High amplitude/high frequency acoustic field effects on coaxial inkection

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1. Introduction

High-frequency thermoacoustic instabilities are one of the biggest issue limiting **liquid rocket engines (LREs)** reliability.

Pressure fluctuations produced by combustion can **couple** with the **resonant mode** of the combustion chamber, leading to the modulation of the local instantaneous rate of the heat release.

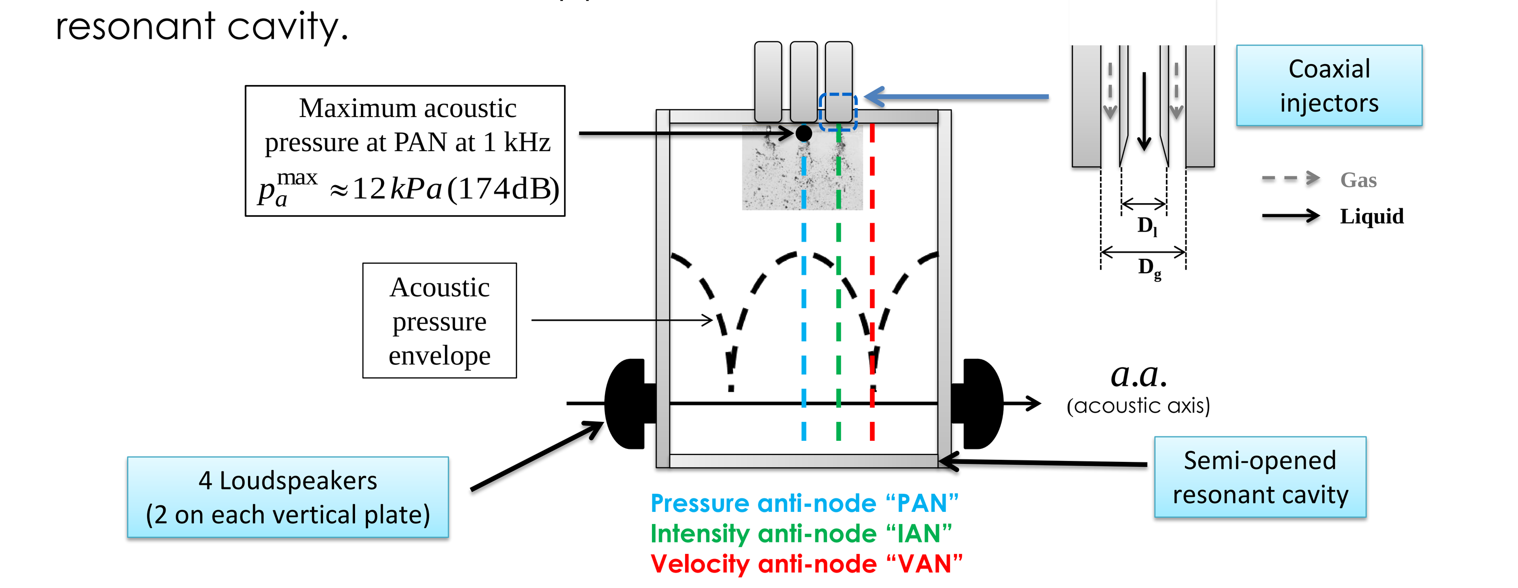
Despite many years of research, the understanding and the capacity of predicting combustion instabilities are still limited. Due to the complexity and multiplicity of the processes involved, a global approach cannot identify the dominant mechanisms and a **local approach** is needed.

2. Objectives

- Investigation of **air-assisted liquid jets response** to the acoustic perturbation
- Validation of a **theoretical model** based on **non-linear acoustics** describing **jet dynamic**

3. Experimental setup and acoustic field

- Semi-opened resonant cavity + compression drivers to reproduce acoustic field similar to what can be found in a combustion chamber
- The **acoustic field** can be approximated as the **2nd transverse mode** of the resonant cavity.



