TDMF Workshop

A.Renaud

Low-swirl burner

Experimental setup

Operating Point

Temporal evolution

Conclusion and perspectives

Time-resolved analysis of thermo-acoustic instability triggering in a low-swirl burner using simultaneous high-speed laser diagnostics.

Antoine Renaud[1], Kotaro Moriyama[2], Takeshi Yokomori[2], Shigeru Tachibana[3]

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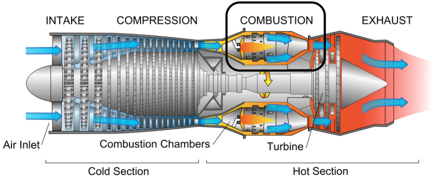
[2]Faculty of Science and Technology, Keio University
[3]Aeronautical Technology Directorate, Japan Aerospace Exploration Agency (JAXA)

November 28, 2017

Industrial context

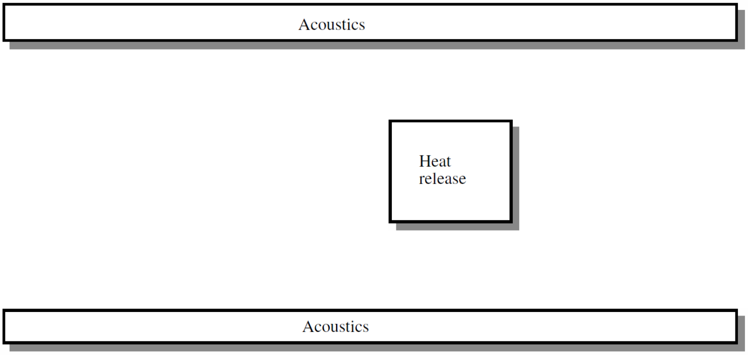
Lean premixed flames for aircraft engines

Industrial goals	Improve efficiency Reduce pollutant emissions
New approach	Lean premixed combustion
Technological solutions	Multipoint injection Staging Low-swirl
Scientific challenge	New flame dynamics to understand



Scientific Context

Thermo-acoustic instabilities



Candel, S., Proceedings of the Combustion Institute 29, 2002

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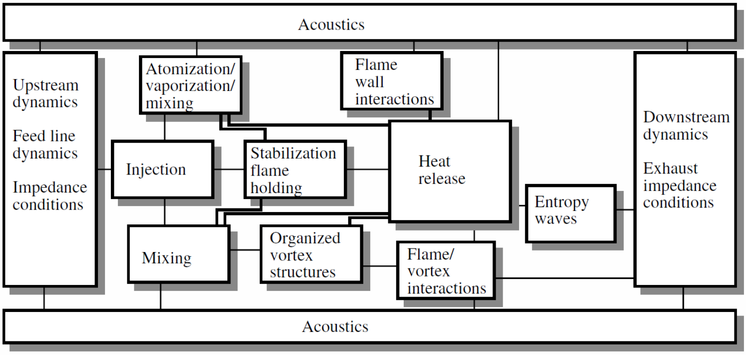

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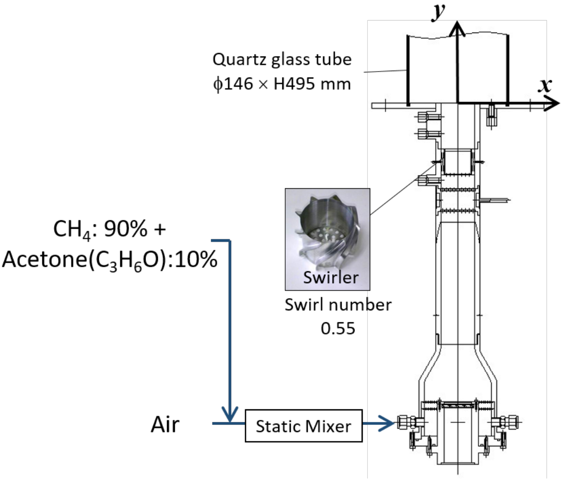
Experimental Setup

