Thermo-acoustic Fenomena in Hydrogen-Ammonia Flames

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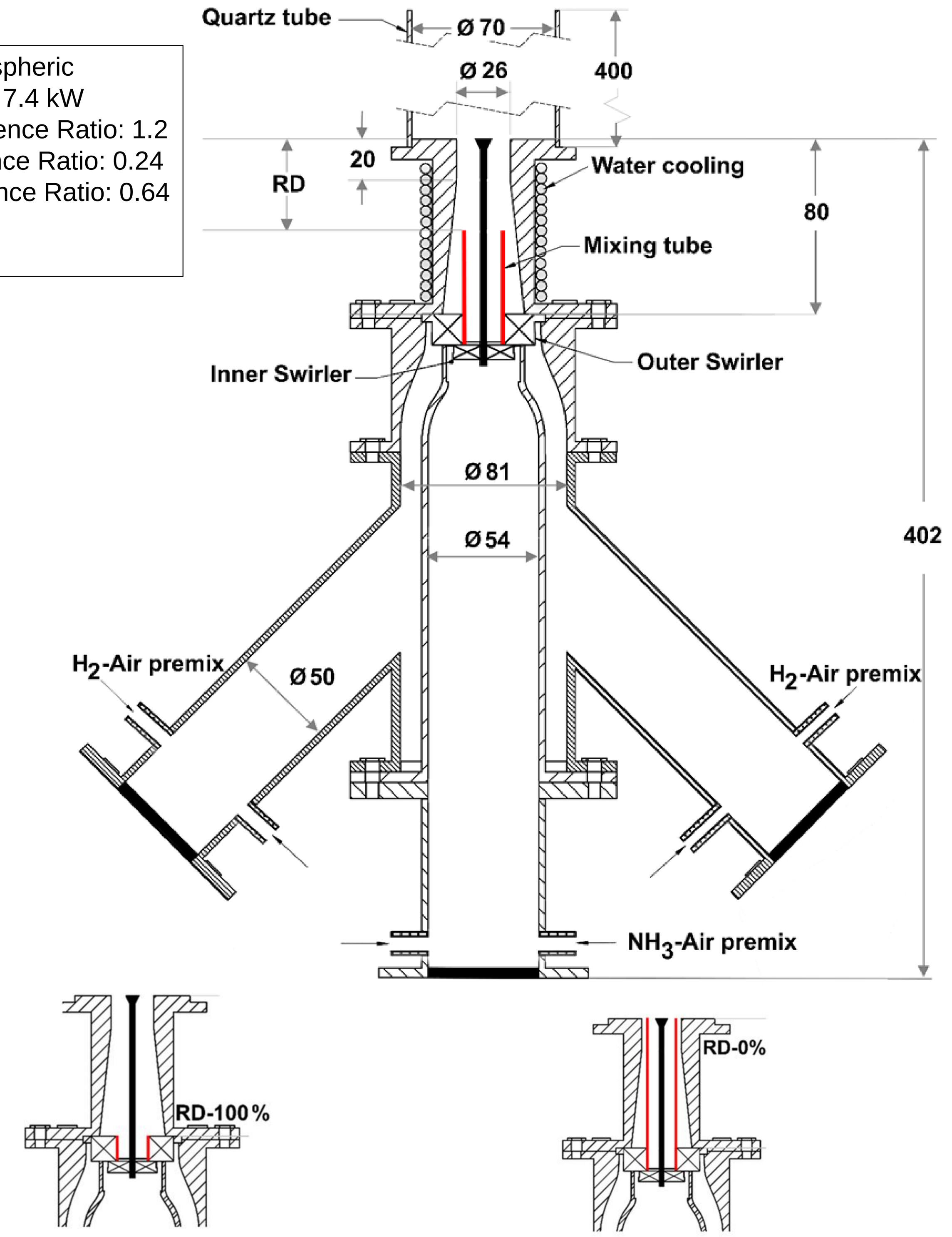
Introduction

- To be burned in gas turbine engines, hydrogen and ammonia should first be evaluated in terms of risk of thermo-acoustic instabilities.
- The overall acoustic response of a combustor is composed of its pure acoustic modes along with a thermo-acoustic mechanism intrinsically linked to the flame (ITA).
- In this study, the acoustic behavior of a dual-swirl hydrogen-ammonia burner is investigated at atmospheric pressure.
- The shape of the flame and the presence of ITA modes is studied by altering the mixing level between ammonia and hydrogen prior to injection into the combustion chamber.

