جامعة الملك عبدالله للعلوم والتقنية
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Clean Combustion Research Center

Modelling of an hydrogen transient jet

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KAUST Research Conference: Hydrogen-Based Mobility and Power

Introduction

The decarbonization of truck and marine transportation is required. Although the power-to-weight ratio of batteries is appropriate for passenger cars, this is not the case for so-called "heavy duty" applications. Internal combustion engines fuelled by green hydrogen are a prime contender for these modes of transport.

How does it work?

- Hydrogen fuel jets injected transiently
- Spark or compression ignition
- Power production

Why hydrogen car?

- Rapid refuelling time : good customer acceptance
- Relatively cheap transition for operator
- Part of anticipated change to UK's infrastructure

The project aim is to develop a set of 1-D computer codes (MatLab) to guide experiments and formulate accessible design tools for hydrogen propagation into the combustion chamber. The codes aim to improve combustion efficiency, avoid knock or pre-ignition and low NOx emission by promoting lean mixtures through rapid mixing. Design variables include multiple injection schedules.

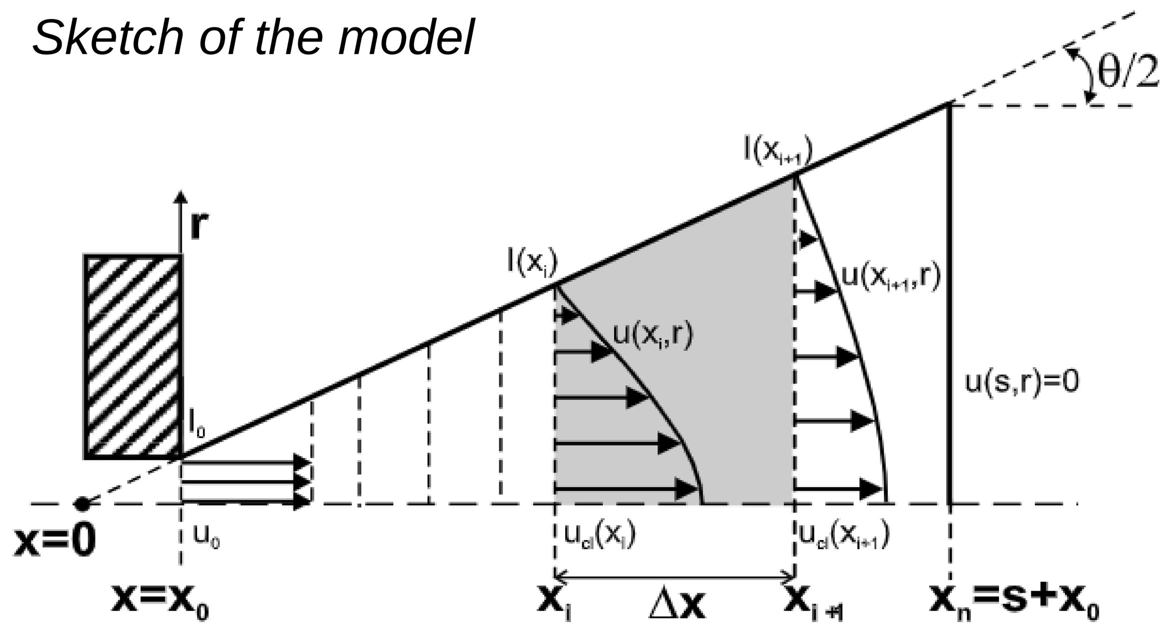
Theory

A basic analysis of a steady jet gives for the velocity u :

$$\boxed{u \propto \frac{\rho_h d_0 u_0}{x \rho_a}}$$

ρ_h: density of hydrogen
d_0 :diameter of the nozzle
u_0: inlet velocity
ρ_a: density of the combustion chamber air