Low swirl burner



ϕ=0.66→0.70

Power=45→48 kW

U_{bulk}=10 m/s

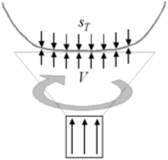
From Moriyama *et al.*, PRTEC 2016

Experimental Setup

Low swirl burner

Cheng et al., J. Eng. Gas Turbines Power 130, 2008

- Flame stabilization without recirculation



- Ultralow NOx and CO emissions potential

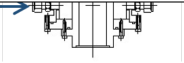
.70

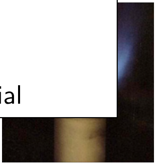
48 kW

m/s

CH_4:
Acetone(C

Air
Static Mixer

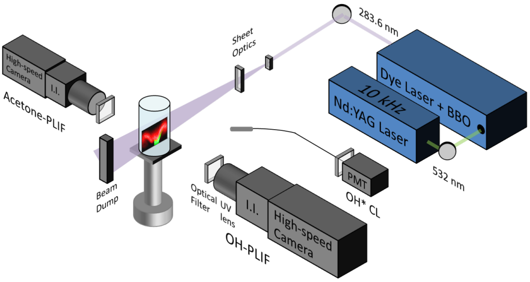




From Moriyama *et al.*, PRTEC 2016

Experimental Setup

Simultaneous high-speed OH and acetone PLIF



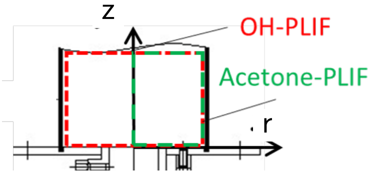
From Moriyama *et al.*, PRTEC 2016

Frame rate: 10000 fps

Number of images: 43684

Laser sheet thickness: 1 mm

Resolution: 0.13 mm/pixel



Pressure transducer and OH* photomultiplier recorded at 200 kHz.

Experimental Setup

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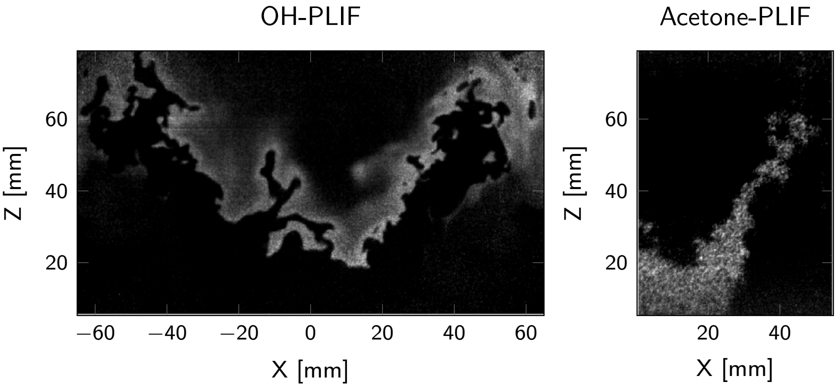
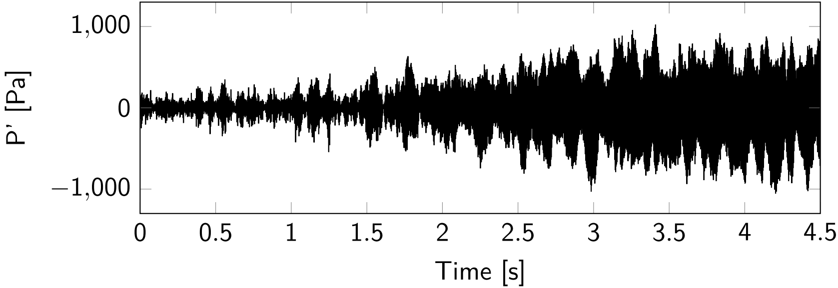


Operating Point

Pressure transducer signal



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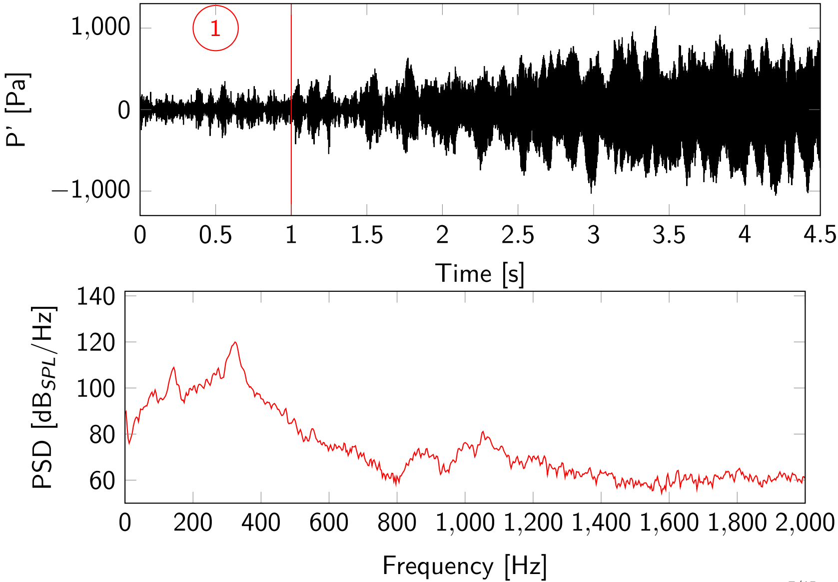

