ภาควิชาวิศวกรรมเครื่องกล

คณะวิศวกรรมศาสตร์ มหาวิทยาลัยขอนแก่น

ข้อสอบปลายภาค ประจำภาคปลาย ปีการศึกษา 2552

วิชา 185 232 Thermodynamics II

วันที่ 25 กุมภาพันธ์ 2553 **เวลา 13.00-16.00 น.**

ผู้ออกและตรวจข้อสอบ: รศ.ดร.สมหมาย ปรีเปรม

คำสั่ง

1. ให้เขียน ชื่อ-สกุล กลุ่ม ห้องสอบ และ ที่นั่งสอบ ลงในกระดาษข้อสอบทุกแผ่น
2. ข้อสอบทั้งหมดมี 6 ข้อ จำนวน 7 แผ่นรวมทั้งแผ่นนี้ ให้ทำทุกข้อ
3. มีตาราง Thermodynamics แจกให้ ห้ามขีดเขียนในตารางโดยเด็ดขาด
4. อนุญาตให้ใช้เครื่องคำนวณที่ไม่มีการบันทึกข้อมูลของรายวิชานี้ไว้
5. ห้ามนำเอกสารใดๆออกจากห้องสอบ
6. ให้ทำข้อสอบในแผ่นข้อสอบของข้อนั้นๆเท่านั้น (สามารถใช้ด้านหลังได้)

ชื่อ-สกุล...รหัส .... กลุ่ม.....ห้องสอบ................ที่นั่งสอบ............

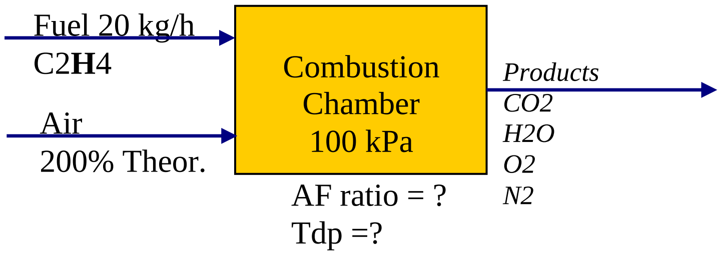
ข้อ	คะแนนเต็ม	คะแนน
1	*10*	
2	*10*	
3	*10*	
4a	*5*	
4b	*5*	
5	*10*	
6	*10*	
รวม	***60***	

Solution by Assoc.Prof.Sommai Priprem, PhD.
16 February 2010

ชื่อ-สกุล..รหัส .... กลุ่ม.....ห้องสอบ................ที่นั่งสอบ...........

1. Ethylene (C_2H_4) is burned at a rate of 20 kg/h with 200 percent theoretical air during a combustion process. Assuming complete combustion and a total pressure of 100 kPa, determine (a) the air-fuel ratio and (b) the dew-point temperature of the products. *(10 marks)*

Analysis
(a) write the chemical reaction equation at 200% theoretical air
Air Fuel Ratio, AF = mair/mfuel
(b) Tdp = Tsat @ Pv (H2O)
Ideal gas mixture: Dalton's Law:



(a) the chemical reaction equation at 100% theoretical air based on 1 kmol of C_2H_4

$$C_2H_4 + a\,(O_2 + 3.76\,N_2) \;\text{-->}\; bCO_2 + cH_2O + dN_2$$

Carbon balance:	$b =$	2		
Hydrogen balance:	$c =$	$4/2$	$=$	2
Oxegen balance:	$a =$	$(2b + c)/2$	$=$	3
Nitrogen balance:	$d =$	$3.76a$	$=$	11.28

the chemical reaction equation at 200% theoretical air

$$C_2H_4 + 2a\,(O_2 + 3.76\,N_{2)} \;\text{--->}\; 2CO_2 + 2H_2O + 1aO_2 + (1.2x3.76)aN_2$$

$$\mathbf{C_2H_4 + 6\,(O_2 + 3.76\,N_{2)} \;\text{--->}\; 2CO_2 + 2H_2O + 3O_2 + 22.56N_2}$$

*mass of air, mair = NM =(6*4.76 kmol)(28.97kg/kmol) = 827.4 kg*
mass of fuel, mfuel = NM =(1 kmol)[(12x2 + 4x1)kg/kmol]=28.0 kg
Air-Fuel ratio = (Nm)air/(Nm)fuel = 827.4/28
Air-Fuel ratio, AF = 29.55 kg air/kg fuel Answer
mFuel = 20 kg/h
$m_{Air} = m_{Fuel} * AF =$ *(20 kg/h)(19.31) =* ***591.0 kg/h Answer***

