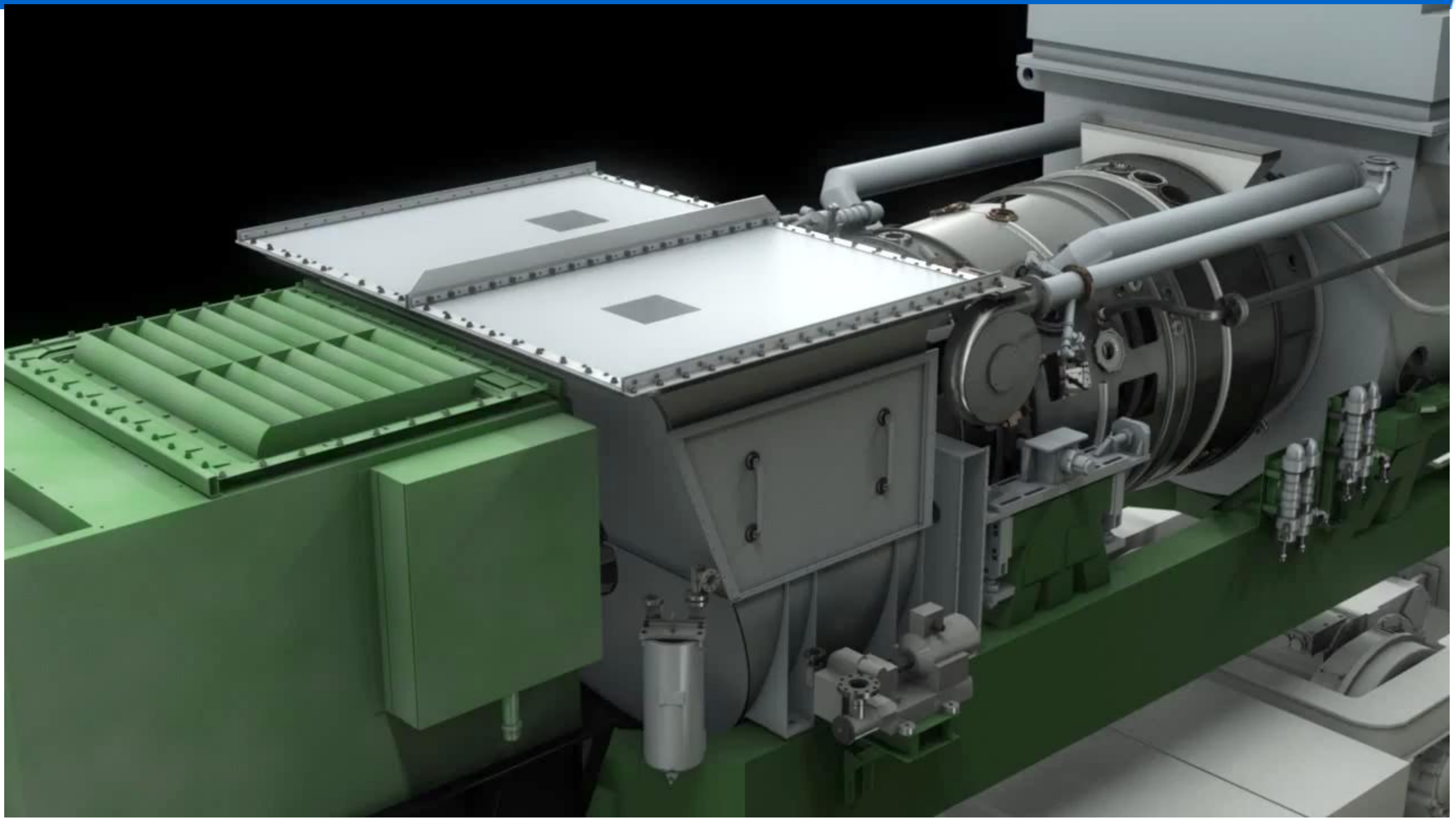
An animation



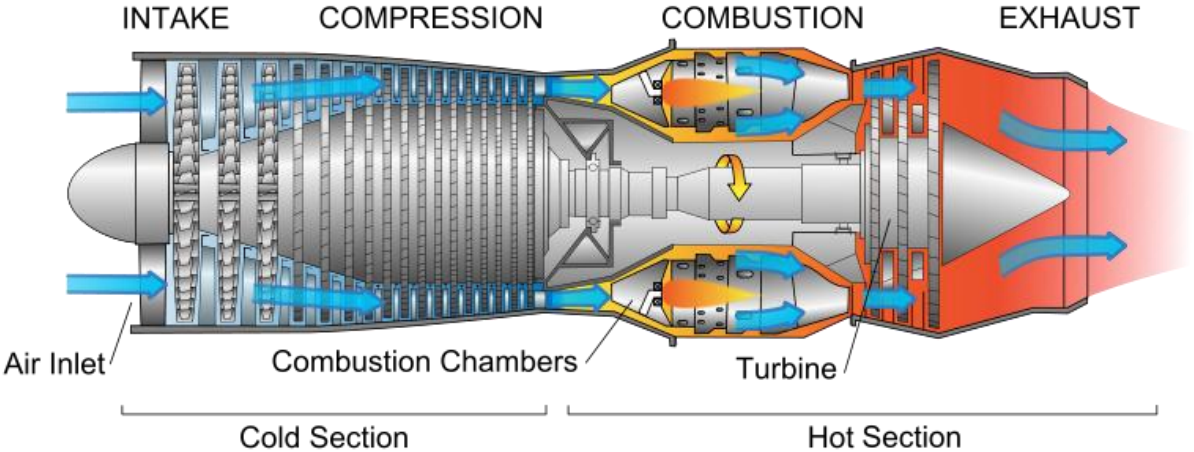
Also see youtube link to Turbo fan engines
For a nice explanation of
modern jet engines: turbo fan engines



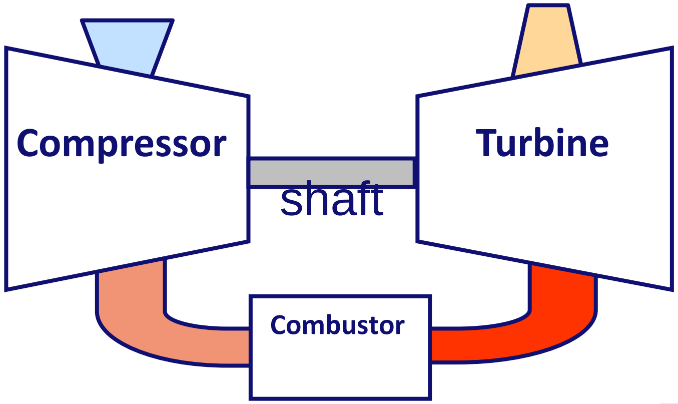
An animation of a stationary example



The Jet Engine



- **Control volume models**



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Contents

- **Ideal Gas mixtures**
  - **Thermodynamic Properties of a mixture (2.9)**
  - **Where hides combustion**
  - **Adiabatic flame temperature, an application of Nasa thermodynamic tables.**

- **Cycle analysis of a jet engine using thermodynamic tables**
  - **Combustor**
  - **Diffusor**
  - **Etc..**

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Cycle analysis of a jet engine using thermodynamic tables