Operating Point

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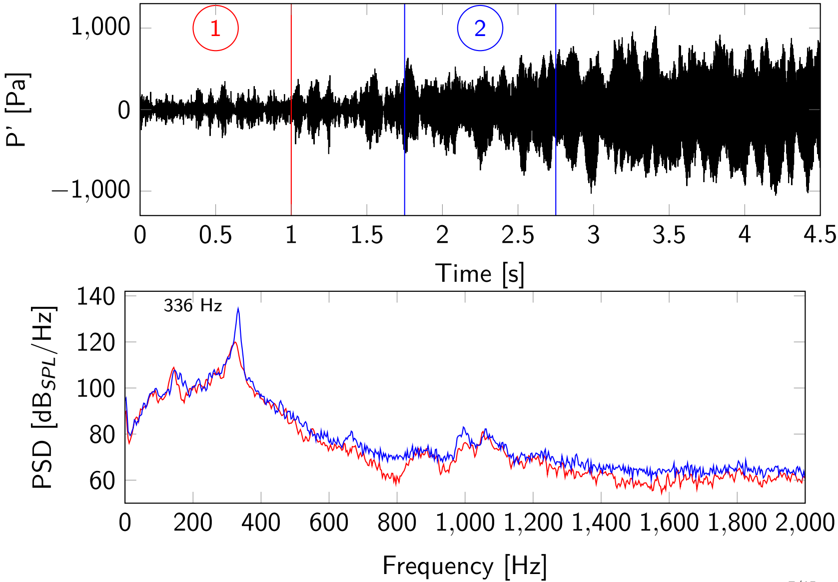

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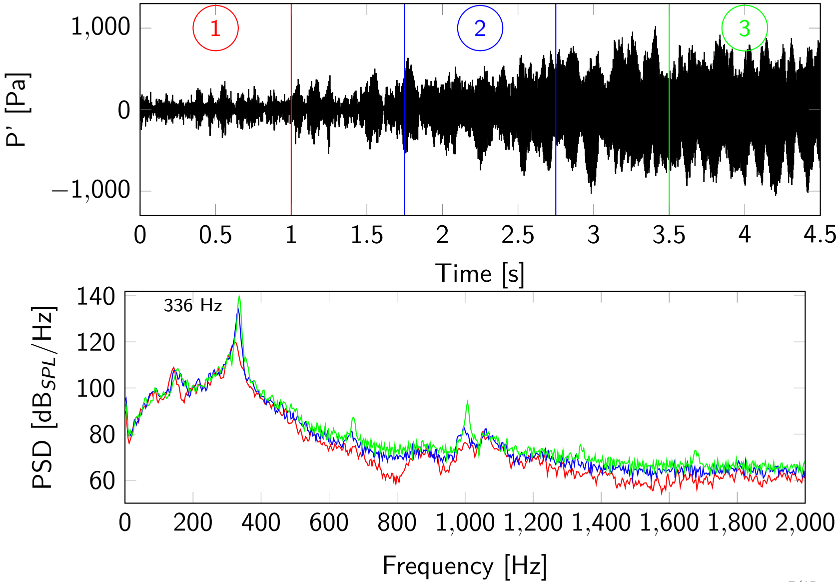
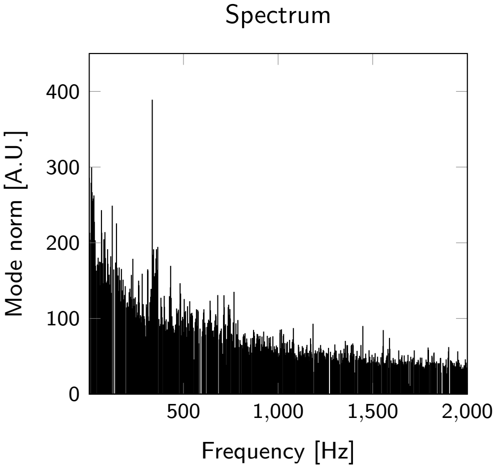


