Aerospace Engineering
Seoul National University

2020년 한국연소학회 춘추계 통합 온라인 학술대회

희박 예혼합 저선회 연소기의 화염전달함수 수치해석

정황희[1], 신재렬[1], 이복직[2†]

[1]㈜넥스트폼 기술연구소, [2]서울대학교 항공우주공학과

2020. 09. 24.

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- Introduction
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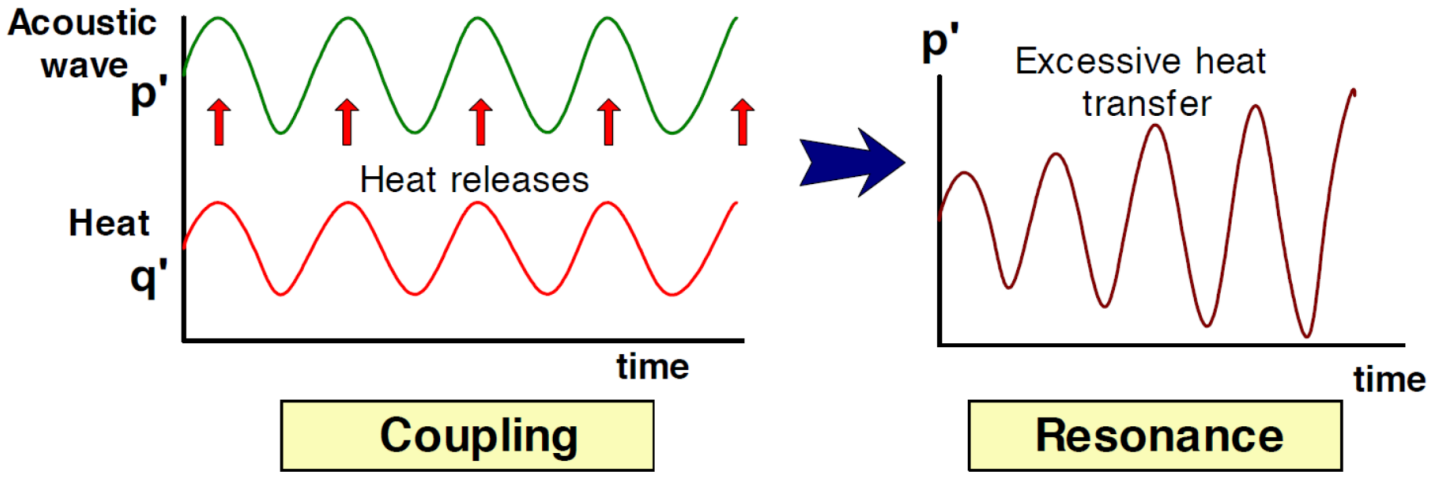
Introduction : Thermoacoustic instability

- A resonant phenomena as a result of mutual coupling between acoustic wave and unsteady heat release perturbation from the combustion process
- It could be accompanied by a large pressure fluctuation and pose a threat to system safety
- The predictive capability of combustion instability is required to design the combustion system



Introduction : FTF

- **Flame Transfer Function**

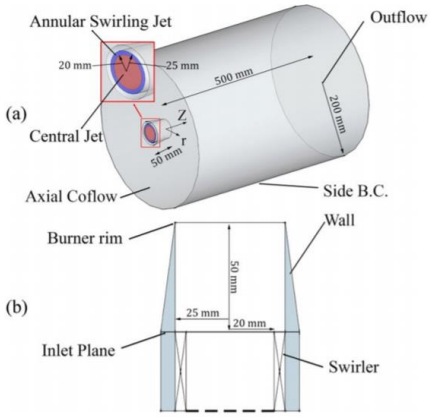
A flame transfer function describes the change in the rate of heat release in response to perturbations in the inlet flow as a function of frequency.

$$FTF(f) = \frac{q'(f)/\bar{q}}{u'(f)/\bar{u}}$$

A measure of representing flame response to acoustic disturbance

Introduction : Reference research

- **M. Shahsavari et al., 27th ICDERS. (2019)**
- FTF simulation In low-swirl burner



Low swirl configuration of Lund Univ.