Experimental Setup

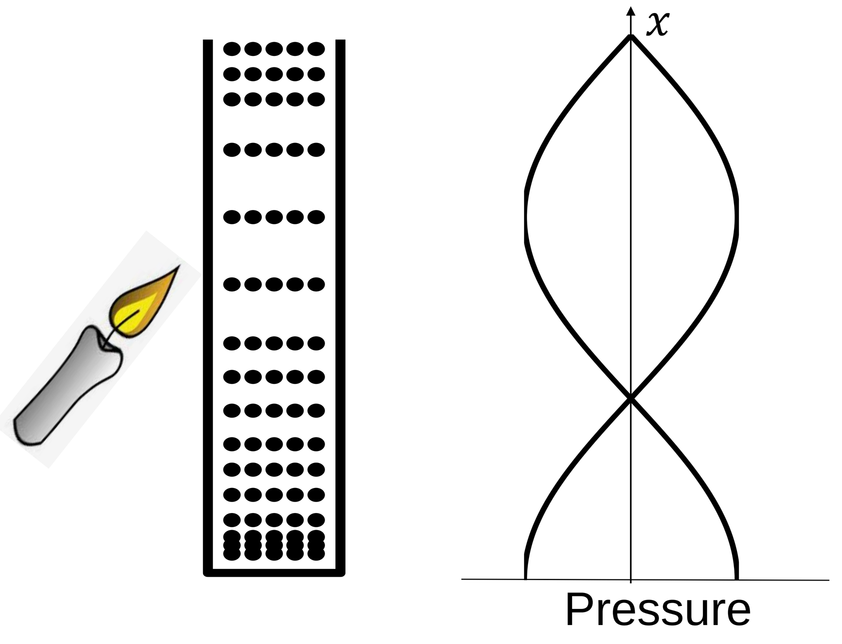
Pressure: Atmospheric
Thermal Power: 7.4 kW
NH_3-Air Equivalence Ratio: 1.2
H_2-Air Equivalence Ratio: 0.24
Global Equivalence Ratio: 0.64
V_{bulk} = 8.3 m/s
V_{bulk} = 9.7 m/s



Combustion Instability Mechanism

Pure Acoustic Modes

- When a flame heats a gas filled cavity, pressure waves are generated. These waves are partly reflected at the exit boundary of the combustion chamber, from where they travel back. This results in a standing wave at a frequency corresponding to an acoustic mode of the system.
- The acoustic frequency ω can be calculated by solving the wave equation for the pressure P with the appropriate boundary conditions:



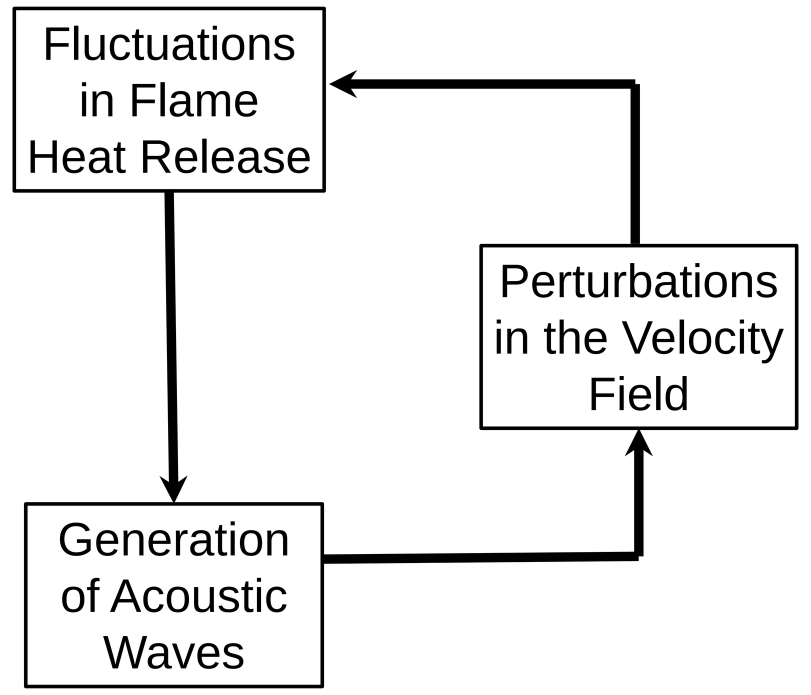
Wave equation: $\frac{\partial^2 P}{\partial t^2} = c^2 \frac{\partial^2 P}{\partial x^2}$

