Analysis of preferential diffusion behavior in turbulent premixed hydrogen combustion

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Center of Excellence in Combustion

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Analysis of preferential diffusion behavior in turbulent premixed hydrogen combustion

Gabriela Sanchez Bahoque*, Jeroen van Oijen

*** g.e.sanchez.bahoque@tue.nl**

Introduction

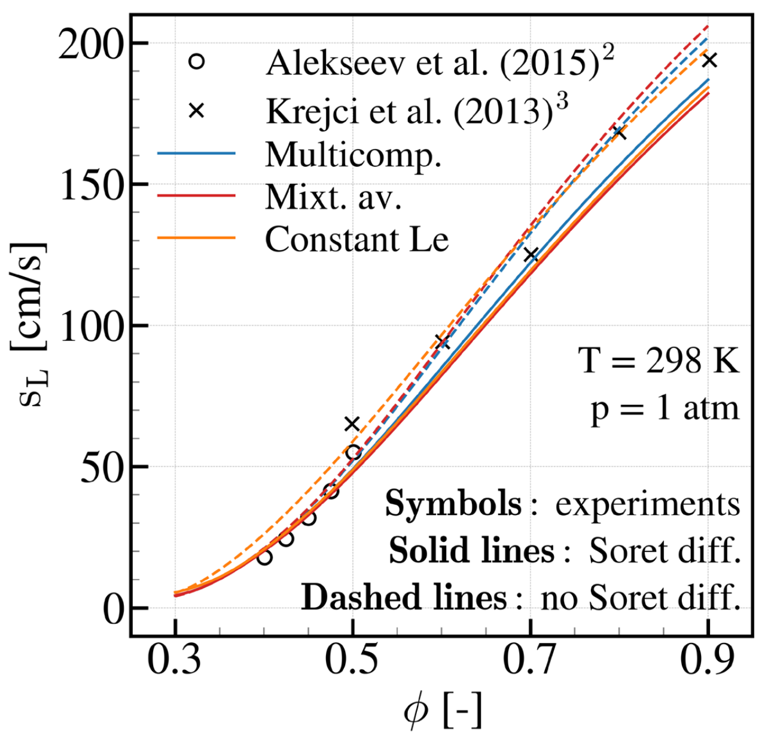
- The **Center of Excellence in Combustion (CoEC)** was created to develop advanced simulation software that support the decarbonization goals of the EU within the energy and transportation sectors[1].
- Hydrogen has become relevant as a cleaner fuel alternative.
- Combustion behaviors of H_2 are considerably different than those of hydrocarbon fuels and are still not fully understood.
- H_2 has a higher diffusivity than methane, leading to **preferential diffusion effects** and different flame dynamics.
- Objective: Investigate the interaction between H_2 premixed flames and turbulence.

Transport models

Due to the high diffusivity of H_2, it is important to choose a transport model that can predict the behavior of premixed H_2 flames accurately with a low computational cost.

The following models were studied with and without Soret diffusion: **multicomponent, mixture averaged** and **constant Lewis numbers**.

- **Flat flames**



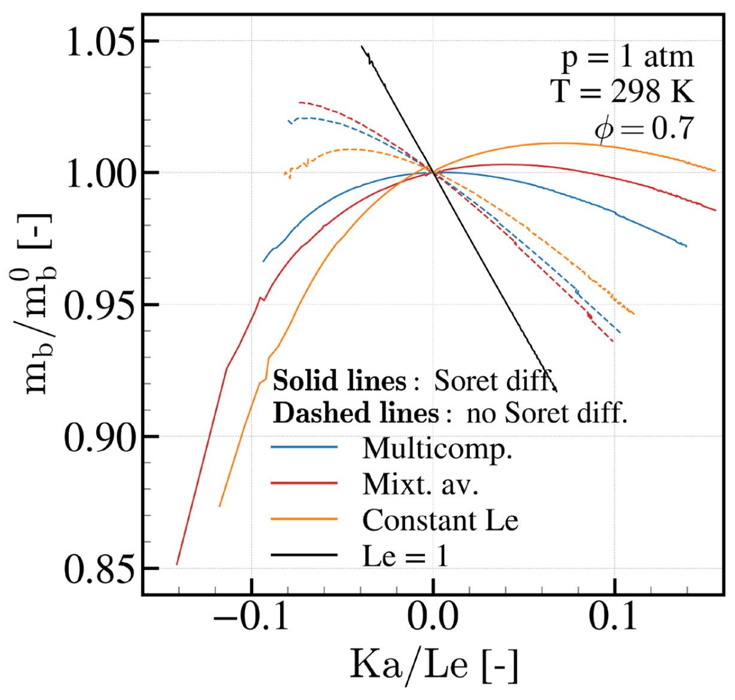
The figure at the left shows that the laminar flame speed of 1D premixed and lean H_2/air flames is well predicted by all the transport models and the reaction mechanism proposed by Burke et al. (2012)[4] when Soret diffusion is taken into account.