Sketch of the model



Methodology

Reasoning

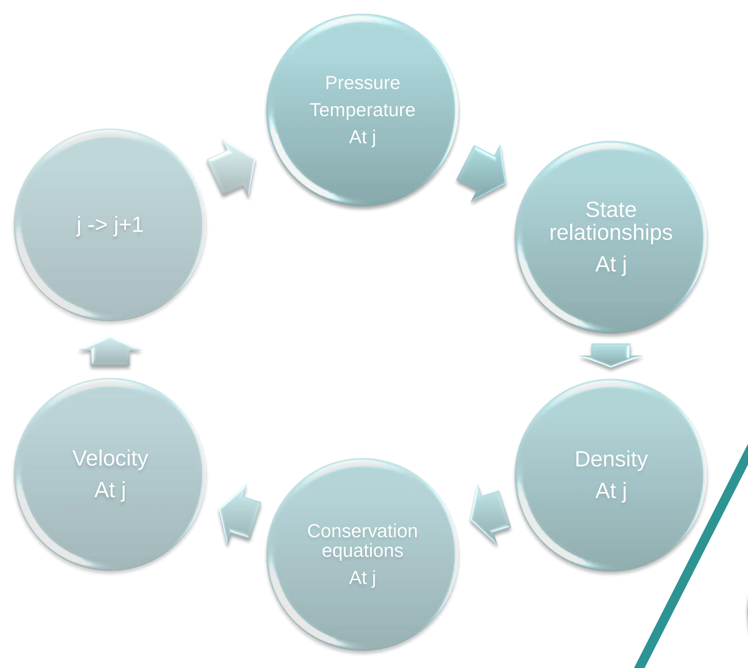
- A MatLab code for each method was developed
- Investigation on the way the different parameters influence both the steady and the transient jet
- Comparing the results from the two model
- Study how to improve the emissions from a hydrogen-fuelled engine using different injection schedules

2 MatLab codes written to predict the behaviour of the jets :

- Nozzle diameter
- Velocity inlet
- Density

Influencing

- Jet velocity
- Mixing fraction
- Tip penetration
- Entrainment rate

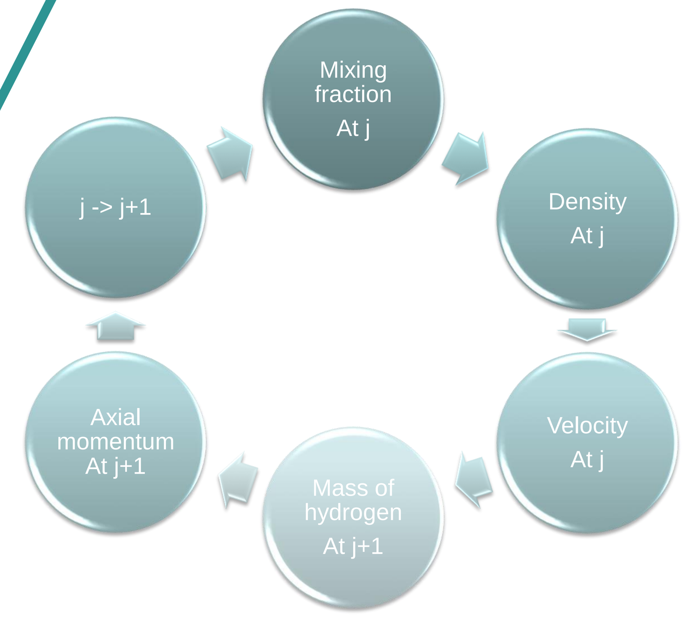


Musculus's approach [1]