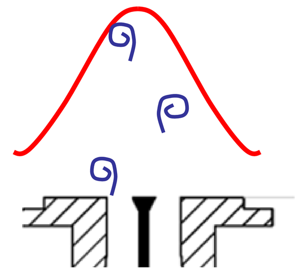
Boundary Conditions: $\begin{cases} P(0,t) = maximum \\ P(L,t) = 0 \end{cases}$

$$\Rightarrow \omega = \omega(Temperature, Length)$$

Intrinsic Thermoacoustic (ITA) Modes

- Perturbations in the bulk velocity affects the heat release of the flame. As a consequence, acoustic waves are generated and feed back the velocity field, closing the loop.
- This mechanism is related to the flame itself and does not depend on the length of the combustor. Instead, it is sensitive to the bulk velocity and the length of the flame.





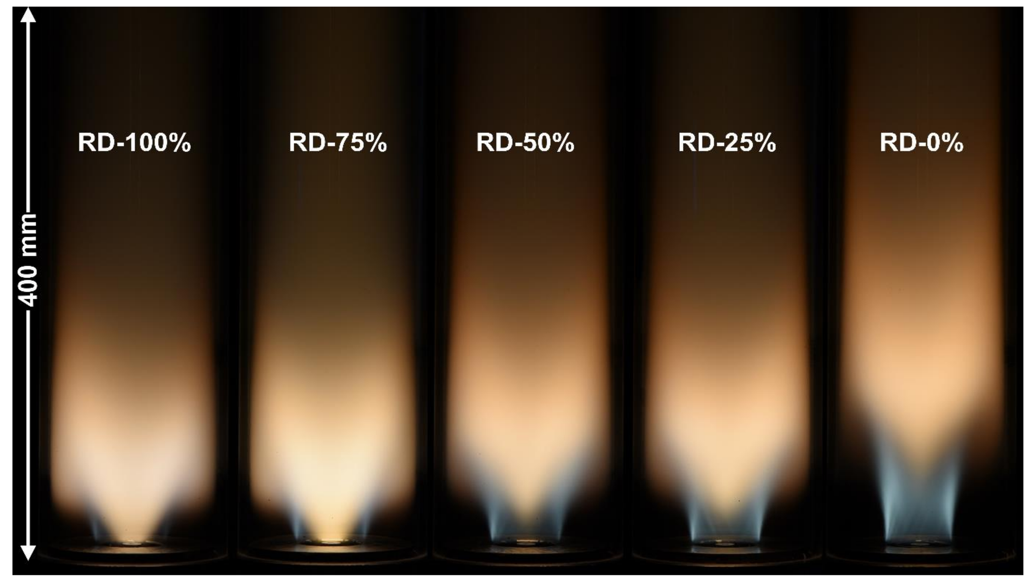
$$t_{base\ to\ flame\ front} = \frac{L_{Flame}}{V_{Bulk}}$$