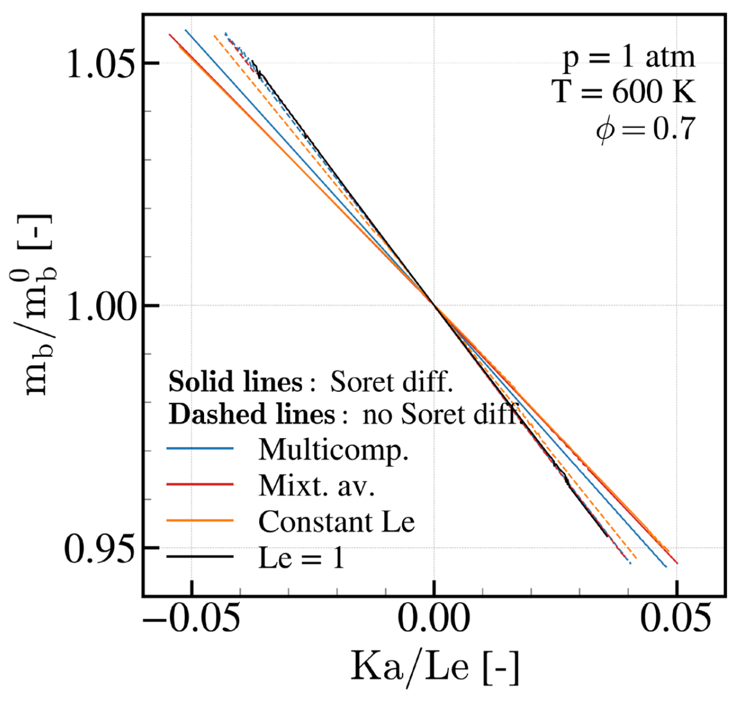
- **Stretched flames**

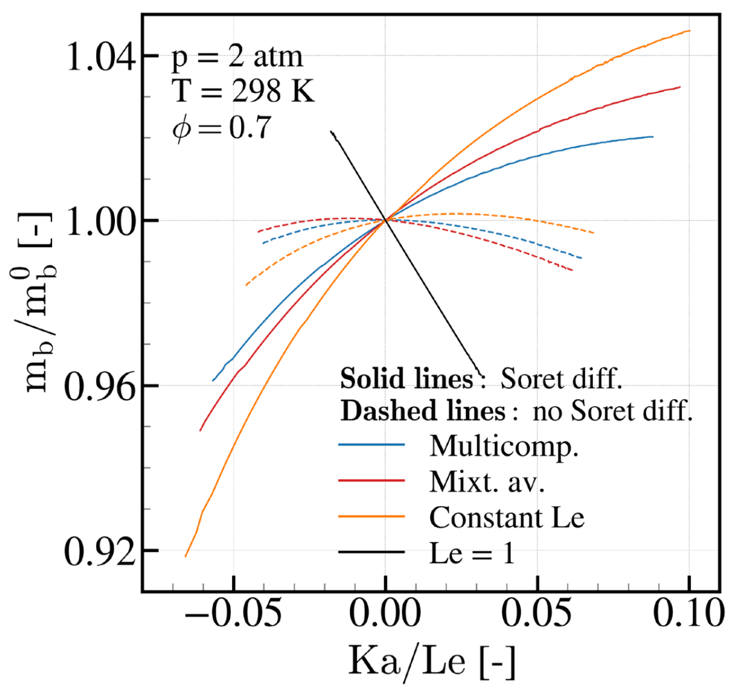
The mass burning rate of stretched H_2 flames is given by the sum of the **stretch effect** and **preferential diffusion effects**[5].

The figures at the right show the scaled mass burning rate of lean stretched H_2/air flames at different conditions vs. the Karlovitz number (dimensionless stretch rate).

