Combustion in Air-breathing Aero Engines
Assignment No. 3

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This assignment contains 8 multiple choice questions with 4 possible answers to each. Only one of the choice is correct and so select the choice that best answers the question. Correct choice rewards you with 1 point for each question. Wrong answers will reward you with 0 points (no negative marking). The questionnaire contains both numerical and concept-based questions. All the best!!!

Q1: Consider two fluids: A and B, to be used for two applications. One fluid will be used in bearing while other will be used in a heat-exchanger. If Pr denotes the Prandtl no. and $Pr_A > Pr_B$, then which one will you choose for what application.

1. Fluid A for bearing application; Fluid B for heat-exhanger
2. Fluid A for heat-exchanger; Fluid B for bearing application
3. Both fluids can be used for either application, effectively
4. Data is insufficient to conclude

Ans: $Pr = \frac{\nu}{\alpha}$ is the ratio of kinematic viscosity ν to thermal diffusivity α. It is a crucial parameter for determining the thickness of the boundary layers. Since, for bearing application we need the momentum to be diffused quickly, we'll use fluid A. For heat-exchanger application we need heat to diffuse quickly, hence we'll use fluid B. Thus, the correct choice is 1. Also note that the Pr for water, which is commonly used in car radiators, is 7, while for oils it is between 100 to 40,000.

Q2: Match the following in table 1 and select the correct choice.

	A		B
a.	Fick's law	p.	mass diffusion due to temperature gradient
b.	Fourier's law	q.	Thermal diffusion due to concentration gradient
c.	Soret effect	r.	Thermal diffusion due to temperature gradient
d.	Dufour effect	s.	mass diffusion due to concentration gradient

Table 1

1. a-q; b-s; c-p; d-r
2. a-s; b-r; c-p; d-q
3. a-r; b-q; c-p; d-s
4. a-s; b-r; c-q; d-p

Ans: The correct choice is 2.

Q3: Which of the following holds true? The symbols have their usual meaning as discussed in the lectures.

(a) $\Sigma Y_i \boldsymbol{V}_i = 0$

(b) $\Sigma Y_i \boldsymbol{v}_i = 0$

(c) $\Sigma Y_i \boldsymbol{v}_i = \boldsymbol{v}$

(d) $\Sigma Y_i \boldsymbol{V}_i = \boldsymbol{v}$

1. Only a.
2. Both a. and c.
3. Only b.
4. Both b. and d.

Ans: The correct choice is 2.

Q4: The following is an assertion and reasoning question. Select the correct choice from the situations given in the table 2
Assertion: For H_2-air combustion, binary diffusion approximation can be used
Reason: Diffusivity of H_2 is greater than O_2

Choice	Assertion	Reason	Remark
1.	True	True	Explanation is correct
2.	True	True	Explanation is incorrect
3.	False	True	
4.	False	False	

Table 2

Ans: The correct choice is 2. Both the assertion and reason are individually correct statements. However, the binary approximation in H_2-air combustion can be made because of the amount of N_2 is relatively more compared to H_2 and O_2.

Q5: Consider a quiescent combustible mixture in a large, closed spherical vessel. The mixture is ignited at the center at time $t = 0$ and a spherical laminar flame is formed. Let t_f and t_m denote the final time and some intermediate time ($t_m < t_f$). Which of the following assumption will you make to simplify your governing equations:

1. $\frac{\partial P}{\partial t}$ and $\boldsymbol{\nabla} P$ to be negligible for $0 \leq t \leq t_f$
2. $\frac{\partial P}{\partial t}$ to be negligible for $0 \leq t \leq t_f$
3. $\frac{\partial P}{\partial t}$ to be negligible for $0 \leq t \leq t_m$ and $\boldsymbol{\nabla} P$ to be negligible for $0 \leq t \leq t_f$
4. No assumptions can be made

Ans: Since, the combustion is subsonic and symmetric about the center of the vessel, the spatial gradients in pressure $\boldsymbol{\nabla} P$ can be neglected in consonance with low Mach no. approximation. Also, the spherical vessel is large so the change in pressure with time can also be considered negligible. However, since the vessel is closed, the temporal change in pressure cannot be neglected for the entire duration. After some time say $t_m < t_f$, the temporal change in pressure $\frac{\partial P}{\partial t}$ will no longer be negligible. Thus, the correct answer is 3.