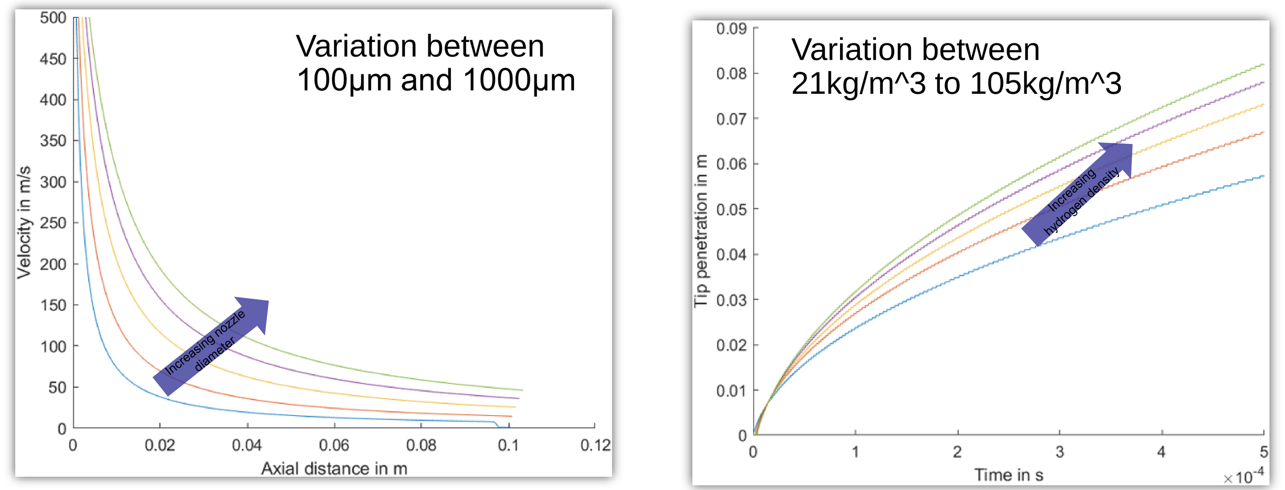
Provides a system of equation for the mass and the axial momentum

Involves the implicit solution of mass and momentum based on assumed similarity profiles

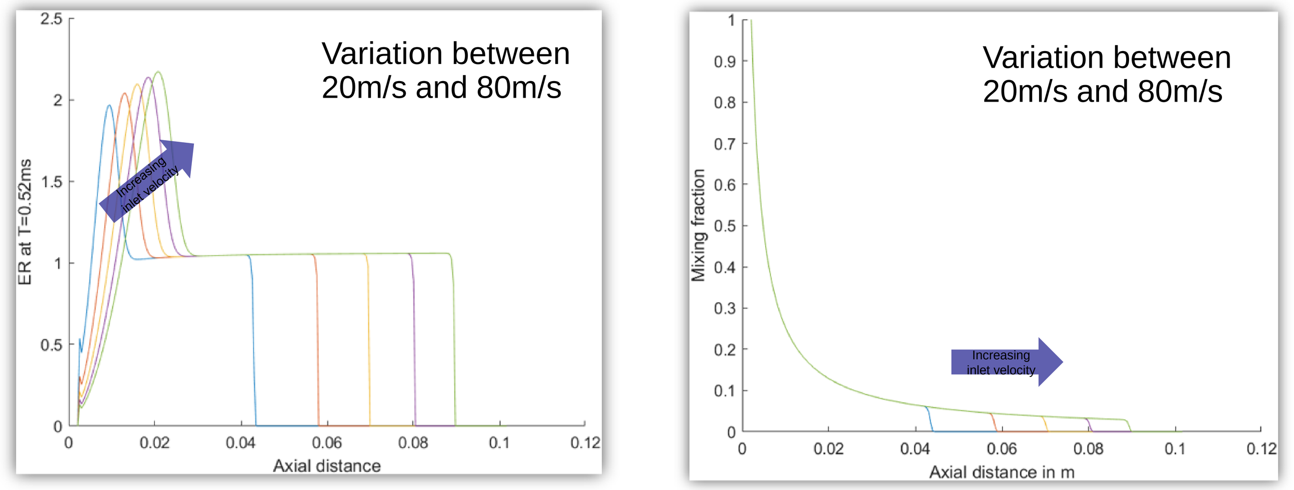
Pastor's approach [2]