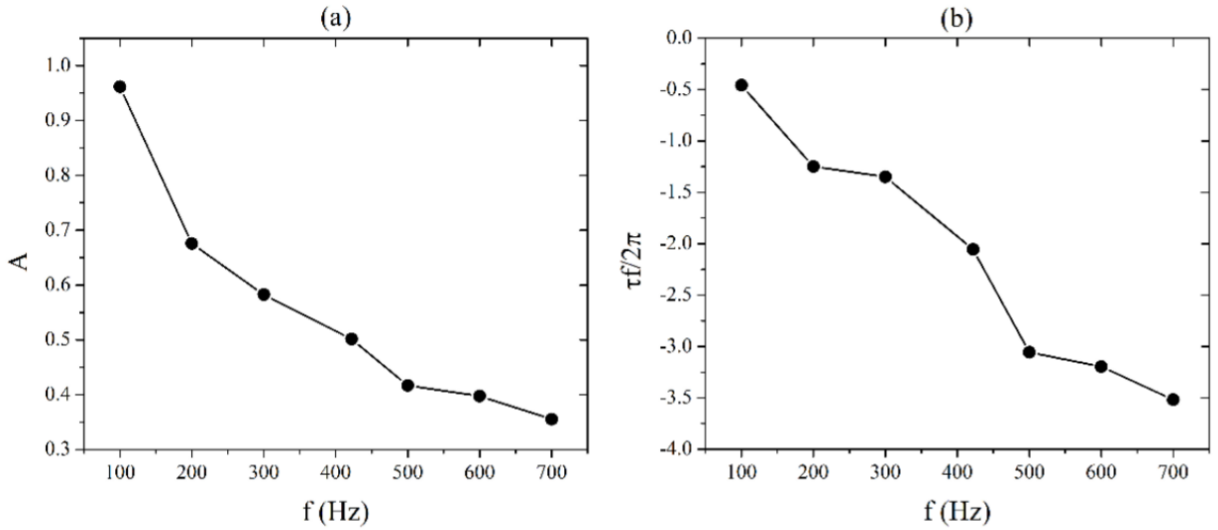


Figure 7. (a) Frequency and (b) phase of the low swirl flame response

Introduction : Reference research

- **H. Jegal et al., Proc. Combust. Inst. (2020)**
- FTF experiment In low-swirl burner

