Phase-defined density fluctuation maps of a resonant air-methane premixed flame using laser vibrometry

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Incentive

- Highly-time resolved optical measurement technique for rapid combustion instability sensing
- Towards embedded sensing technologies for gas turbines
- Laboratory application: A lightweight method for mapping coherent structures in flames with phase-averaged resolution up to the kHz domain
- Fully automated acquisition chain at TU Graz

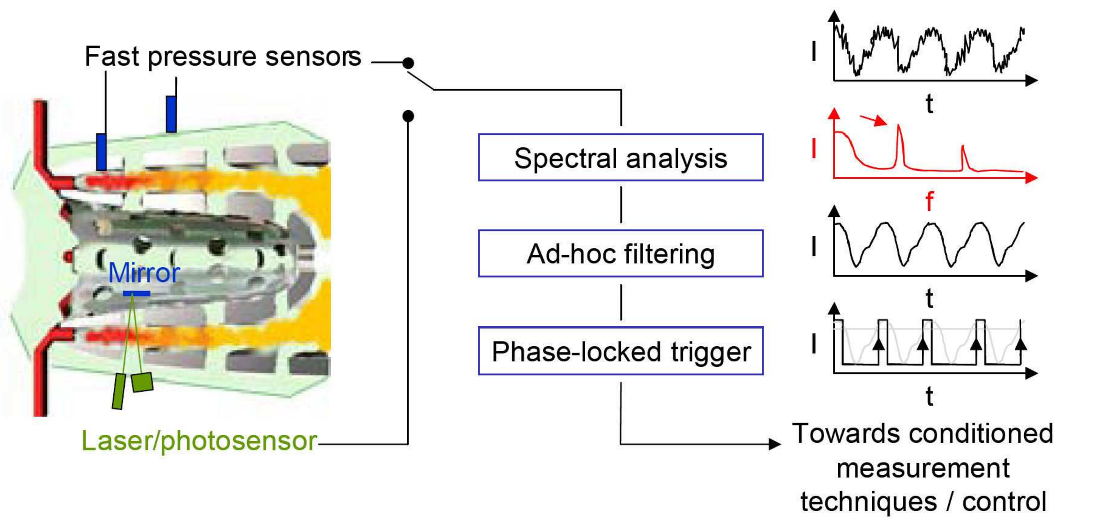

Figure 1: Sensing strategies studied at TU Graz for combustion stability monitoring. Left: combustor with wall-mounted pressure sensor OR optical set-up. Right: schematic data processing for real-time feedback loop.

Principles of laser vibrometry

- Origin: laser-based, line-of-sight measurement technique for vibration analysis
- adapted at TU Graz for the observation of coherent vortices in a turbulent flow [1]
- Application to combustion: monitoring the stability of combustion

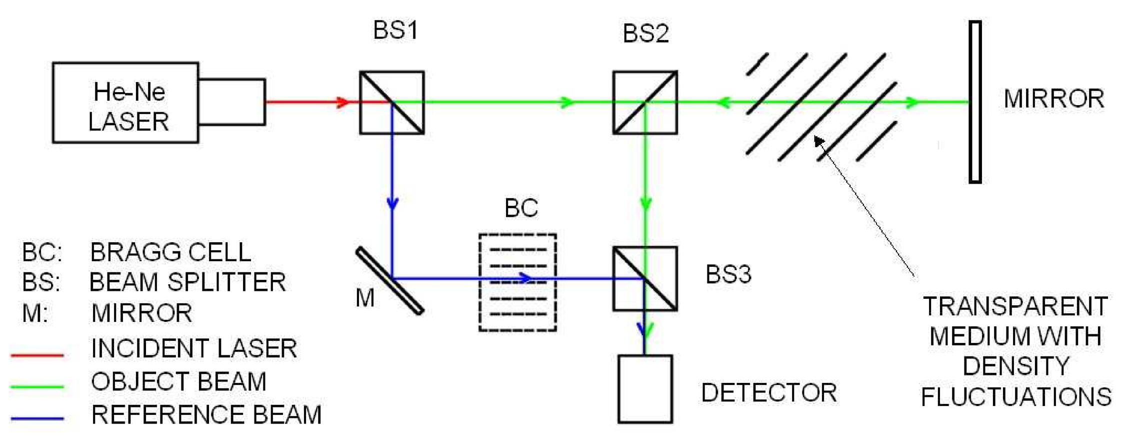

Figure 2: Principle of laser vibrometry

Physical measurement: time derivative of the density fluctuation ρ' at frequency f

$$u_f = \frac{G}{k}\int_Z \frac{\partial \rho'_f}{\partial t} dz$$

Advantage in comparison with other techniques based on extinction or interferometry: a better signal-to-noise ratio in the high frequency domain