Operating Point

Thermo-acoustic instability

Stacked DMD[1]: OH-PLIF (4×4 bins), acetone-PLIF (4×4 bins) and pressure signal, 5000 samples



[1] Richecoeur et al., Center for Turbulent Research, Proceedings of the Summer Program 2012

Operating Point

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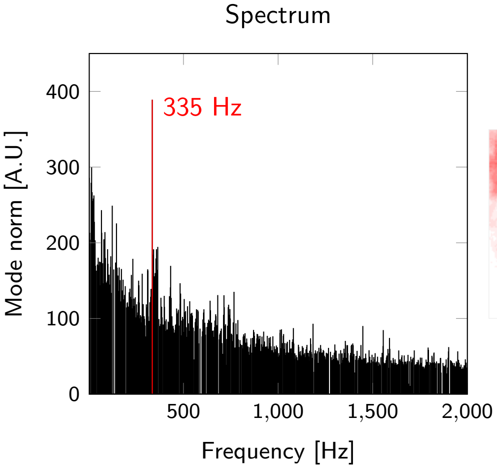

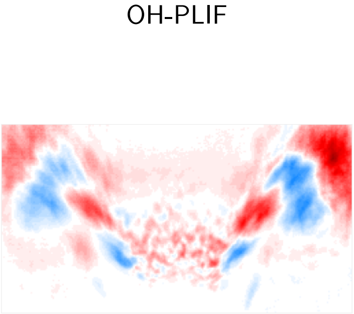

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Operating Point

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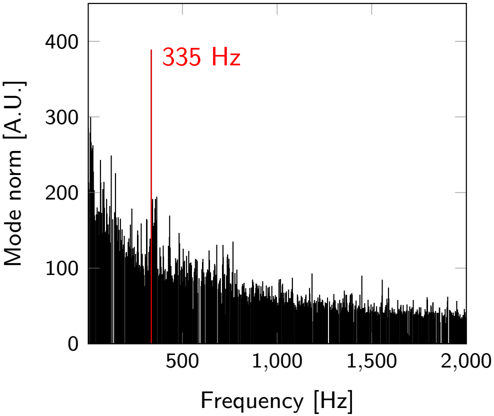
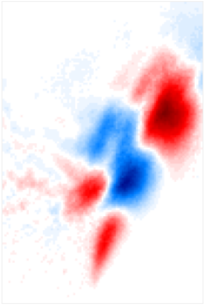
Spectrum



Acetone-PLIF

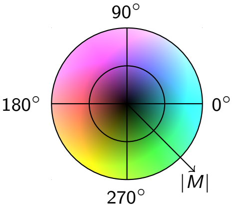


[1] Richecoeur et al., Center for Turbulent Research, Proceedings of the Summer Program 2012

Operating Point

Thermo-acoustic instability

DMD Mode: $M(x,y,t) = A(x,y)e^{i\phi(x,y)}e^{(a+i\omega)t}$



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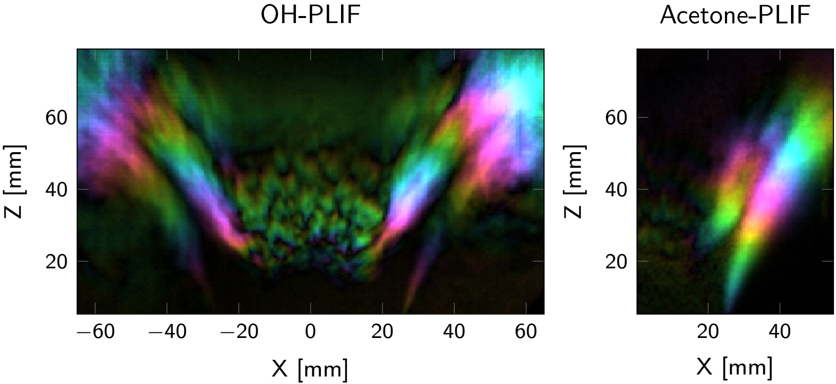