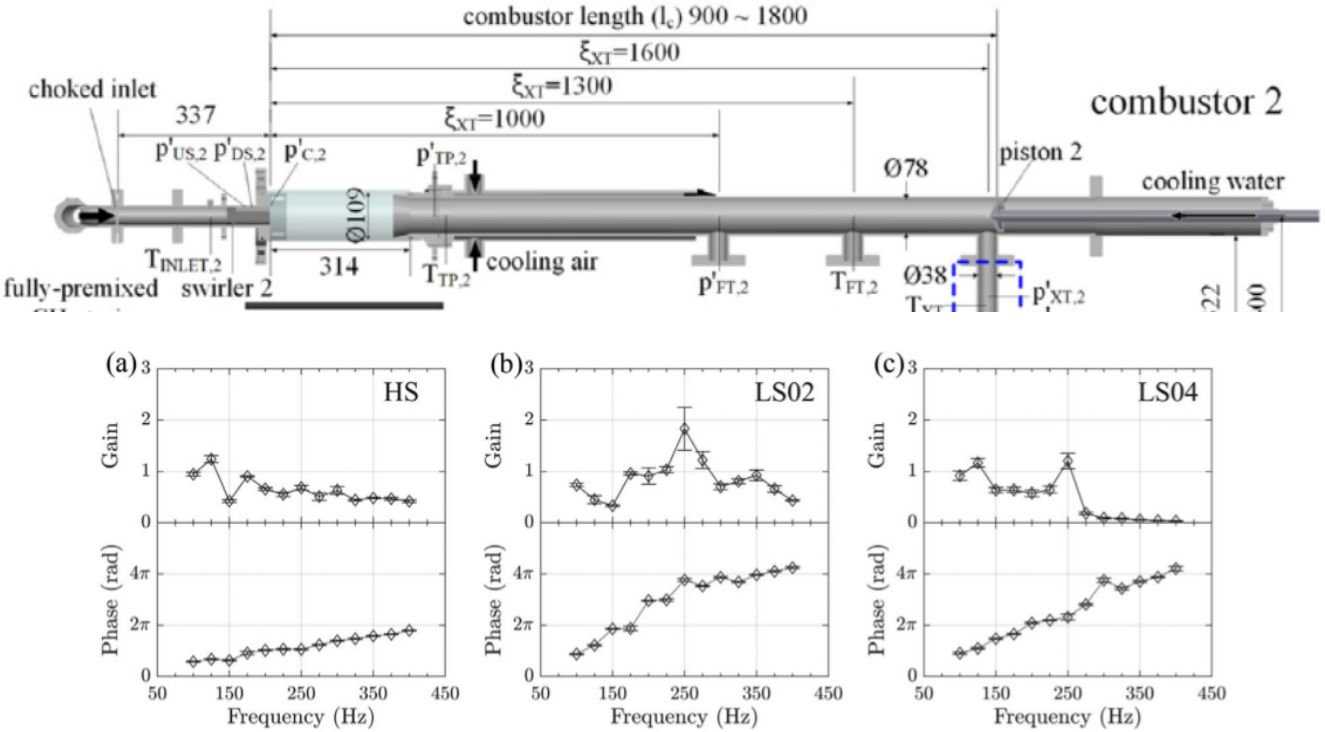
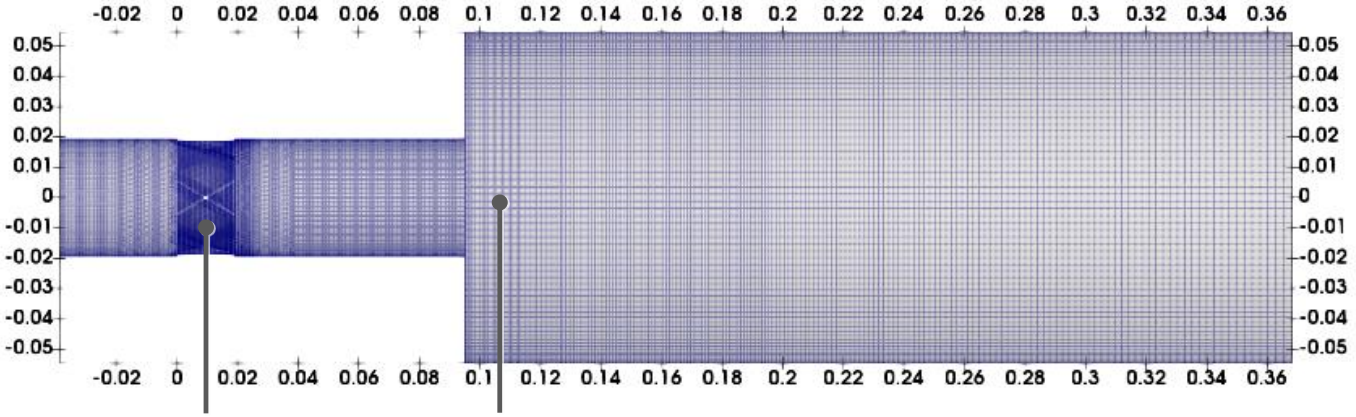


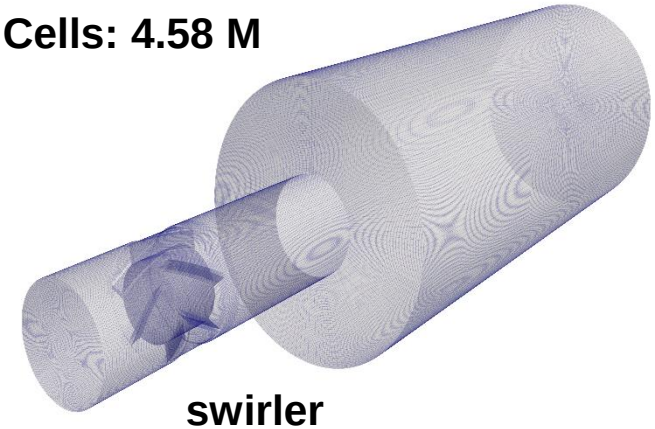
Fig. 4. Flame transfer functions (FTF) of the HS, LS02, and LS04 flames at $\phi_1 = \phi_2$ =0.65. The FTF is defined as the ratio of the normalized heat-release-rate fluctuations ($q'/\bar{q}$) to the normalized inlet velocity fluctuations ($u'/\bar{u}$).