Anti-node : spatial location where the amplitude of fluctuations of the considered acoustic quantity (e.g. pressure, velocity or intensity) is maximum.

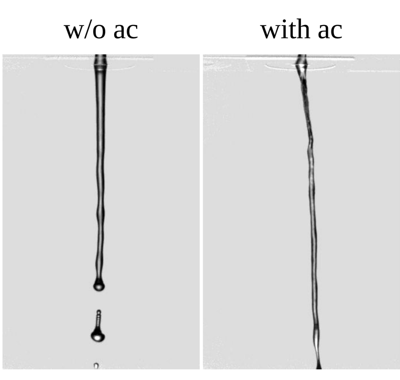
4. Air-assisted jets response to the acoustic field

Jet response depends on the position in the acoustic field

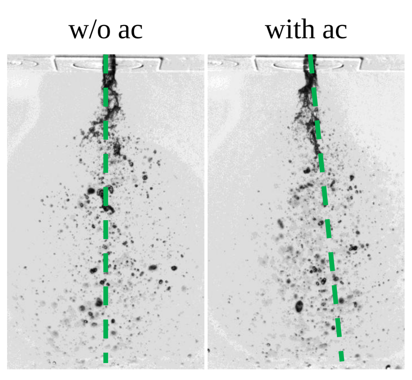
NO EFFECTS AT PAN

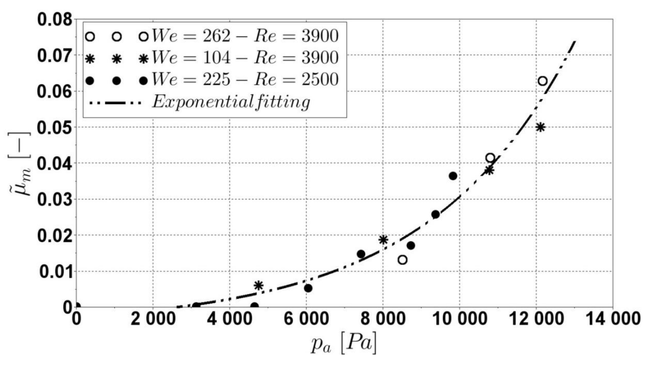
JET DEVIATION AROUND IAN

Low Weber - $We_g = 9$	High Weber - $We_g > 100$



See theoretical model in §5

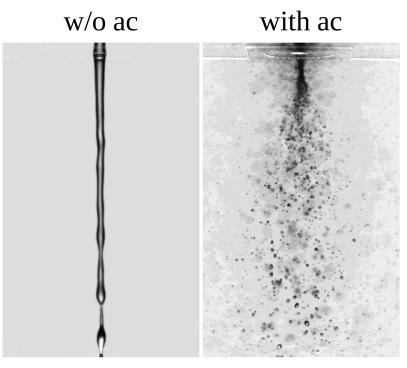




$\tilde{\mu}_m$: droplet spatial distribution mean value

ATOMIZATION PROCESS IMPROVEMENT AROUND VAN

Low Weber - $We_g = 9$	High Weber - $We_g > 100$



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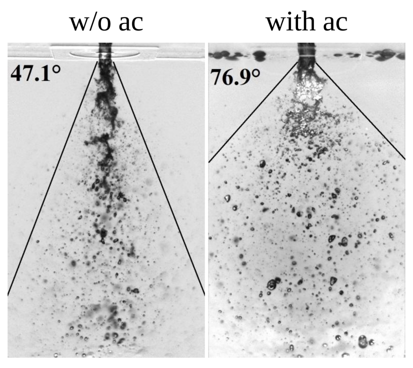


Position	$PR = N_{d,ac} / N_{d,0}$	
	Membrane ($We_g = 100$, $Re_l = 2200$)	Fiber ($We_g = 220$, $Re_l = 2500$)
VAN	9.4	1.8
VAN-IAN	7.6	1.2

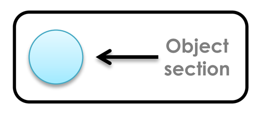
$N_{d,ac}$: Number of droplets with acoustics