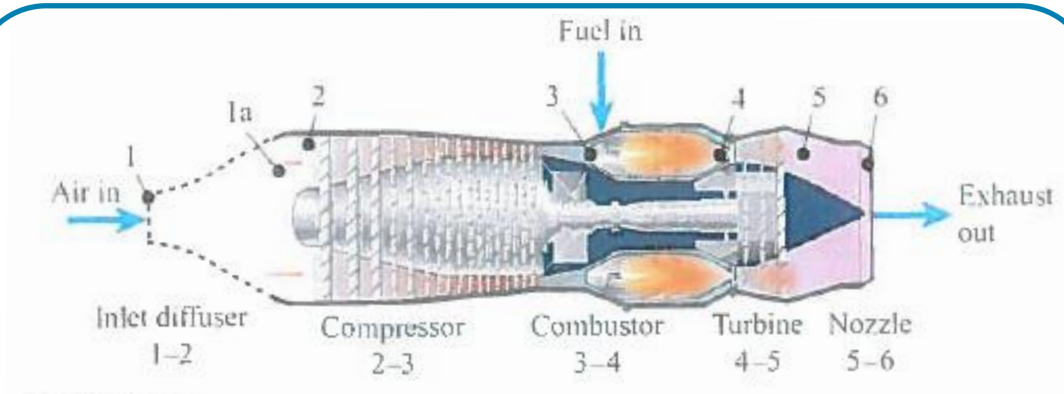

FIGURE 8.14

Using Nasa tables

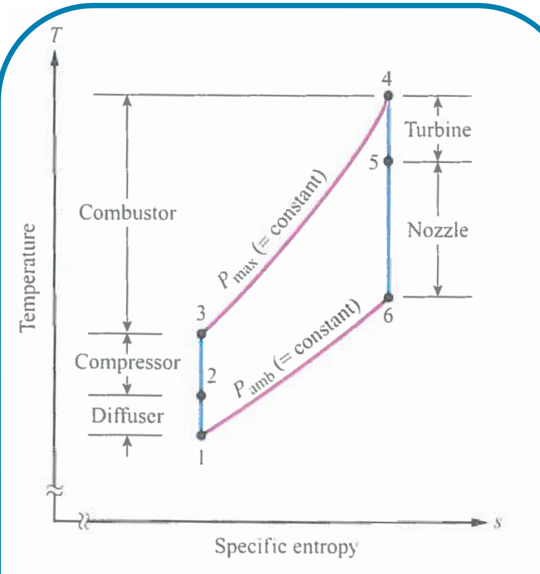

FIGURE 8.19
T–s diagram for ideal turbojet cycle. See Fig. 8.14 for definition of the diffuser (1–2).

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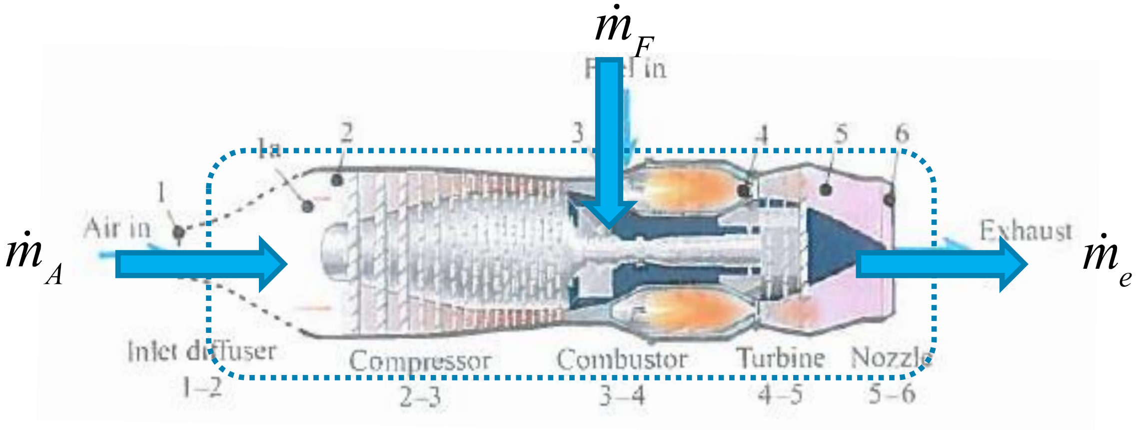
Cycle analysis of a jet engine using thermodynamic tables