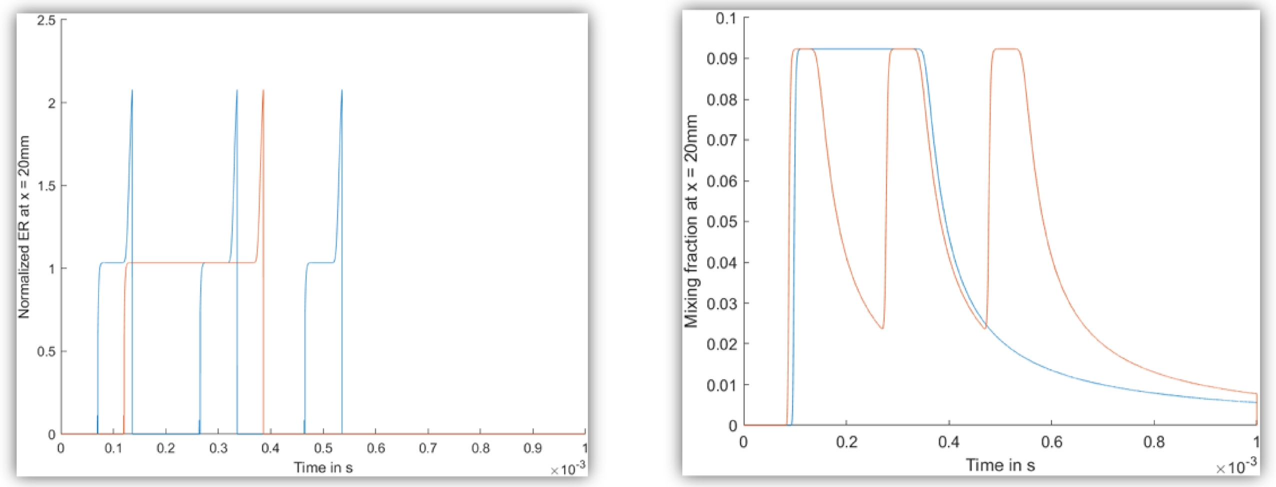
Results



Velocity for different nozzle diameter and tip penetration for different density



Entrainment rate and mixing fraction for different velocity inlet



Normalized entrainment rate at x = 20mm and mixing fraction at x = 20mm

We clearly observe that globally, the 2 models predict the same behaviour of the jets. However for further analyse we face a trade off between the accuracy and the time to run the simulation.

- The bigger the inlet velocity is, the bigger is the velocity, tip penetration and entrainment rate
- The bigger the nozzle diameter, the bigger is the velocity, mixing fraction, tip penetration and the entrainment rate
- The bigger the ratio hydrogen density / air density is, the better is the velocity, tip penetration and the entrainment rate

Injection strategy

We observed that the average mixing fraction is 12% bigger for the strategy with many pulses whereas the average entrainment rate is 40% bigger

Better to inject many small pulses than a big one (till 15 pulses in other combustion engine):
- Bigger mixing fraction (up to 15/20% for some configuration)
- More entrainment wave inducing a better mixing (up to 100% for 10 pulses)

Therefore we obtain a better combustion which allows a leaner mixture fraction, inducing a lower temperature and NOx.

Models Comparison

Musculus's approach

- Easier to implement
- Faster to run
- Slightly higher velocity predicted

Pastor's approach

- More accurate
- Possibility to compute more parameters
- More stable
- Heavy computation

Summary

If increasing the nozzle diameter, inlet velocity or hydrogen density allow us to obtain a more powerful jet and penetrating over a bigger distance, other strategies could induce a better combustion.
Indeed, a precise calibration of the injection with a series a short pulses is much more efficient to get a better mixing, so a better combustion, so less emissions, so a car greener !

References
[1]: Mark P. B. Musculus and Kyle Kattke (2009) Entrainment Waves in Diesel Jets. *SAE International*. [In press] URL: https://www.jstor.org/stable/10.2307/26308462
[2]: José V. Pastor, J. Javier López, José M. García, José M. Pastor (2008) A 1D model for the description of mixing-controlled inert diesel sprays. *Fuel.* [In press] doi:10.1016/j.fuel.2008.04.017