Numerical Method

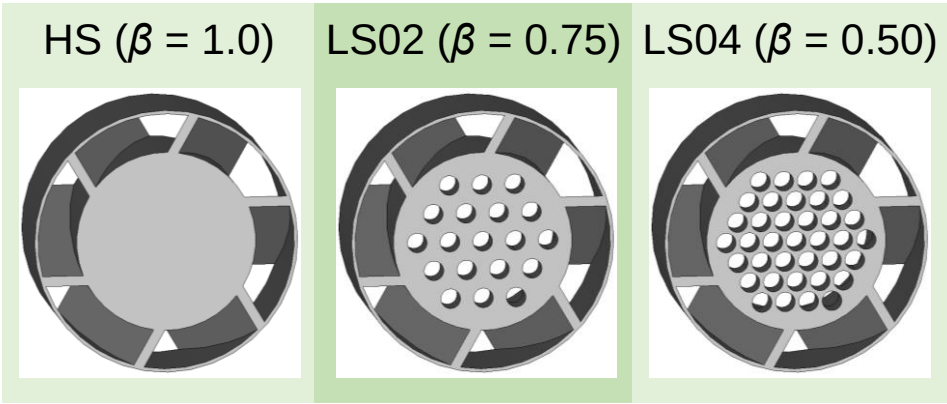
- **Computational domain**



Cells: 4.58 M



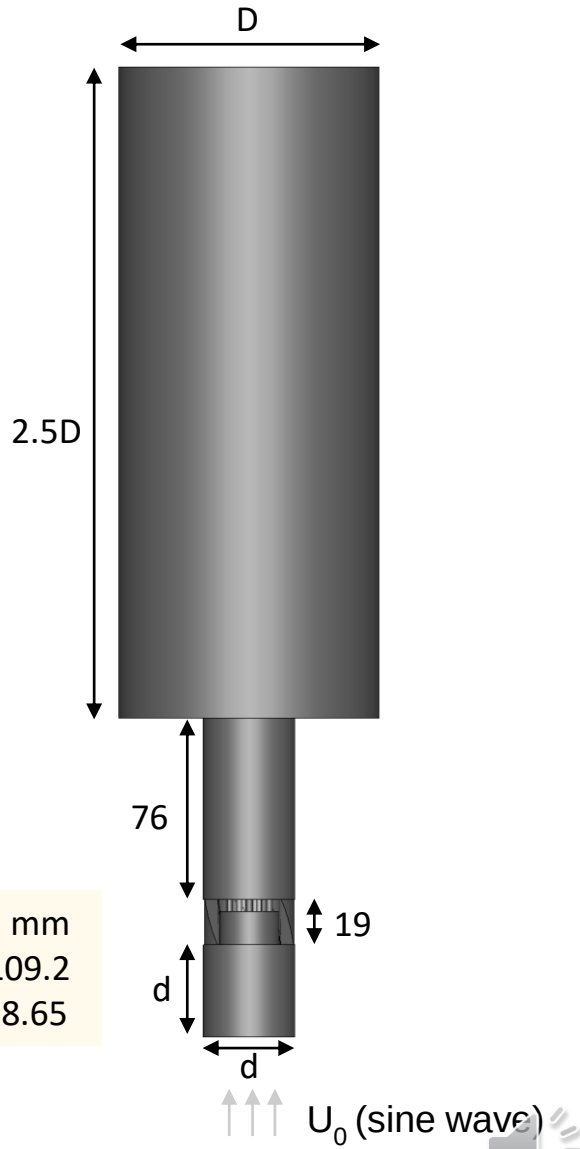
swirler



Numerical Method

- Reactant: **premixed methane/air**
- Equivalence ratio: **0.65**
- Outlet pressure: **1 atm**
- Inlet temperature: **473 K**
- Inlet mean velocity: **11.48 m/s**

- Excitation
  - **sine wave**
  - frequency: **100 ~ 400 Hz**
  - amplitude: **10 %**



Numerical Method

- **FGM (Flamelet Generated Manifold)**

Turbulent flow

- LES (Large Eddy Simulation)
- Dynamic One-equation model
- Mesh generation
  - snappyHex w/ Salome