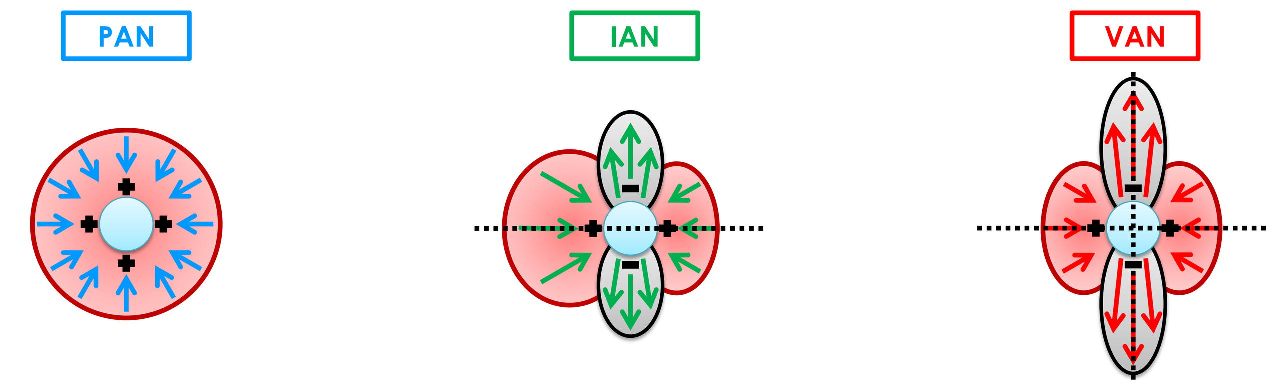
$N_{d,0}$: Number of droplets without acoustics

5. Theoretical model

Nonlinear acoustic model for cylindrical or spherical objects based on:

- **Radiation pressure** distribution: $P_{rad} = \frac{\langle p_a^2 \rangle}{2\rho_g c^2} - \frac{\rho_g}{2}\langle \vec{u}'\vec{u}' \rangle$
- **Radiation force** effects: $\vec{F}_{rad} = -\iint_S P_{rad} \cdot \vec{n} dS = G\, f(\eta) \frac{p_a^2}{4} \sin 2kh\, \vec{e}$

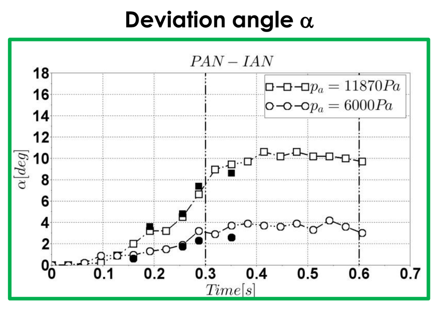




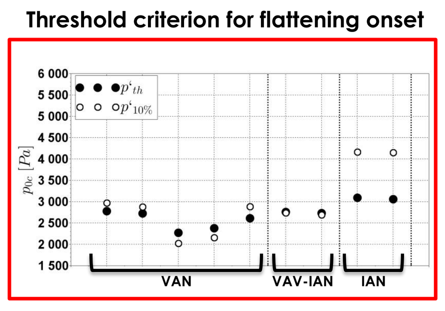
PAN	IAN	VAN
Uniform distribution of p_{rad} acts like a pressurized environment	Non symmetric distribution of p_{rad} along the acoustic axis	Non uniform distribution of p_{rad}
$F_{rad} = 0$	$F_{rad} \neq 0$	$F_{rad} = 0$
NO DEVIATION NO DEFORMATION	DEVIATION AND DEFORMATION	NO DEVIATION DEFORMATION

Model validation
- Filled markers: calculation
- Empty markers: experimental results