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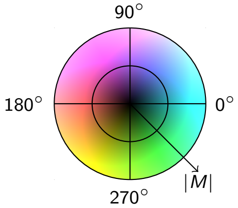

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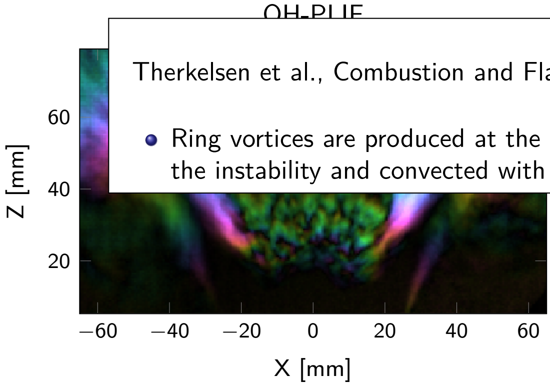
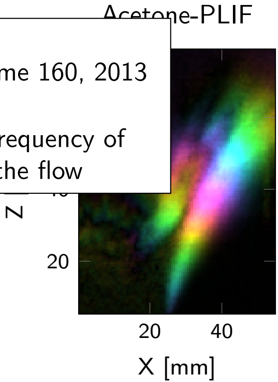


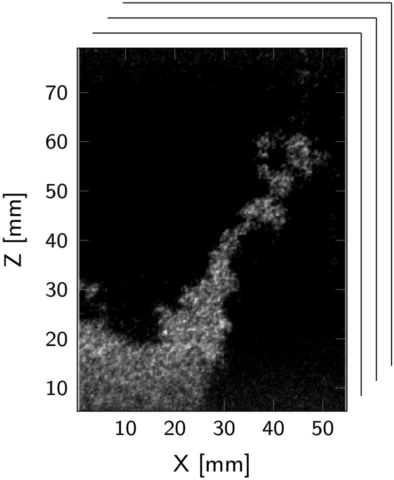


Therkelsen et al., Combustion and Flame 160, 2013

- Ring vortices are produced at the frequency of the instability and convected with the flow

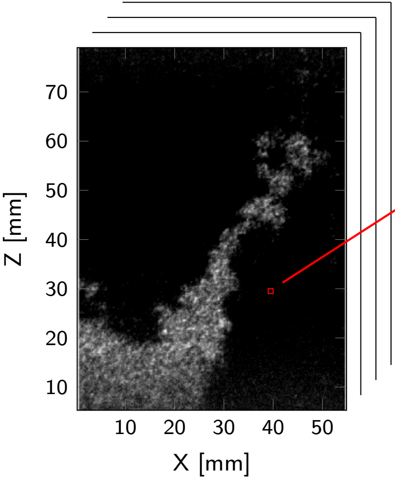
Temporal evolution

Approach



Temporal evolution

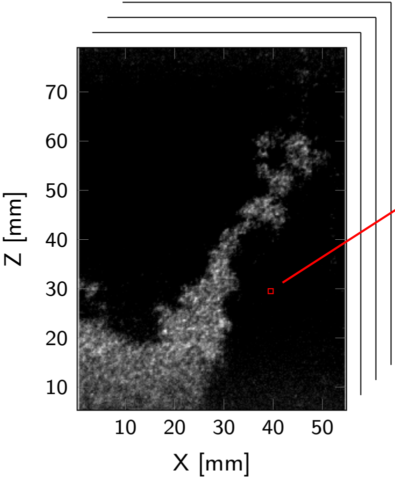
Approach



10×10 pixels bin
$S_{x,z}(t)$

Temporal evolution

Approach



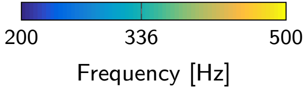
10×10 pixels bin
$S_{x,z}(t)$

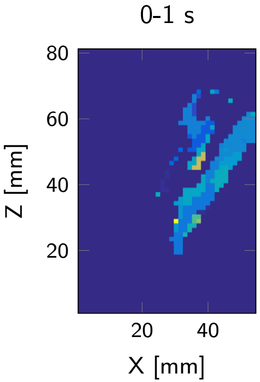
Possibility to use common time-series processing tools.