Turbulent Combustion modeling

3D manifold

- Detailed Chemistry (GRI30) w/ Cantera
- Heat loss
- PV(Progress Variable)
- Variance of PV

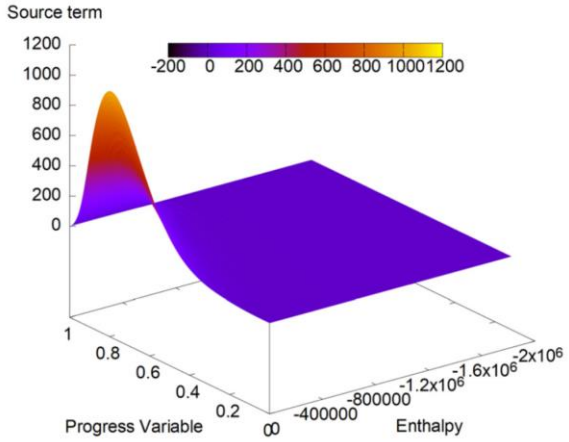
Presumed PDF

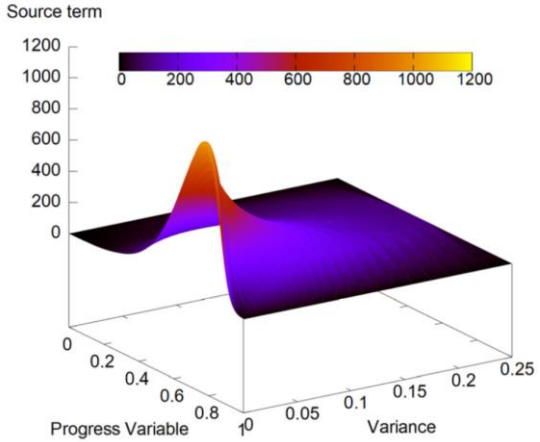
- β-PDF approach

convolution

$$\overline{\dot{\omega}}_Y = \int_0^1 \overline{\dot{\omega}_Y(Y)}\, P(Y) dY$$

3D Flamelet-Generated Manifold





Numerical Method

- **Non-reflecting Boundary Conditions**

Advection equation

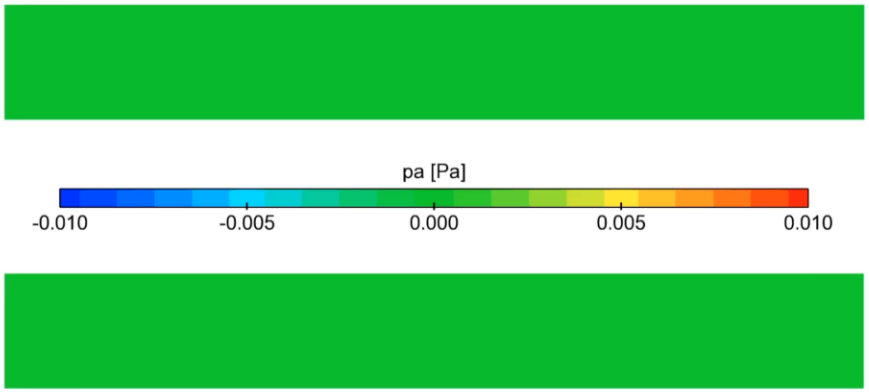
$$\frac{D\phi}{Dt} = \frac{\partial \phi}{\partial t} + \boldsymbol{U} \cdot \nabla \phi = 0$$

$$\frac{D\phi}{Dt} \approx \frac{\partial \phi}{\partial t} + \boxed{U_n} \cdot \frac{\partial \phi}{\partial \boldsymbol{n}} = 0$$

Advection speed :

$$U_n = u_n$$

Reflecting B.C.



Non- Reflecting B.C.