Total pressure of products = 100 kPa

Components	N	yi	Pi
	kmol		kPa
CO2	2	0.0677	6.7659
H2O	2	0.0677	6.7659
O2	3	0.1015	10.1488
N2	22.56	0.7632	76.3194
Sum	29.56	1.0000	100

Interporation: Table A-5

P (kPa)	*T (C)*
5	*32.88*
6.7659	*38.11*
7.5	*40.29*

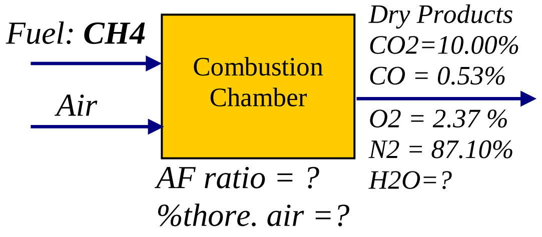
Interporation at Pv = 6.7659 kPa Tdp = 38.11 ^oC

Therefore, the dew point temperature of the products is 38.11 ^oC Answer

Solution by Assoc.Prof.Sommai Priprem, PhD.
16 February 2010

ชื่อ-สกุล..รหัส .... กลุ่ม.....ห้องสอบ................ที่นั่งสอบ...........

2) Methane (CH_4) is burned with an unknown amount of air during a combustion process. An analysis of the combustion products **on dry basis** is as follow: **CO_2 = 10.00%, CO = 0.53%, O_2 = 2.37%, N_2 = 87.10%**. Determine *(a)* the air-fuel ratio and *(b)* the percentage of theoretical air used during this process. *(10 marks)*



System: *CH_4 + Air; Combustion*
Assumption: *Ideal gas*
Analysis: *$\%n_i = \%V_i$*
$AF = m_{air}/m_{fuel}$
$\%\text{theore air} = AF_{actual}/AF_{theor.)}*100\%$
Solution
(a) ***Combustion eqn. based on 100 kmol of DRY PRODUCTS***

$$xCH_4 + a(O_2 + 3.76\,N_2) \text{ ---> } 10.00CO_2 + 0.53CO + 2.37O_2 + 87.1N_2 + bH_2O$$

C balance: $x = 10.00 + 0.53 = 10.53$
N_2 balance: $a = 87.1/3.76 = 23.16$
H_2 balance: $b = 4x/2 = 21.06$
O_2 balance: $2a = 46.33 = 2*10.00 + 0.53 + 2.37*2 + b = 46.33$ check

Divided by x to get the combustion equation based on 1 kmol of fuel

$$\boldsymbol{CH_4 + 2.20(O_2 + 3.76\,N_2) \text{ ---> } 0.95CO_2 + 0.05CO + 0.23O_2 + 2H_2O + 8.27N_2}$$

*mass of air, m_{air} = NM = (2.20*4.76 kmol)(28.97kg/kmol) = 303.4 kg*
mass of fuel, m_{fuel} = NM = (1.0 kmol)[(12+4)kg/kmol] = 16.0 kg
Air-Fuel ratio = (Nm)air/(Nm)fuel = (303.4kg)/(16kg)
*= **18.96 kg air/kg fuel** **Answer***

(b) ***Theoretical Combustion***

$$CH_4 + 2\,(O_2 + 3.76\,N_2) \text{ --> } CO_2 + 2H_2O + 2*3.76N_2$$

*mass of air, m_{air} = NM = (2.0*4.76 kmol)(28.97kg/kmol) = 275.8 kg*
mass of fuel, m_{fuel} = NM = (1.0 kmol)[(12+4)kg/kmol] = 16.0 kg
Theoretical Air-Fuel ratio = (Nm)air/(Nm)fuel = (275.8)/(16kg)
AF theoretical = 17.2372 kg air/kg fuel
%Excess air = [AFactual/AFtheoretical] x 100%
*= **(18.96kg air/kg fuel)/(17.24kg air/kg fuel)** *100*
*= **110.0 %** **Answer***

Solution by Assoc.Prof.Sommai Priprem, PhD.
16 February 2010

ชื่อ-สกุล...รหัส .... กลุ่ม.....ห้องสอบ................ที่นั่งสอบ...........