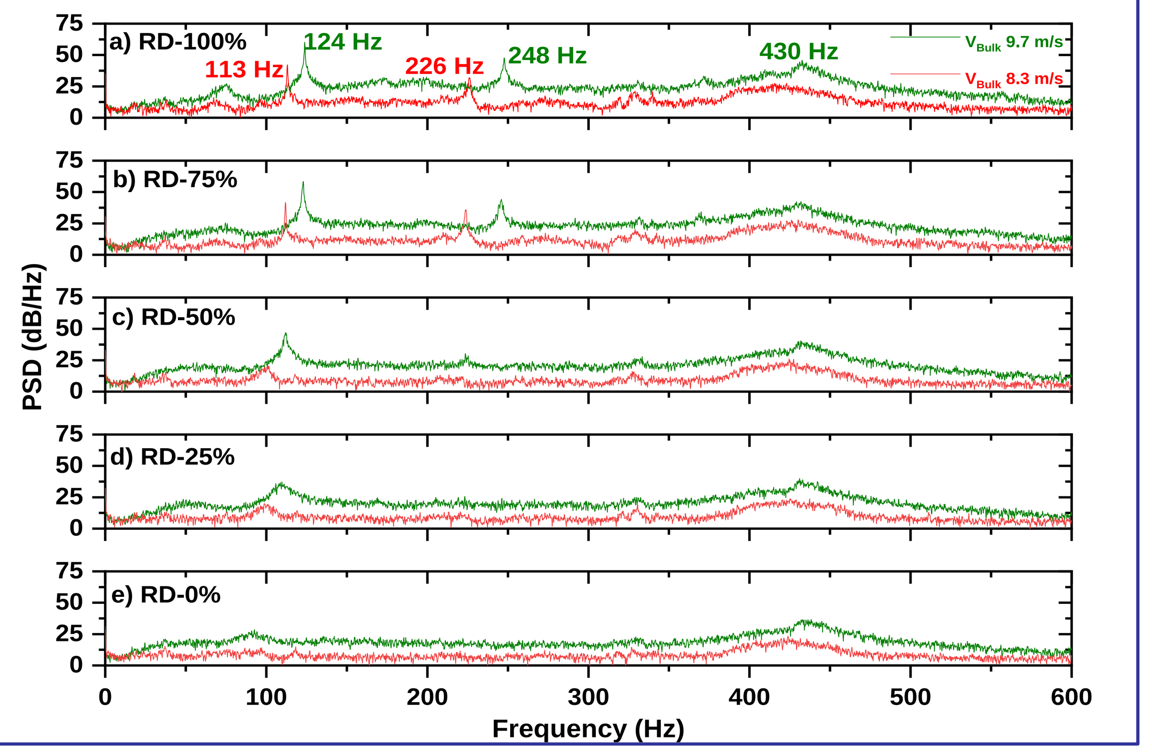
$$\Rightarrow \omega_{ITA} \propto \frac{V_{Bulk}}{L_{Flame}}$$

$\uparrow V_{Bulk}$	$\uparrow \omega_{ITA}$
$\uparrow L_{Flame}$	$\downarrow \omega_{ITA}$

Results

- The most compact flames present ITA modes while the least compact ones are stable.
- Increasing the bulk flow velocity from 8.3 to 9.7 m/s increases the pressure peak frequencies: the time for a vortex generated at the base of the flame to be convected to the flame front decreases with the bulk flow velocity.
- For all flames, a "broadband" peak centered at a frequency corresponding the 3/4-wave mode of the combustor is observed, regardless of the bulk flow velocity.
- The temperature of the burned gases, T_b, is calculated for $\omega = 430\ Hz$ by solving the wave equation: T_b = 1263 K.
- The average burned gases temperature was also measured: $T_{b\text{-}expe}$ = 1379 K.
- As $T_b \approx T_{b\text{-}expe}$, the broad pressure peak near 430 Hz is indeed the 3/4-wave acoustic mode of this combustor.





Summary

- The acoustic response of the combustor is composed of pure acoustic modes plus ITA modes.
- Increasing the bulk flow velocity increases the ITA frequencies; decreasing the length of the flame increases both frequency and amplitude of the ITA modes.
- It is possible to alter the thermoacoustic behavior of carbon-free burners by tailoring the injection of ammonia and hydrogen without modifying the global fuel composition or thermal power.

References

- A. Katoch, T. Guiberti, D. Vigarinho de Campos, D, Lacoste, Dual-fuel, dual-swirl burner for the mitigation of thermoacoustic instabilities in turbulent ammonia-hydrogen flames, Combustion and Flame 246 (2022) 112392.
- M. Hoeijmakers, V. Kornilov, I.L. Arteaga, P. de Goey, H. Nijmeijer, Intrinsic instability of flame–acoustic coupling, Combustion and Flame 161 (2014) 2860-2867.