- **Simple analysis. 1 control volume**



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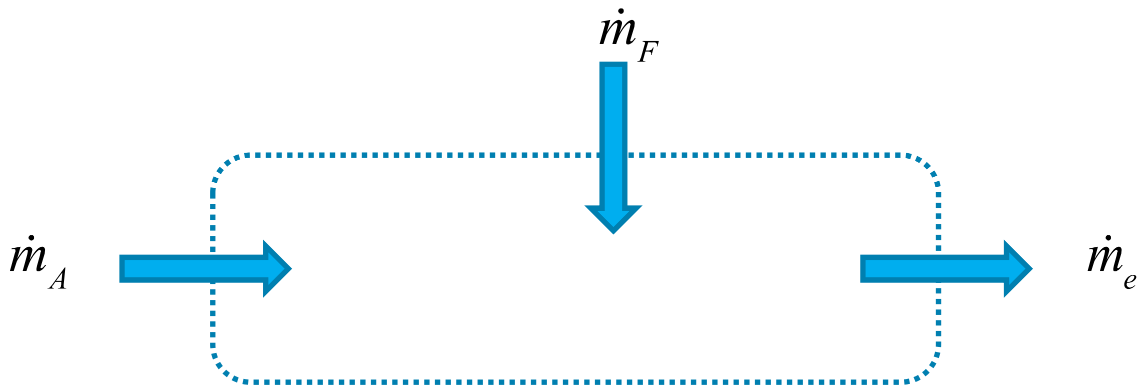
Cycle analysis of a jet engine using thermodynamic tables

- **Simple analysis. 1 control volume**



	Conservation of
$\dot{m}_A + \dot{m}_F = \dot{m}_e$	Mass
$\dot{m}_A\left(h_A + \frac{1}{2}(v_A)^2\right) + \dot{m}_F h_F = \dot{m}_e\left(h_e + \frac{1}{2}(v_e)^2\right)$	Energy

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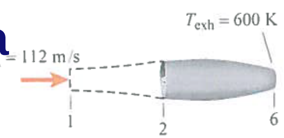
Cycle analysis of a jet engine using thermodynamic tables

Exercise 5(p547-549):

1. **create figure 8.18 using Nasa polynomials using gasoline.**
2. **Compute exit velocity v_e**

Example 8.7

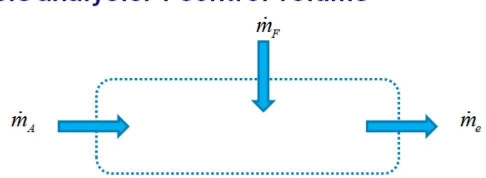


Determine the exhaust jet velocity for a turbojet engine operating with a fuel–air ratio of 1:100. The air enters the engine at 112 m/s (250 miles/hr) and 300 K (station 1 in Fig. 8.14) and the fuel enters at 300 K with negligible velocity. The temperature at the exhaust plane is 600 K. Assume the following simplified thermodynamic properties[4] for the air, fuel, and products:

i. The specific ~~heats of the fuel, air, and products are~~ constants and equal (i.e., $c_{p,F}$ = ~~$c_{p,A} = c_{p,e} = 1200$ J/kg·K).~~
ii. The enthalp~~y of formation of the air and of the~~ products is zero; the enthalpy of ~~formation of the fuel is 4 × 10^7 J/kg~~. The reference state temperature ~~is 300 K.~~

Cycle analysis of a jet engine using thermodynamic tables

- Simple analysis. 1 control volume



Conservation of	
Mass	$\dot{m}_A + \dot{m}_F = \dot{m}_e$
Energy	$\dot{m}_A\left(h_A + \frac{1}{2}(v_A)^2\right) + \dot{m}_F h_F = \dot{m}_e\left(h_e + \frac{1}{2}(v_e)^2\right)$

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Hints

- Determine $Y_{i,AF}$ to determine $Y_{i,e}$
- Compute h_{ini} for range of T
- “ h_e “
- Plot them

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Cycle analysis of a jet engine using thermodynamic tables

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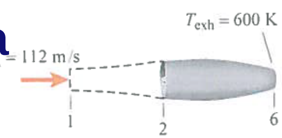