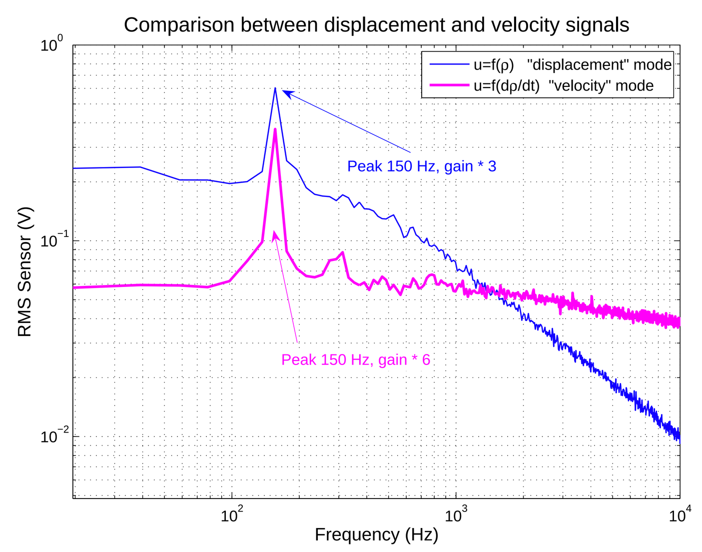

Figure 3: Sensitivity of laser vibrometry: comparison between a time dependant density fluctuation with its characteristic $1/f$ decay in the high-frequency domain, and the time derivative of the same signal

Set-up and operating conditions

Application on an excited flame with known dynamics (vortex-driven combustion oscillation, with the ONERA siren [2])

- Characterisation at atmospheric conditions [3]
- Validation of the technique at intermediate pressure [4]

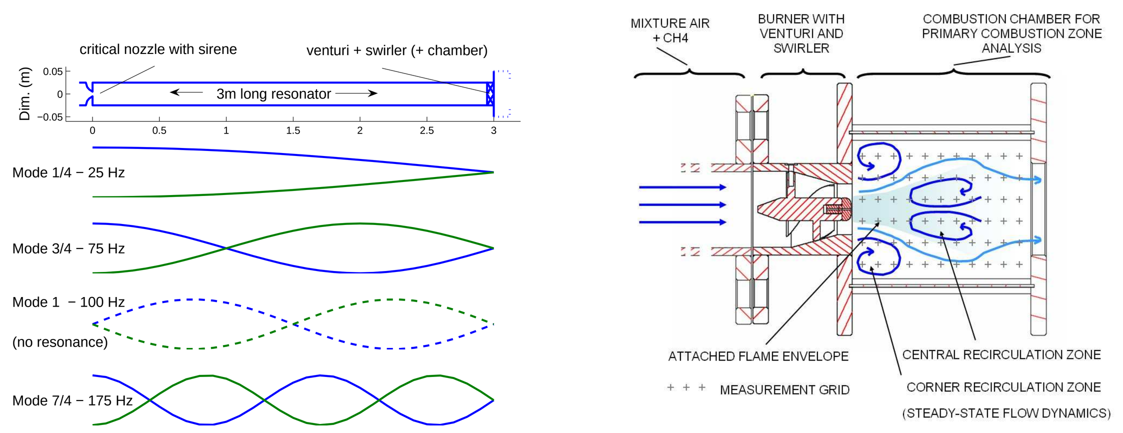

Figure 4: Test rig. Left: amplified modes with the siren and quarter-wave resonator. Right: premixed air-methane burner detail with optional bluff-body combustion chamber.

CONFIGURATION	
Resonator length	3m
Amplified modes	25 + N*50 Hz, N={1, 2, 3...}
Axial swirl angle	45°
Number of blades	3
Venturi ratio	2/5
Chamber dimensions	100*100*120mm

OPERATING CONDITIONS	
P and T_{inlet}	room conditions, 1 bar, 300K
Air - Methane flow rates	10 g/s - 0.47 g/s
Equivalence ratio	Φ=0.8
Axial inlet velocity	U_{mean}=12.6m/s
Injector pressure loss	ΔP_{inj} = 240 Pa
Swirl number S	0.8
Max. T_{wall}	950 K (uncooled)
Siren excitation range	110-120 dB SPL
T_{out}	1300 K