Source: https://youtu.be/J-52qLLDku4

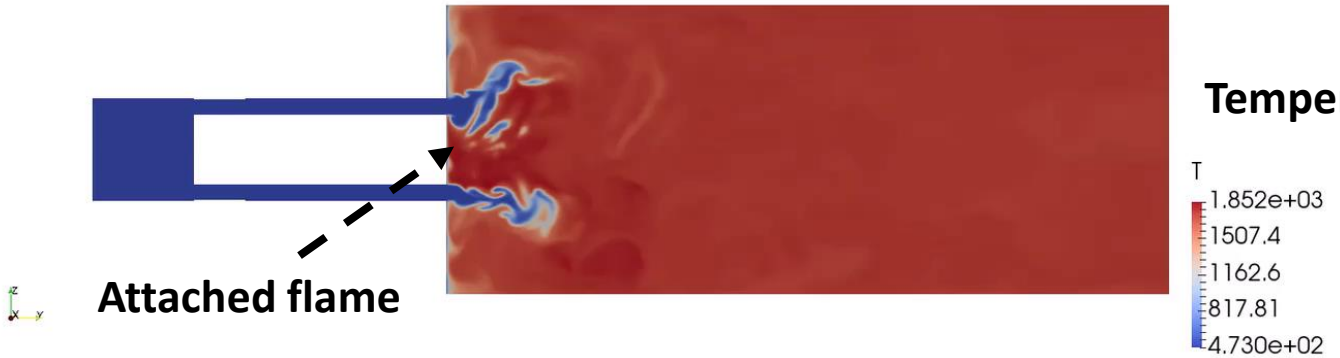
Results

- **Comparison injector**

HS vs LS02

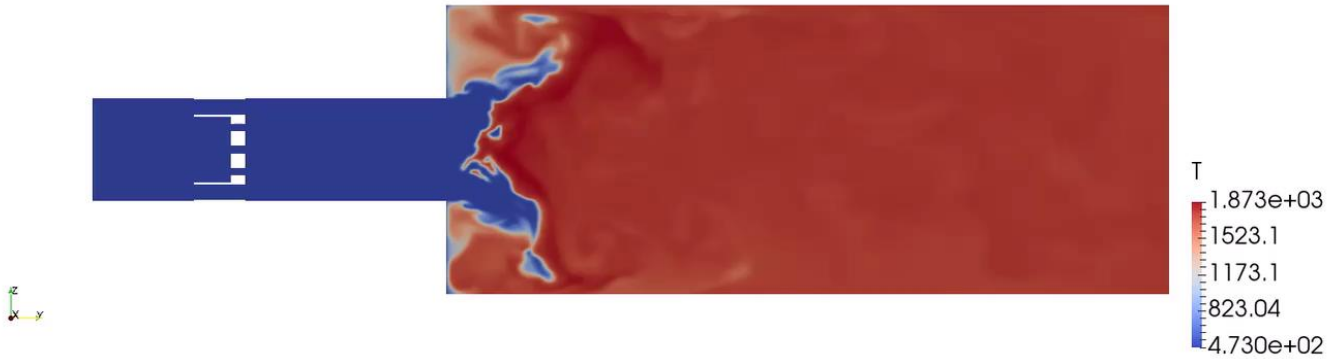
Time: 0.2000 s

HS



Time: 0.2000 s

LS02



Results

- **Comparison injector**

Previous experiment

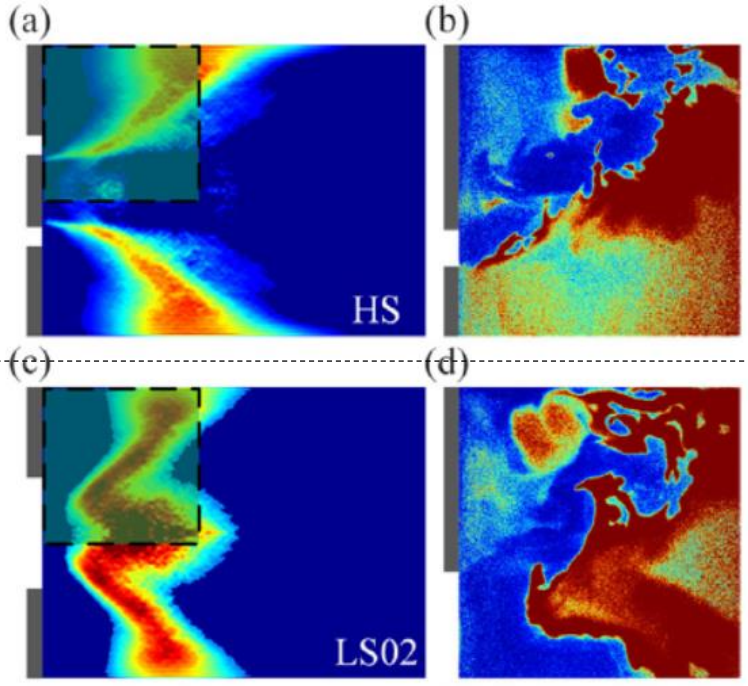
Present simulation

CH* chemilumi.