Temporal evolution

Frequency maps

Dominant frequency in the spectrum





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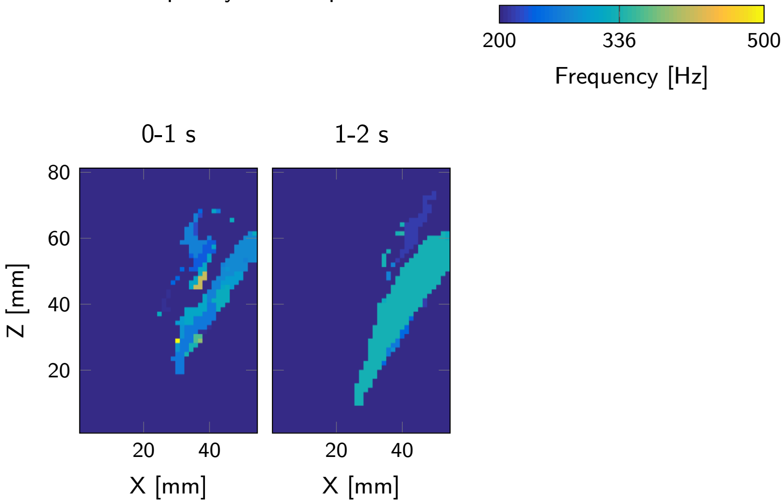

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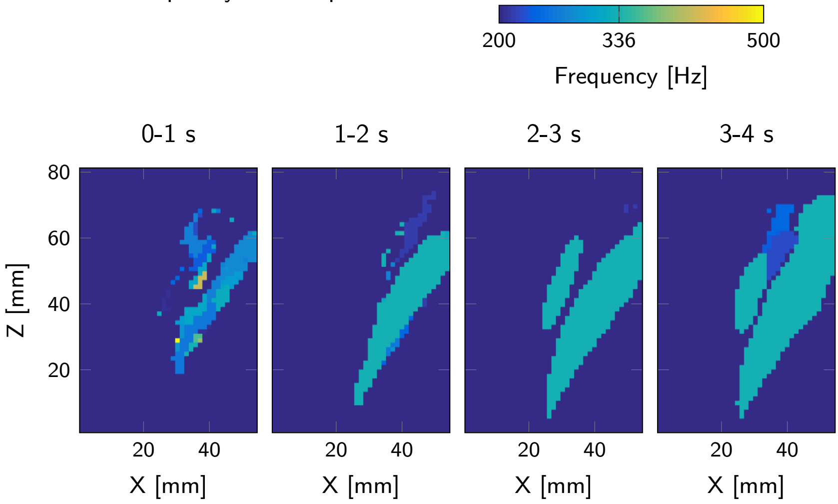

Temporal evolution

Instantaneous signal properties: Hilbert transform and analytic signal

Hilbert transform of a signal $s(t)$:

$$H_s(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{s(\tau)}{t-\tau} d\tau \tag{1}$$

Temporal evolution

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$$s_a(t) = s(t) + iH_s(t) \qquad (2)$$

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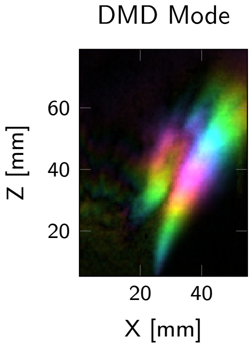
Instantaneous amplitude: $A(t)$