3. Benzene gas (C_6H_6) at 25°C is burned during a steady-flow combustion process with 95 percent theoretical air that enters the combustion chamber at 25°C. All the hydrogen in the fuel burns to H_2O, but part of the carbon burns to CO. If the products leave at 1000 K, determine

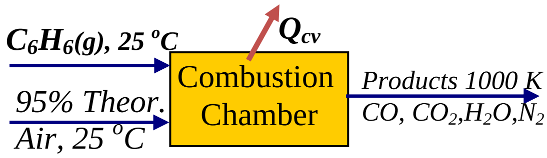
(a) the mole fraction of the CO in the products and

(b) the heat transfer from the combustion chamber during this process.

(10 marks)

System: cv combustion chamber:

Combustion: C_6H_6 + Air



%CO = ?

Q_{cv} =?

Assumptions:

1. SSSF process
2. w = 0, ΔKE=ΔPE=0
3. Air and combustion gases are ideal gas

Analysis:

1. Write the combustion equation equation based on 1 kmol of C_6H_6
2. Apply 1 st Law to determine Q_{cv}

$$Q_{cv} + \Sigma N_i \bar{h}_i = W_{cv} + \Sigma N_e \bar{h}_e$$

$$\Sigma N_i \bar{h}_i = \Sigma N_e \bar{h}_e$$

$$\Sigma N_R \{\bar{h}_f^o + (\bar{h} - \bar{h}^o)\}_R = \Sigma N_P \{\bar{h}_f^o + (\bar{h} - \bar{h}^o)\}_P$$

$$\because \text{reactants are at reference state} (\bar{h} - \bar{h}^o)_R = 0$$

$$\Sigma N_R \{\bar{h}_f^o\}_R = \Sigma N_P \{\bar{h}_f^o + (\bar{h} - \bar{h}^o)\}_P$$

Theoretical Combustion equation equation based on 1 kmol of C6H6

C_6H_6 +7.5(O_2 + 3.76 N_2) --> 6 CO_2 + 3H_2O + 28.2N_2

Combustion with 95% theoretical air

C_6H_6 +0.95*7.5(O_2 + 3.76 N_2) --> xCO_2 + yCO+ 3H_2O + zN_2

C balance:	*x + y =*	6		
O balance:	*2x + y + 3 =*	0.95*7.5*2 =14.25		
	2x + y	= 11.25		
	x	= 11.25 - 6	=	5.25
	y	= 6 - 5.25	=	0.75
	z	= 0.95*7.5*3.76	=	26.79

therefore the combustion equation is (Tp = 1,000K, so water is in vapor form)

C_6H_6 (g) +7.125(O_2 + 3.76 N_2) --> 5.25 CO_2 + 0.75 CO+ 3 H_2O(g) + 26.79 N_2

Σn in products = 5.25+0.75+3+26.79 = 35.79 kmol

% CO in products = *(n_{CO}/Σn)*100% = (0.75/35.79)*100%*

= ***2.10 %   Answer***

(b) Energy analysis of the combustion process

Reactants at 25 °C: $H_R = h^o_f(C_6H_6) = 82{,}930$ kJ/kmol

Products at 1000 K

Components	n	h^o_f	h_{1000}	h_{298}	$(h_t - h_{298})$	nh
	(Kmol)	(kJ/kmol)	(kJ/kmol)	(kJ/kmol)	(kJ/kmol)	(kJ)
CO2	5.25	- 393,520	42,769	9,364	33,405	-1,890,603.8
CO	0.75	- 110,530	30,335	8,669	21,666	-66,648.0
H2O	3.00	- 241,820	35,882	9,904	25,978	-647,526.0
N2	26.79	-	30,129	8,669	21,460	574,913.4
					Sum (Hp)	**- 2,029,864.4**

$Qcv = Hp - Hr = -2{,}112{,}794.4$ kJ/kmol fuel

$Mfuel = 78$ kg/kmol

$qcv = -2{,}112{,}794.4$ (kJ/kmol fuel)/79(kg/kmol)

$= -27{,}087.1$ kJ/kg

the heat transfer from the combustion chamber is 27,087.1 kJ/kg fuel ***Answer***

Solution by **Assoc.Prof.Sommai Priprem, PhD.**

16 February 2010

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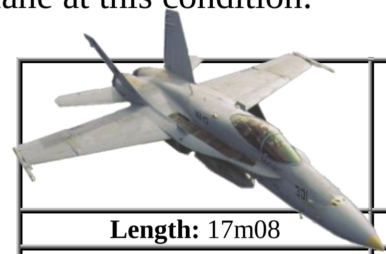
4a) Consider the F-18 Fighter plane specification. If the air temperature at the crusing altitude is about -70°C. Determine the maximum Mach number of this plane at this condition. *(5 marks)*