Deviation angle α



Threshold criterion for flattening onset



6. Droplet spatial distribution: clustering effect

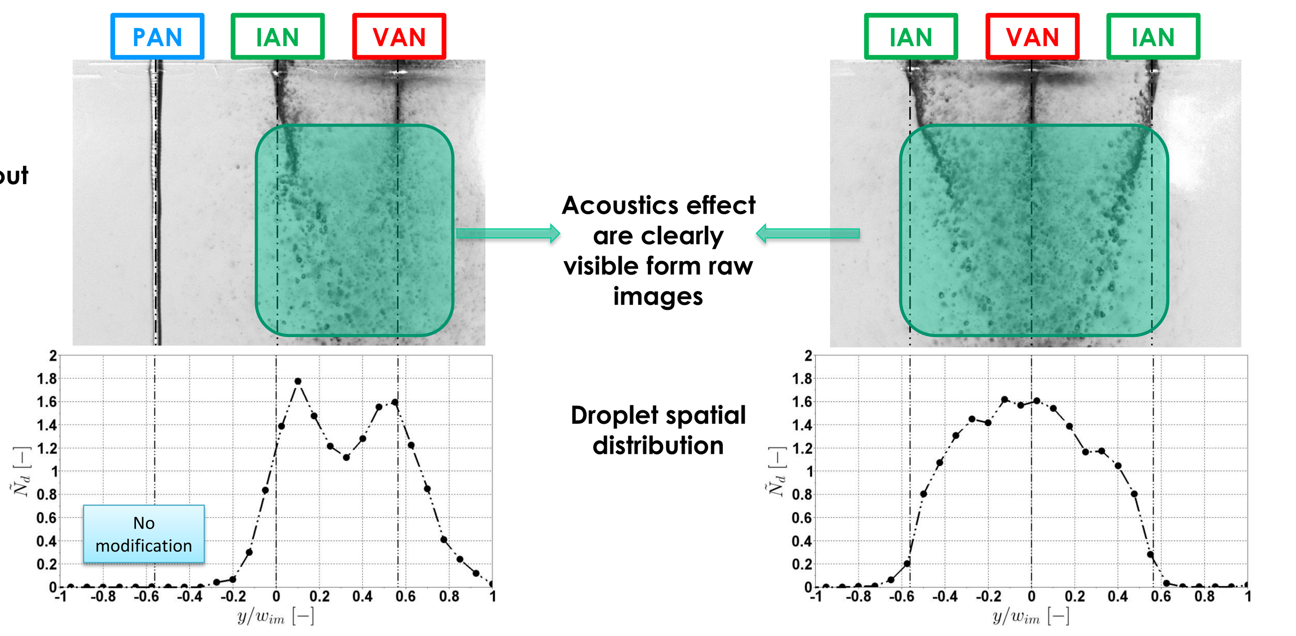
Low Weber - $We_g = 9$

Drastic modification induced by acoustics

- No atomization without acoustics
- Atomization with acoustics

Acoustics effect are clearly visible form raw images

Droplet spatial distribution



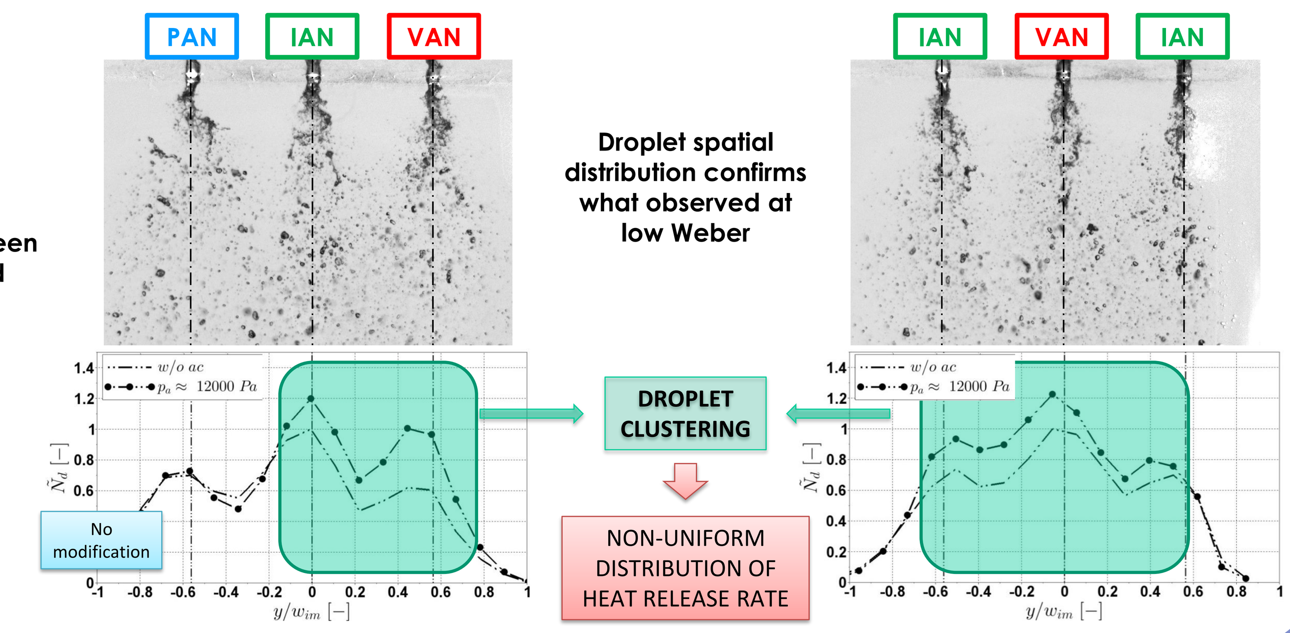
High Weber - $We_g = 190$

- Image processing necessary at high Weber
- Competition between aerodynamics and acoustics

Droplet spatial distribution confirms what observed at low Weber

DROPLET CLUSTERING

NON-UNIFORM DISTRIBUTION OF HEAT RELEASE RATE



7. Conclusions

- ❑ Acoustics can drastically affect jet dynamics according to the position of the injector w.r.t. the acoustic field.
- ❑ Two main phenomena have been observed:
  - An **intensification of the atomization process**, particularly strong at VAN;
  - A **deviation toward the velocity anti-node**, nearby IAN.

  → **Droplet clustering** in the region around IAN and VAN
- ❑ Theoretical model based on **radiation pressure** and **radiation force** distribution well describe jet behavior.
  - ➢ The model must be completed to take into account different object geometries and the energy balance between flattening and deviation.