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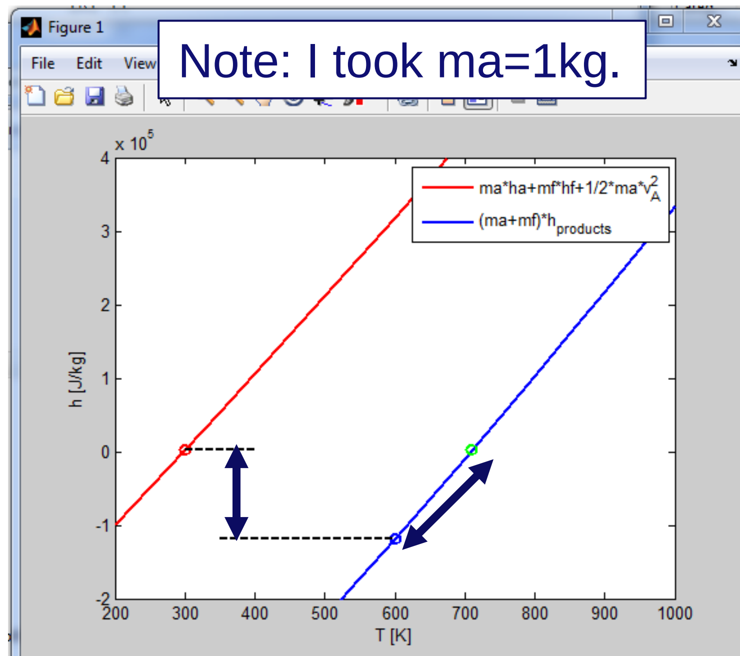
ii. The enthalpy of formation of the air and of the products is zero; the enthalpy of ~~formation of the fuel is 4×10^7 J/kg.~~ The reference state temperature ~~is 300 K.~~

	Initial Xi	Initial Yi	Final Xi	Final Yi
Gasoline	0.002704	0.009901	0.000000	0.000000
O2	0.209432	0.230611	0.178494	0.197753
CO2	0.000000	0.000000	0.020856	0.031780
H2O	0.000000	0.000000	0.017604	0.010980
N2	0.787864	0.759488	0.783046	0.759487
T	300.00	[K]	600.00	[K]
v	112.00	[m/s]	487.11	[m/s]
Book v	112.00	[m/s]	293.59	[m/s]
FA	0.01			
AF	100.00			

Different because according to database
hf = 43 MJ/kg instead of
hf = 40 MJ/kg
and
c_p = 1070 J/kg/K instead of
c_p = 1200!



Note: I took ma=1kg.

Contents

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  - Diffusor
  - Etc..

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Cycle analysis of a jet engine using thermodynamic tables