	Name: F/A-18 Hornet **Constructor:** McDonnell Douglas	**Armament:** 1 cannon 20 mm 2 Sidewinders 6,220 kg max payload
Length: 17m08	**Max Speed:** 1,900 km/h	**Ceiling:** 15,250 m
height: 4m63	**Weight Max:** 22,317 kg	**Range:** 3,670 km
Span: 11m44	**Crew:** 1	**Engines:** 2

System: Air, Ideal gas

Analysis: $M = V/c$

$c = \sqrt{kRT}$

Solution *Maximum speed* $= 1{,}900$ km/h

Velocity $= (1{,}900\text{km/h})*(1{,}000\text{m/km})/(3{,}600 \text{ s/h}) = 527.8$ m/s

Table A-1 for air: $R = 0.287$ kJ/kgK

Table A-2a at 300 K: $k = 1.4$

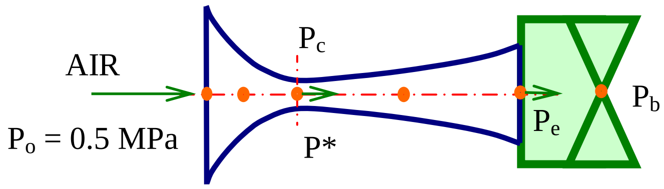
$c = \sqrt{kRT} = \sqrt{(1.4)(287 \text{ J/kgK})(273-70)\text{K}}$

$= 285.6$ m/s

$M = V/c = (527.8 \text{ m/s})/(285.6 \text{ m/s}) = 1.85$

The maximum Mach number of this plane at this condition is 1.85 Answer

4b) Air enters a converging-diverging nozzle at 0.5 MPa with a negligible velocity. Assuming the flow to be isentropic, determine **the back pressure** that will result in an exit Mach number of 1.8. *(5 Marks)*



System: *Air, Conv.-Div.Nozzle*

Assumption: *Ideal gas, constant sp.ht.*

Isentropic flow

Solution *Fluid: Air k = 1.4*

Given $P_o = 500$ kPa

$M_e = 1.8$

Table A-34, @ M=1.8 $= P/P_o = 0.17404$

$P_B = P_e = 0.17404 * P_o = (0.17404)*(500 \text{ kPa}) = 87.02$ kPa

The back pressure, P_B is 87.02 kPa Answer

Solution by Assoc.Prof.Sommai Priprem, PhD.

16 February 2010

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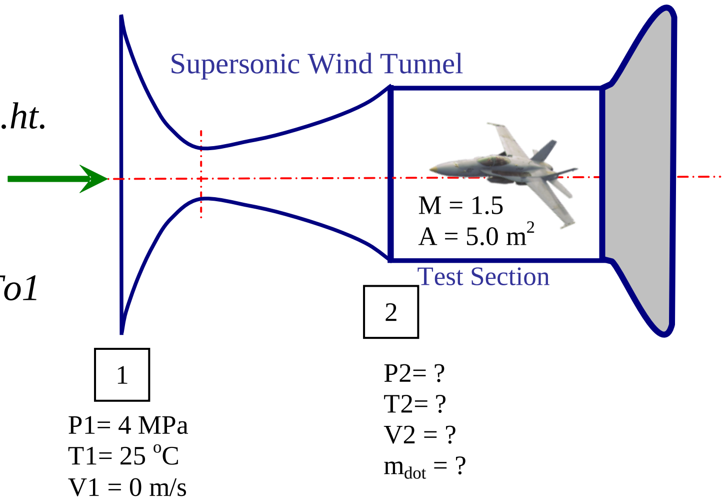
5. Consider a supersonic wind tunnel as shown in the figure below. Air enters a **converging-diverging nozzle** at 4 MPa and 25°C with a low velocity. The cross-sectional area of the test section is equal to the exit area of the nozzle, which is 5 m^2. If it is required that the velocity of the air entering the test section is one and a half time of the speed of sound (Mach number, Ma = 1.5). **Calculate** the pressure, temperature, velocity, and mass flow rate in the test section (8 marks). **Explain why the air inside this system must be very dry.** (2 marks)



System: *Air, Conv.-Div.Nozzle*
Assumption: *Ideal gas, constant sp.ht.*
Isentropic flow
Analysis: *V1= 0 then*
To1 = T1 and Po1 = P1
Isentropic flow: Po2 = Po1, To2=To1
*Mdot = Rho*A*V*
V = MC
Solution:
Po = 4 MPa = 4000 kPa
To = 25 °C = 298 K