References

[1] Yang, V., Anderson, W., *Progress in Astronautics and Aeronautics*, **169**, (AIAA, Washington, DC, 1995).
[2] King, L.V., *Proceedings of the Royal Society of London A*, **147** (861), 212-240 (1934).
[3] Zhuk, A. P., *Prikladnaya Mekhanika i Tekhnicheskaya Fizika*, **22**. No. 7, 103-108, (1986).
[4] Baillot, F., Blaisot, J.B., Boisdron, G., Dumouchel, C., *Journal of Fluid Mechanics*, **640**, 307-344 (2009).
[5] Baillot, F., Blaisot, J.B., Richard, C., Théron, M., 25th European Conference on Liquid Atomization and Spray Systems (ILASS), Chania Crete (2013).
[6] Ficuciello, A., Blaisot, J.B., Baillot, F., Richard, C., Théron, M., 13th Triennial International Conference on Liquid Atomization and Spray Systems (ICLASS), Tainan, Taiwan (2015).
[7] Ficuciello, A., Blaisot, J.B., Baillot, F., Richard, C., Théron, M., International Symposium on Thermoacoustic Instabilities in Gas Turbines and Rocket Engines, Munich, Germany (2016).
[8] Ficuciello, A., Blaisot, J.B., Baillot, F., Richard, C., Théron, M., AIAA 2016-5085, 52nd AIAA/SAE/ASEE Joint Propulsion Conference, Salt Lake City, Utah (2016).

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