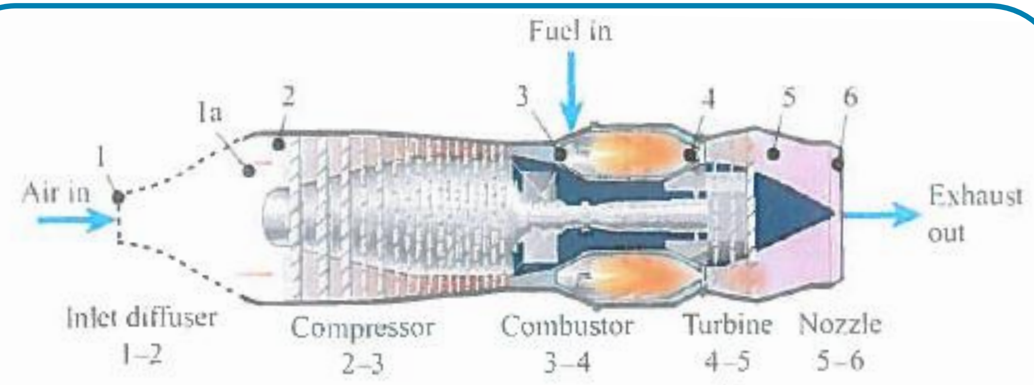


FIGURE 8.14

Using Nasa tables

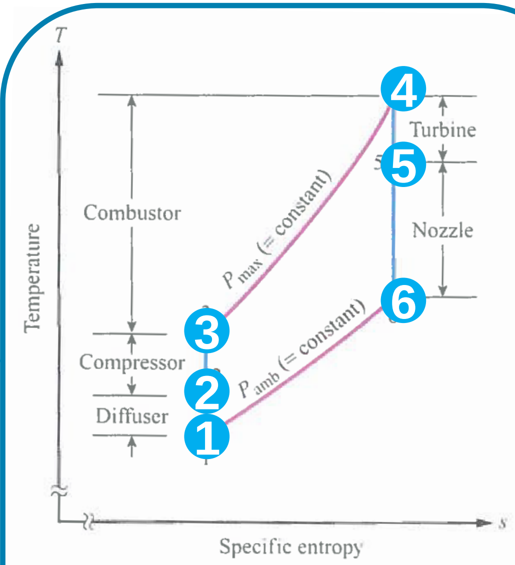
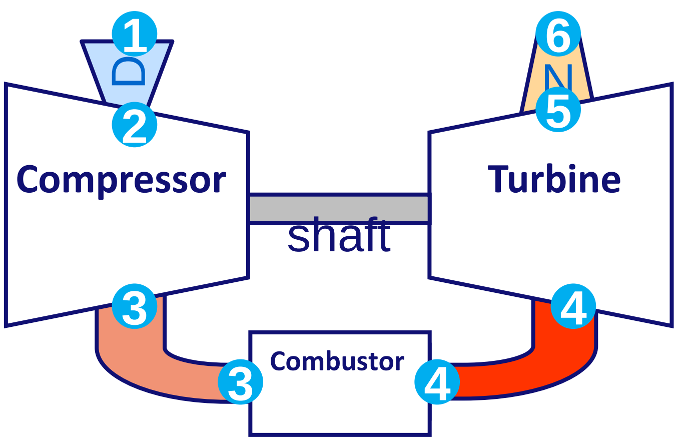


FIGURE 8.19

T–s diagram for ideal turbojet cycle. See Fig. 8.14 for definition of the diffuser (1–2).



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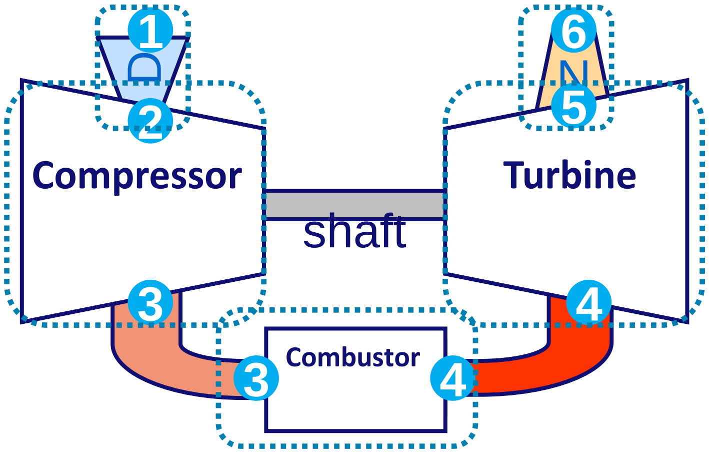
Cycle analysis of a jet engine using thermodynamic tables