At the exit plane
Using Table A-34 for M = 1.5, P/Po =0.27240 , and T/To = 0.68965

P_2 = 0.2724 Po = 0.2724 * 4000 kPa = **1,089.6 kPa** ***Answer***

T_2 = 0.68965 To = 0.68965 * 298 K = ***205.5 K*** ***Answer***

Table A1, A2 for air at 300K; R = 0.287 kJ/kgK and k = 1.4

Sonic velocity, c = $\sqrt{kRT}$ = $\sqrt{(1.4*(287 J/kgK)*205.5K)}$ = 287.4 m/s

Velocity, V = *Mc* = 1.5*287.4 m/s = ***431.0 m/s*** ***Answer***

Density, ρ = *P/RT* = (1,089.6 kPa)/(0.287 kJ/kgK*205.5K)
= 18.47 kg/m^3

The exit area, A = 5 m^2

The mass flow rate of air, mdot = ρAV = $(18.47\ kg/m^3)(5m^2)(431.0\ m/s)$
= ***39,813.4 kg/s*** ***Answer***

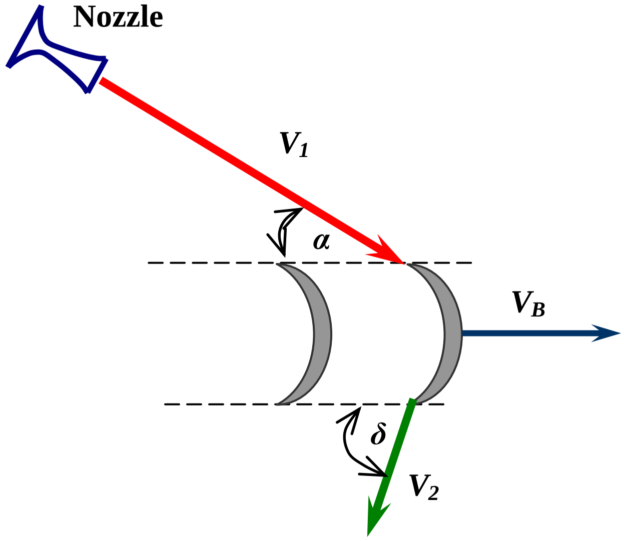
อากาศที่ไหลในอุโมงค์ลมนี้ มีความเร็วสูงมาก (เหนือเสียง) ส่งผลให้อุณหภูมิลดต่ำลงอย่างมาก เช่น ในกรณีนี้ลดลงเป็น 205 K หรือ ประมาณเกือบ -70°C ดังนั้นหากในอากาศมีความชื้น มันจะเปลี่ยนสถานะเป็นของแข็ง (น้ำแข็ง)ทันที เกล็ดน้ำแข็งนี้แม้จะมีขนาดเล็กมากแต่มันเคลื่อนที่ด้วยความเร็วเหนือเสียง นอกจากจะรบกวนกระแสอากาศทำให้การวัดปริมาณต่างๆผิดพลาดแล้ว ยังสามารถทำความเสียหายให้อุปกรณ์ต่างๆ ได้อีกด้วย ดังนั้น ใน Supersonic Wind Tunnel จึงจำเป็นต้องใช้อากาศที่แห้ง โดยกำจัดความชื้นในอากาศออกก่อน

ชื่อ-สกุล...รหัส .... กลุ่ม.....ห้องสอบ................ที่นั่งสอบ...........

6. Steam entering turbine blades with a ***velocity*** of 900 m/s and the ***angle*** is 20^{o}. The ***blade velocity, V_B*** is 300 m/s and the ***blade velocity coefficient, k_B*** is 0.7. The turbine is an ***impulse turbine*** ($P_{folw\ in\ blade}$ = constant) and the blade is ***symmetrical*** (the ***angle*** of the entering relative velocity and the leaving relative velocity are equal). Draw the velocity diagram and calculate for the mass flow of 15 kg/s,

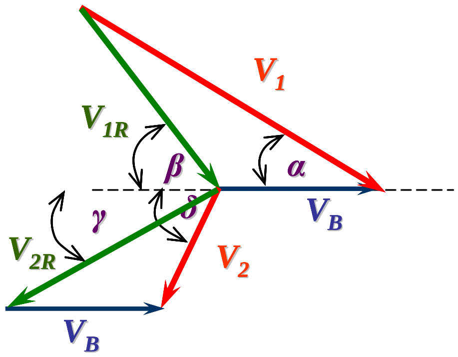
(a) the blade inlet angle
(b) the power out put of the turbine
(c) the blade efficiency (diagram efficiency)
(d) the axial thrust (assume constant x-section flow area) (10 marks)