- For $Le = 1$, the mass burning rate decreases with stretch, due to the direct stretch effect.
- For $Le \neq 1$, preferential diffusion effects take place and the mass burning rate increases.
- Preferential diffusion effects are diminished when increasing the inlet temperature and enhanced with pressure.







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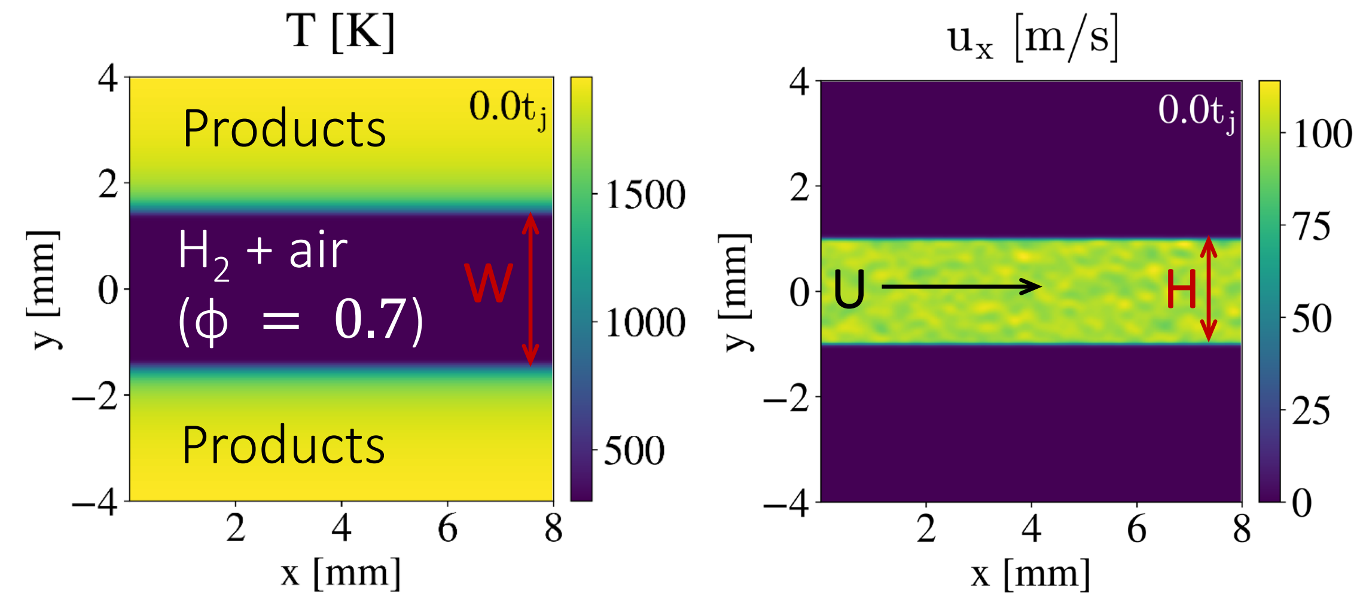
[1] Center of Excellence in Combustion. https://coec-project.eu/.
[2] Alekseev et al. (2015). Combust. Flame, 162(10): 4063-4074.
[3] Krejci et al. (2013). J. Eng. Gas Turbines Power, 135(2): 021503.
[4] Burke et al. (2012). Int. J. Chem. Kinet., 44(7): 444-474.
[5] van Oijen et al. (2016). Prog. Energy Combust. Sci., 57:30-74.
[6] Hawkes et al. (2012). Combust. Flame, 159(8): 2690-2703.

Direct Numerical Simulations

Setup: inspired by Hawkes et al. (2012)[6]