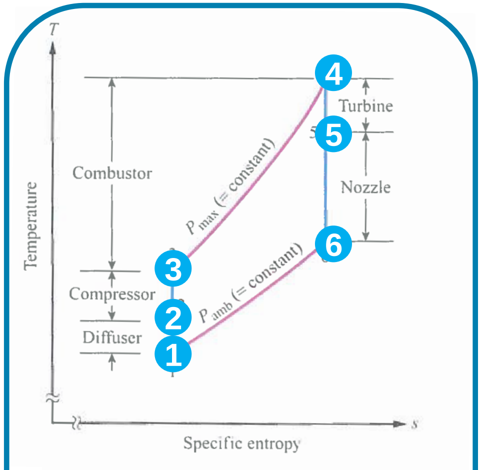


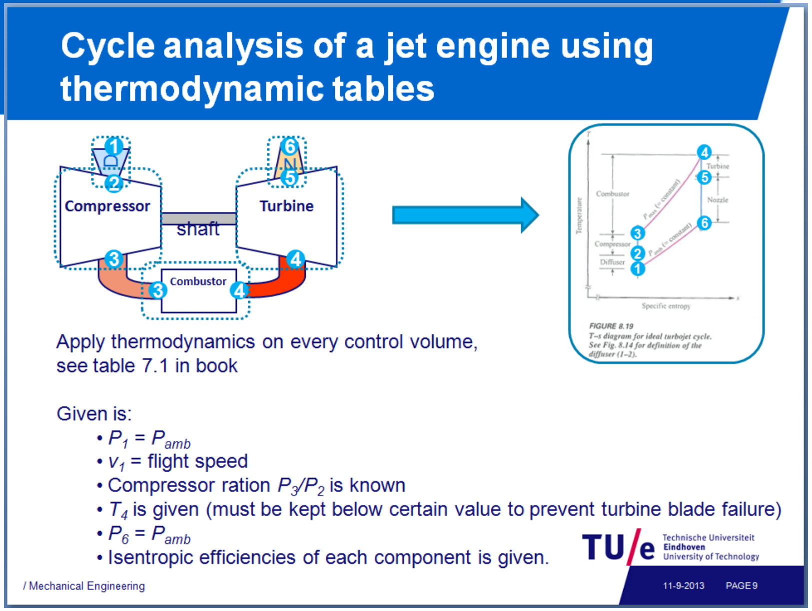
FIGURE 8.19
T–s diagram for ideal turbojet cycle. See Fig. 8.14 for definition of the diffuser (1–2).

Apply thermodynamics on every control volume, see table 7.1 in book

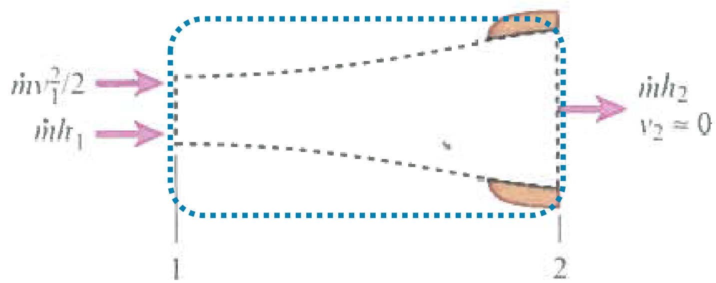
Given is:

- $P_1 = P_{amb}$
- v_1 = flight speed
- Compressor ration P_3/P_2 is known
- T_4 is given (must be kept below certain value to prevent turbine blade failure)
- $P_6 = P_{amb}$
- Isentropic efficiencies of each component is given.

Cycle analysis of a jet engine using thermodynamic tables



Diffuser 1-2:



1. Mass conservation
2. Energy conservation
3. Isentropic

1+2 : $h_2 = h_1 + \frac{1}{2}v_1^2 \longrightarrow T_2$

3 : $s_2 - s_1 = \boxed{\int_{T_1}^{T_2} \frac{c_p}{T'} dT'} - \int_{P_1}^{P_2} \frac{R_g}{P'} dP' \longrightarrow P_2$

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Cycle analysis of a jet engine using thermodynamic tables

Intermezzo: Nasa polynomials

Property	Function Name	Unit
c_p	CpNasa	[J/kg/K]
c_V	CvNasa	[J/kg/K]
h	HNasa	[J/kg]
u	UNasa	[J/kg]
s	SNasa	[J/kg/K]

1+2 : $h_2 = h_1 + \frac{1}{2} v_1^{\,2} \longrightarrow T_2$

3 : $s_2 - s_1 = \boxed{\int_{T_1}^{T_2} \frac{c_p}{T'} dT'} - \int_{P_1}^{P_2} \frac{R_g}{P'} dP' \longrightarrow P_2$

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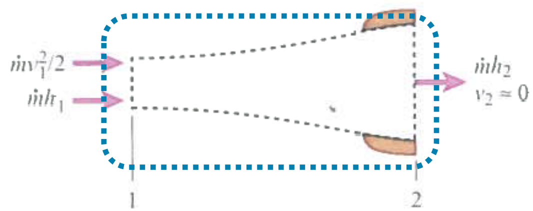
Cycle analysis of a jet engine using thermodynamic tables