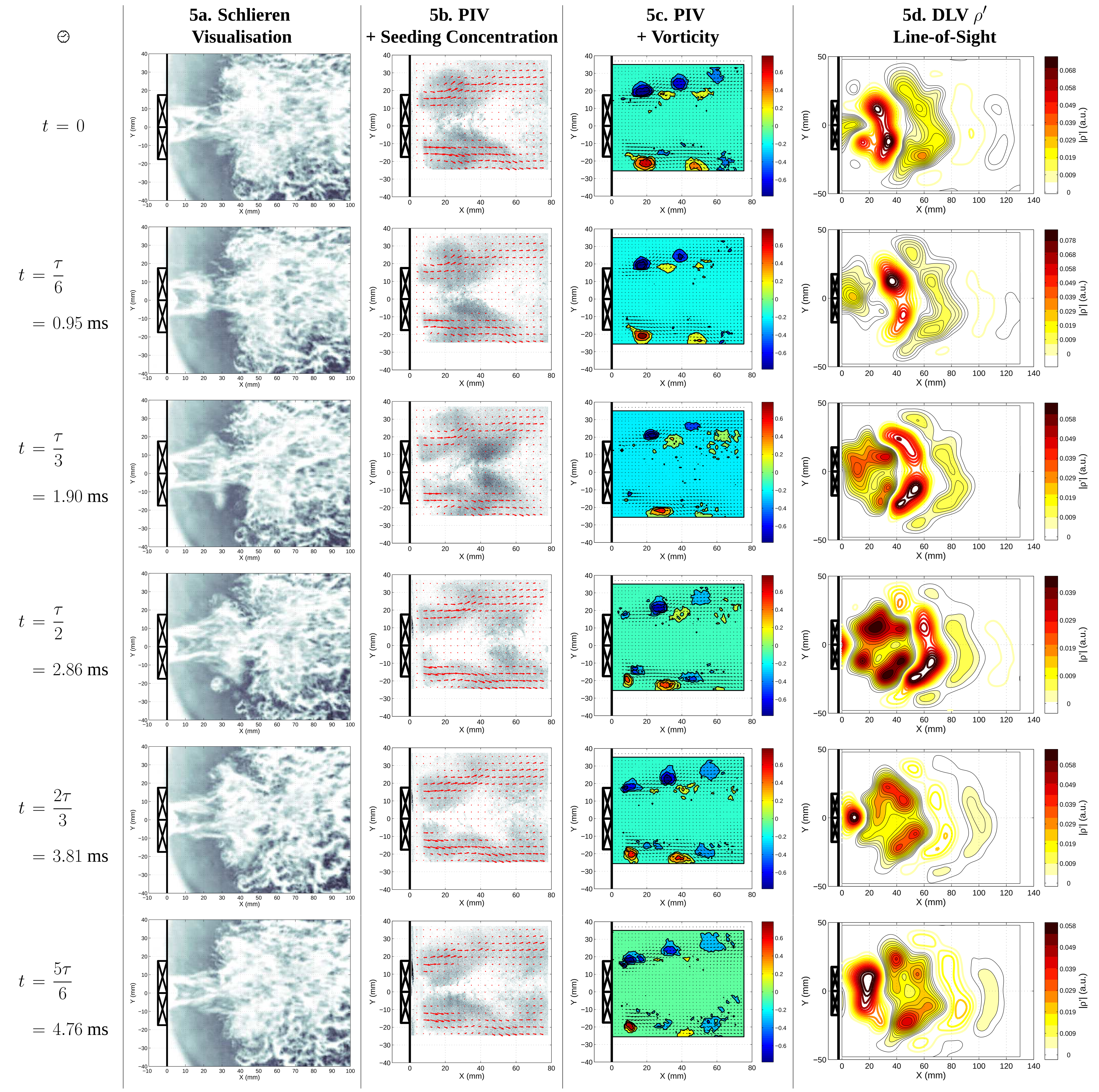

Figure 5: Advected structures observed with schlieren technique and PIV, and fluctuation maps. Pulsation 175 Hz. Six phase-locked subperiodes are displayed with incremental time step $\tau/6$=0.95ms. Vorticity unit is [2π rad/s], computed with the λ_2 criterion. Density fluctuation maps: the line contours display the positive ρ', and the light contours the negative counterpart.

References

[1] N. Mayrhofer, J. Woisetschläger, Frequency analysis of turbulent compressible flows by laser vibrometry, Experiments in Fluids 31 (2001) 153–161.
[2] F. Giuliani, P. Gajan, O. Diers, M. Ledoux, Influence of pulsed entries on a spray generated by an air-blast injection device - an experimental analysis on combustion instability processes in aeroengines, Proceedings of the Combustion Institute 29 (2003) 91–98.
[3] F. Giuliani, B. Wagner, J. Woisetschläger, F. Heitmeir, Laser vibrometry for real-time combustion stability diagnostic, in: ASME Turbo Expo 2006: Power for Land, Sea and Air, Barcelona, Spain, 2006, GT2006-90413.
[4] A. Lang, T. Leitgeb, J. Woisetschläger, A. Strzelecki, P. Gajan, F. Giuliani, Analysis of a pulsed flame at intermediate pressure, in: ISFV13 - 13th International Symposium on Flow Visualization / FLUVISU12 - 12th French Congress on Visualization in Fluid Mechanics, Nice, France, 2008.