$U = 100\ m/s$

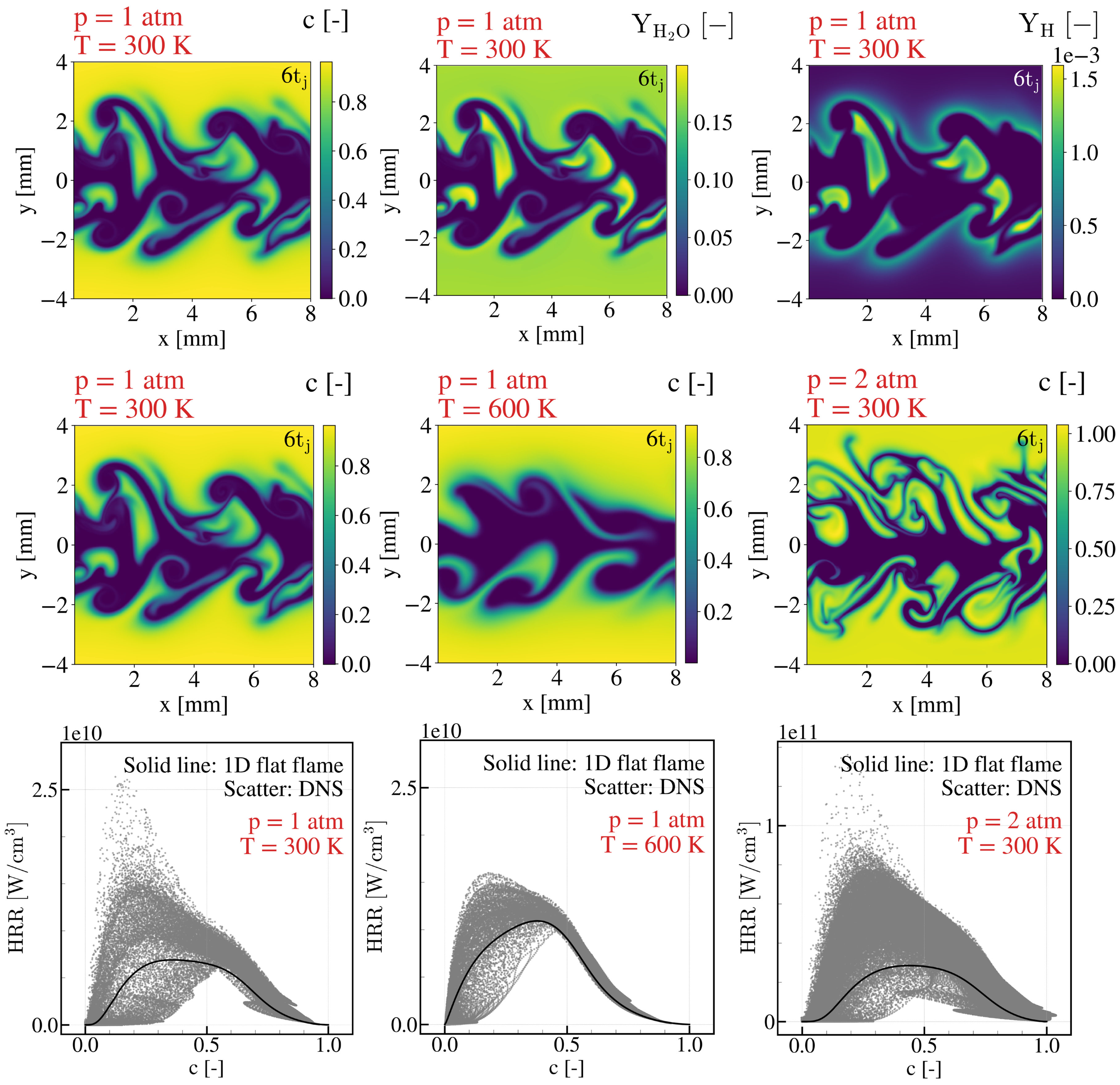
$\Delta x = 25\ \mu m$

$\Delta t = 1 \cdot 10^{-8}\ s$

Jet time $t_j = \frac{H}{U}$

Progress variable $c = \frac{T - T_u}{T_b - T_u}$

2D results



The contour plots of c, Y_{H_2O} and Y_H (first row) show the formation of flame islands where $c < 1$, and H_2O and H are accumulated, due to the higher diffusivity of hydrogen. The contour plots of c (second row) at different conditions show that preferential diffusion effects are reduced with increasing inlet temperature and intensified with pressure. The scatter plots of heat release rate (third row) show high heat release in regions with low c, due to exothermic reactions of radicals.

Conclusions

- Constant Lewis numbers with Soret diffusion is the most cost-effective transport model.
- Preferential diffusion effects take place in stretched H_2/air flames. This effects are reduced with increasing fresh gas temperature and enhanced with increasing pressure.
- Turbulence and high diffusivity of H_2 lead to the formation of flame pockets separated from the original flame front, that burn at an enhanced rate.

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Power and Flow
Department of Mechanical Engineering

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