(note: $k_B = V_{2R}/V_{1R}$*)*

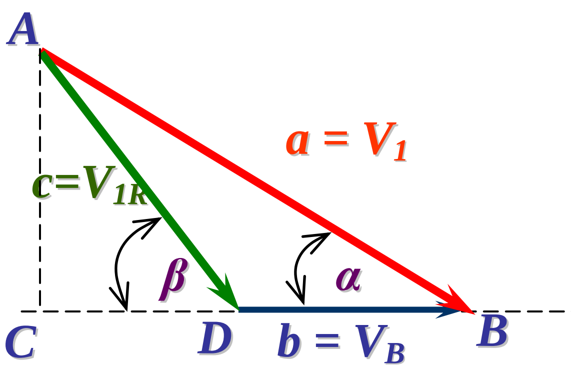


Given:

- V_1 = 900 m/s ; $\alpha = 20^o$
- V_B = 300 m/s
- $k_B = V_{2R} / V_{1R} = 0.7$



Determine: β, W, η_B, R_a



Triangle ACD: law of cosines

$c^2 = a^2 + b^2 - 2ab\cos\alpha$

$V_{1R} = c = 626.5$ m/s

Triangle ABD: law of sines

$c/\sin\alpha = a/\sin(180^o - \beta) = a/\sin\beta$

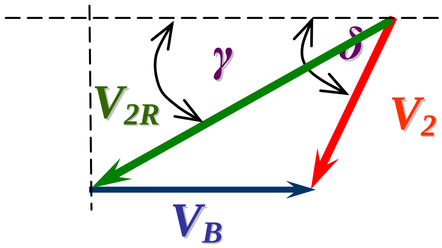
$\sin\beta = (a/c)(\sin\alpha) = 0.491$

the blade inlet angle, $\beta = \sin^{-1}(0.491) = 29.41^o$ ***answer(a)***

Tangential Thrust; $R_t = m_{dot}(V_{1R} \cos\beta + V_{2R} \cos\gamma)$

$k_B = V_{2R} / V_{1R} = 0.7 \rightarrow V_{2R} = 0.7V_{1R} = 0.7x626.5 = 438.5$ *m/s*

symmetrical blading $(\beta = \gamma)$.



$R_t = m_{dot} (626.5 \cos 29.41 + 438.5 \cos 29.41)$

$R_t / m_{dot} = 927.7$ *N/(kg/s)*

the driving force on the wheel per 1 kg/s

$R_t / m_{dot} = 927.7$ *N/(kg/s)*

the turbine power, $W_{dot} = m_{dot} V_B R_T$

$W_{dot} = (15\ kg/s)(300\ m/s)(927.7\ N/kg/s)/(1000\ W/kW) = 1{,}474.5\ kW$

the power out put of the turbine is 1,474.5 kW ***<u>answer</u> (b)***

(e) the blade efficiency, $\eta_D = w/ke_1 = W_{dot}/KE_{1dot}$

$KE_{1dot} = m_{dot} V_1^2/2 = (1kg/s)(900\ m/s)^{2/(}1000\ W/kW) = 810\ kW$

$\eta_B = (278.3\ kW)/(810\ kW)x100\% = 68.7\ \%$

the blade efficiency (diagram efficiency), η_B***, is 68.7%*** ***<u>answer</u> (c)***

Axial Thrust;

$R_a = m_{dot} (V_{2R} \sin\gamma - V_{1R} \sin\beta) - (P_1A_1 - P_2A_2)$

Impulse turbine $\rightarrow \Delta P$ *across blade = 0 ,threrfore,* $P_1 = P_2$

Symmetry blading $\rightarrow A_1 = A_2$

So $(P_1A_1 - P_2A_2) = 0$

then $R_a = m_{dot} (V_{2R} \sin\gamma - V_{1R} \sin\beta)$

$R_a = (15\ kg/s)(438.5 \sin 29.41 - 626.5 \sin 29.41)$

$= [15kg/s]*[- 92.3\ N/(kg/s)] = -1{,}384.5\ N$

The axial thrust is 1.38 kN $\uparrow$ ***<u>answer</u> (d)***

Solution by Assoc.Prof.Sommai Priprem, PhD.
16 February 2010