Instantaneous phase: $\phi(t)$

Instantaneous frequency: $\frac{1}{2\pi}\frac{d\phi(t)}{dt}$

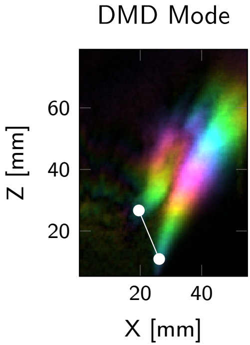
Temporal evolution

Phase evolution



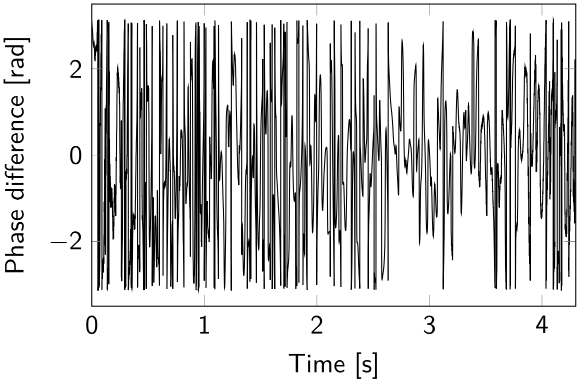
Temporal evolution

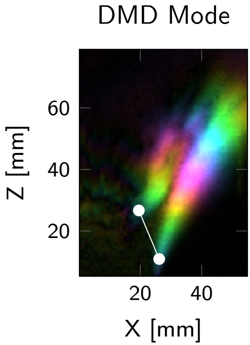
Phase evolution



Temporal evolution

Phase evolution





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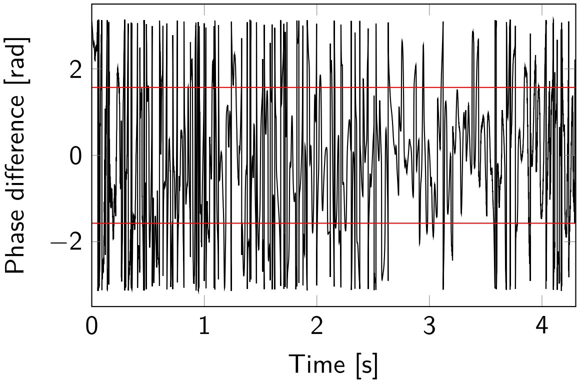

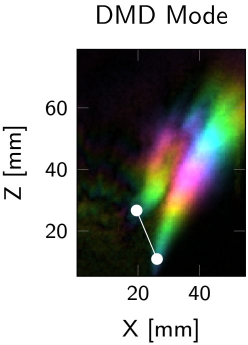

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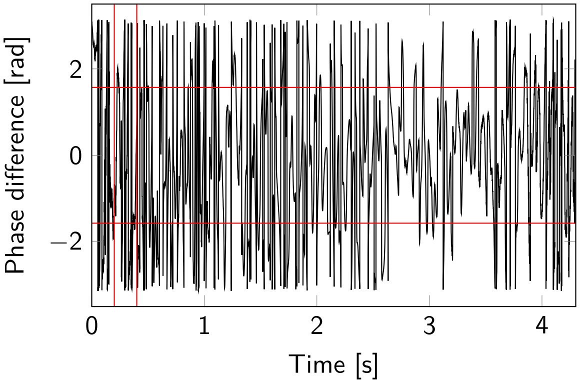

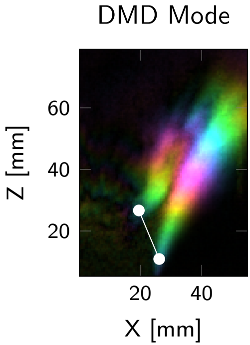

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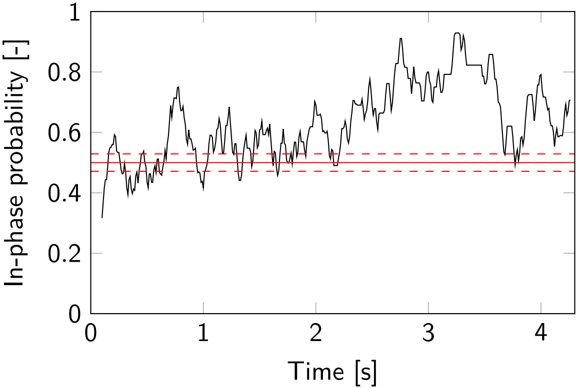

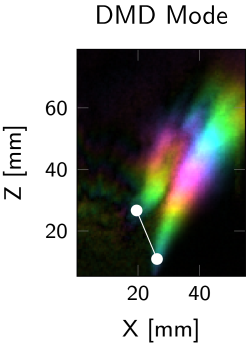

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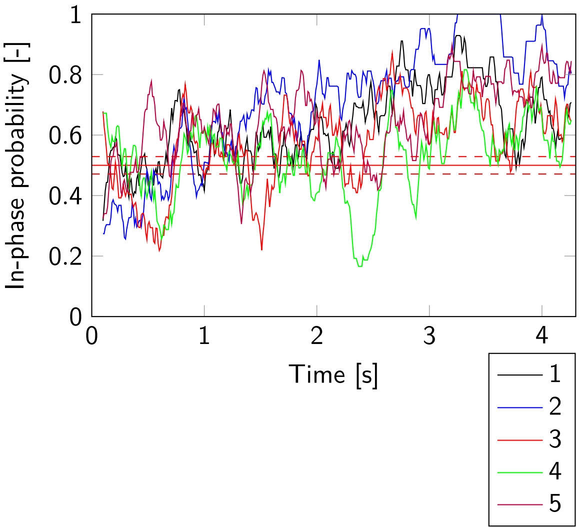