Diffuser 1-2:



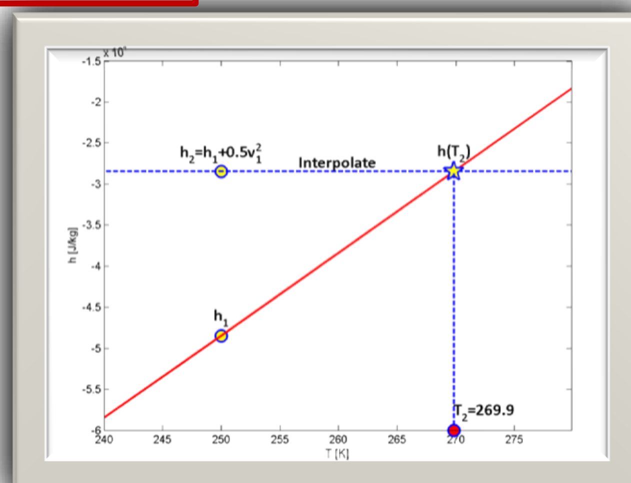
$$h_2 = h_1 + \tfrac{1}{2} v_1^2$$

$$s_2 - s_1 = \boxed{\int_{T_1}^{T_2} \frac{c_p}{T'} dT'} - \int_{P_1}^{P_2} \frac{R_g}{P'} dP'$$

Code snippet

```
%% Range of enthalpies/thermal pa
TR = [200:50:3000];
for i=1:NSp
    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 os 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';
h2 = h1+0.5*v1^2;
T2 = interp1(hair_a,TR,h2); % 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';
s1thermal = Yair*si1';
s2thermal = Yair*si2';
lnPr = (s2thermal-s1thermal)/Rg;
Pr = exp(lnPr);
P2 = P1*Pr;
```

$$SNasa(T, SpS(i)) = \int_{T_{ref}}^{T} \frac{c_{p,i}}{T'} dT'$$



Cycle analysis of a jet engine using thermodynamic tables

Assignment 2

Complete the Template for all control volumes

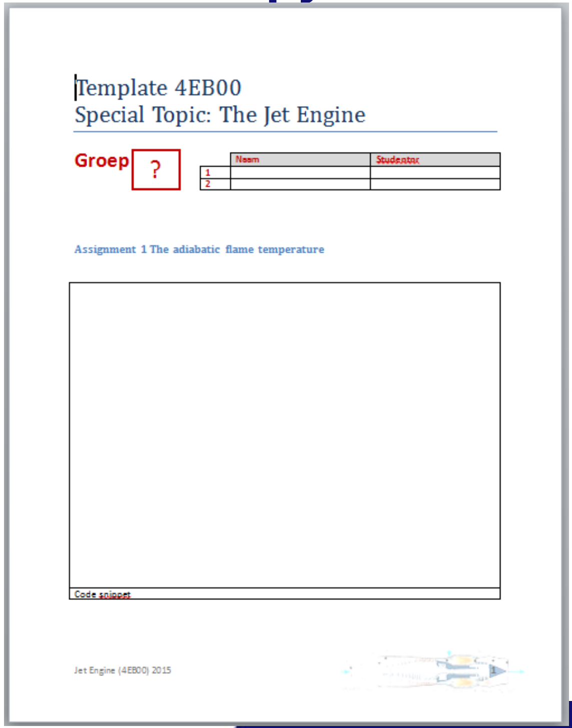
Different groups have different conditions so do not copy.

Will check some codes on copycatting.

Details matter.

Hand in hardcopy at onderwijsburo W by Thursday 22 sept.

Make sure that cover page is filled out correctly.


Template 4EB00
Special Topic: The Jet Engine

Groep ?

	Naam	Studentnr
1		
2		

Assignment 1 The adiabatic flame temperature

Code snippet

Jet Engine (4EB00) 2015