Q6: Consider the species transport equation discussed in the class. Taking a sum over all the species on this equation gives you:

1. A more complex species transport equation
2. Statement for conservation of mass
3. Equation of no consequence
4. None of the above

Ans: The species transport equation is given by:

$$\frac{\partial \rho Y_i}{\partial t} + \boldsymbol{\nabla}.\left[\rho Y_i\left(\boldsymbol{v} + \boldsymbol{V}_i\right)\right] = w_i$$

Now taking a sum over all species i from 1 to N

$$\frac{\partial}{\partial t}\left(\sum_{i=1}^{N} \rho Y_i\right) + \boldsymbol{\nabla}.\left[\sum_{i=1}^{N} \rho Y_i \boldsymbol{v} + \sum_{i=1}^{N} \rho Y_i \boldsymbol{V}_i\right] = \sum_{i=1}^{N} w_i$$

Noting that $\sum_{i=1}^{N} Y_i = 1$; $\sum_{i=1}^{N} Y_i \boldsymbol{V}_i = 0$; and that chemical reactions do produce net change in the mass of a system, i.e., $\sum_{i=1}^{N} w_i = 0$, we get

$$\frac{\partial \rho}{\partial t} + \boldsymbol{\nabla}.\left(\rho \boldsymbol{v}\right) = 0$$

This is the continuity equation or the statement for conservation of mass. Therefore, the correct choice is 2.

Q7: The binary diffusion coefficients were derived using two approaches: a) phenomenological approach and b) collision integrals using a central force field. If the temperature is doubled for a system with a gas of two species, what will be the effect on the binary diffusion coefficients $D_{i,j}$ based on the above approaches.

1. No change in $D_{i,j}$ based on either approach
2. Based on a) $D_{i,j}$ changes by a factor of 2; in b) by a factor of $\sqrt{2}$
3. Based on a) $D_{i,j}$ changes by a factor of $\sqrt{2}$; in b) by a factor of $2\sqrt{2}$
4. In both a) and b) $D_{i,j}$ changes by the same amount $2\sqrt{2}$

Ans: Based on a) $D_{i,j} \propto \sqrt{T}$ and based on b) $D_{i,j} \propto T^{3/2}$. Therefore, the correct choice is 3.

Q8: A velocity field and density field in Cartesian space is given as:

$$\boldsymbol{v} = \frac{L}{t}\boldsymbol{i} \tag{1}$$

$$\rho = K t e^{-x/L} \tag{2}$$

where L and K are constants having dimensions of length and density divided by time, respectively. The flow field is:

1. Compressible
2. solenoidal
3. is not possible
4. Non-solenoidal

Ans: We know,

$$\begin{aligned} \frac{\partial \rho}{\partial t} + \boldsymbol{\nabla}.\left(\rho \boldsymbol{v}\right) &= 0 \\ \frac{D\rho}{Dt} + \rho\left(\boldsymbol{\nabla}.\boldsymbol{v}\right) &= 0 \end{aligned} \tag{3}$$

To assess compressibility, let us evaluate the material derivative $\frac{D\rho}{Dt}$

$$\begin{aligned} \frac{D\rho}{Dt} &= \frac{\partial \rho}{\partial t} + \boldsymbol{v}.\boldsymbol{\nabla}\rho \\ &= K e^{-x/L} + \frac{L}{t}\left(K t\left(-\frac{1}{L}\right)\right) e^{-x/L} \\ &= 0 \end{aligned}$$

Since, the $\frac{D\rho}{Dt} = 0$, the flow is incompressible or solenoidal and since Eqn.(3) is satisfied, the flow does not violate continuity. Thus, the correct choice is 2.