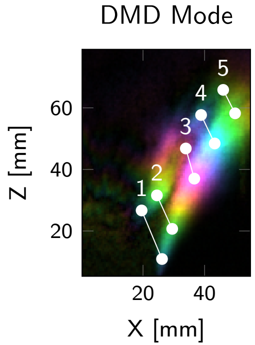

Low-swirl burner

Summary

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Low-swirl burner

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  2. Then on the inside (flame motions)
  3. Coupling of the two fluctuations enables "bursts" of flame
  4. Effect of the change in flame speed

Conclusion and perspectives

- Study of high-speed recordings during non-stationary events
  - High speed video = set of still pictures or set of temporal signals from a sensor array

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The stay of A. Renaud at Jaxa and Keio University has been supported by the Erasmus Mundus EASED program (Grant 2012-5538/004-001) coordinated by CentraleSupelec.

Appendix

Dynamic Mode Decomposition

$$\begin{array}{cc} & \xrightarrow{\text{time}} \\ \text{space} \Bigg\downarrow & \begin{bmatrix} | & | & | & | \\ s & s & s & s \\ n & n & n & n \\ a & a & a & a \\ p & p & p & p \\ 1 & 2 & 3 & 4 \\ | & | & | & | \end{bmatrix} = \end{array}$$

Appendix

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$$\begin{array}{cc} & \xrightarrow{\text{modes}} \\ \text{space}\Bigg\downarrow & \begin{bmatrix} | & | & | & | \\ | & | & | & | \\ D & D & D & D \\ M & M & M & M \\ 1 & 2 & 3 & 4 \\ | & | & | & | \\ | & | & | & | \end{bmatrix} \end{array}$$

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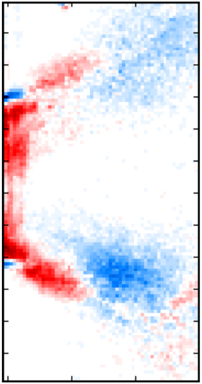
Dynamic Mode Decomposition

$$\begin{array}{cc} & \xrightarrow{\text{time}} \\ \text{space} \downarrow & \begin{bmatrix} | & | & | & | \\ snap1 & snap2 & snap3 & snap4 \\ | & | & | & | \end{bmatrix} \end{array} =$$



$$\begin{array}{cc} & \xrightarrow{\text{modes}} \\ \text{space} \downarrow & \begin{bmatrix} | & | & | & | \\ DM1 & DM2 & DM3 & DM4 \\ | & | & | & | \end{bmatrix} \end{array}$$

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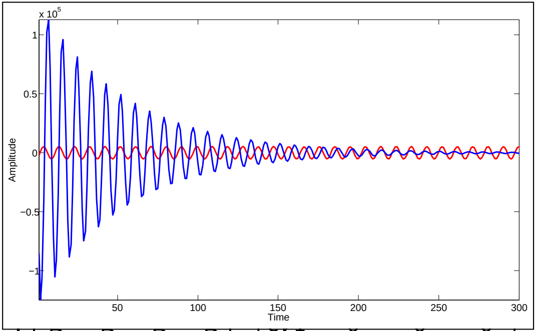
Appendix

Dynamic Mode Decomposition

time



$$\text{space}\ \begin{bmatrix} D & D & D & D \\ M & M & M & M \\ 1 & 2 & 3 & 4 \\ | & | & | & | \\ | & | & | & | \end{bmatrix} \begin{bmatrix} ev1 & 0 & 0 & 0 \\ 0 & ev2 & 0 & 0 \\ 0 & 0 & ev3 & 0 \\ 0 & 0 & 0 & ev4 \end{bmatrix} \begin{array}{c} \text{time} \\ \begin{bmatrix} - & tmp & 1 & - \\ - & tmp & 2 & - \\ - & tmp & 3 & - \\ - & tmp & 4 & - \end{bmatrix} \end{array} \text{modes}$$