OH PLIF

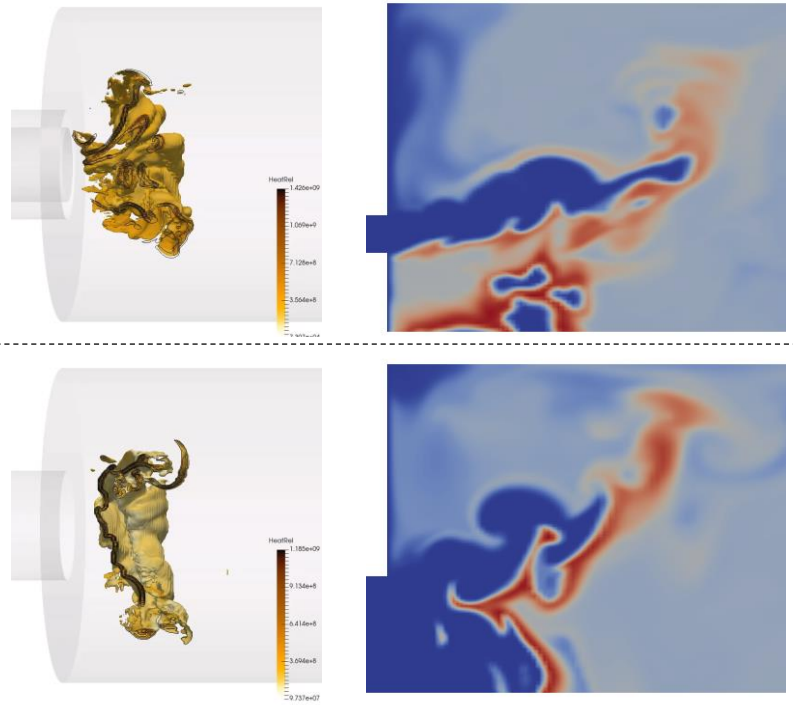
CH

OH



HS

LS02



Results

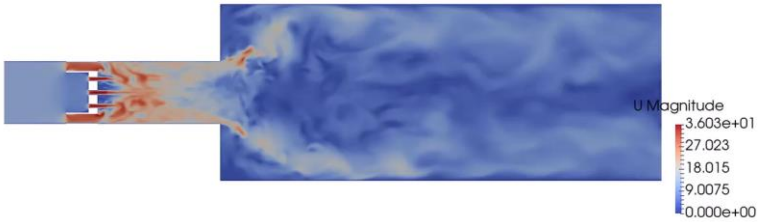
- **Comparison frequency**

LS02

0Hz **250Hz**

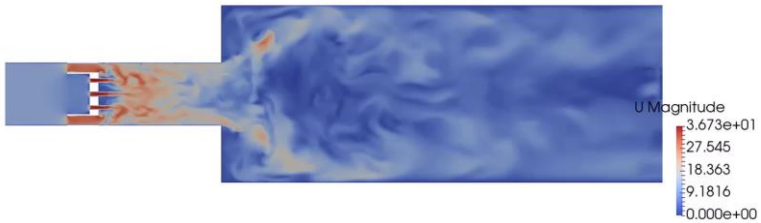
Time: 0.2000 s

U



Time: 0.2000 s

U

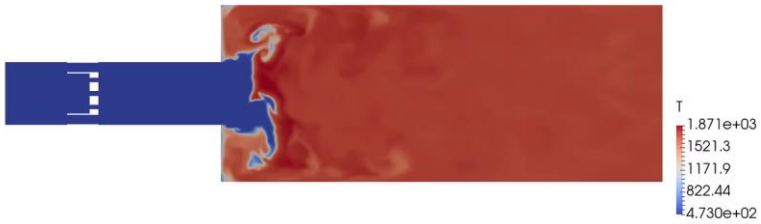


Time: 0.2000 s

T

Time: 0.2000 s

T



Time: 0.2000 s

HRR

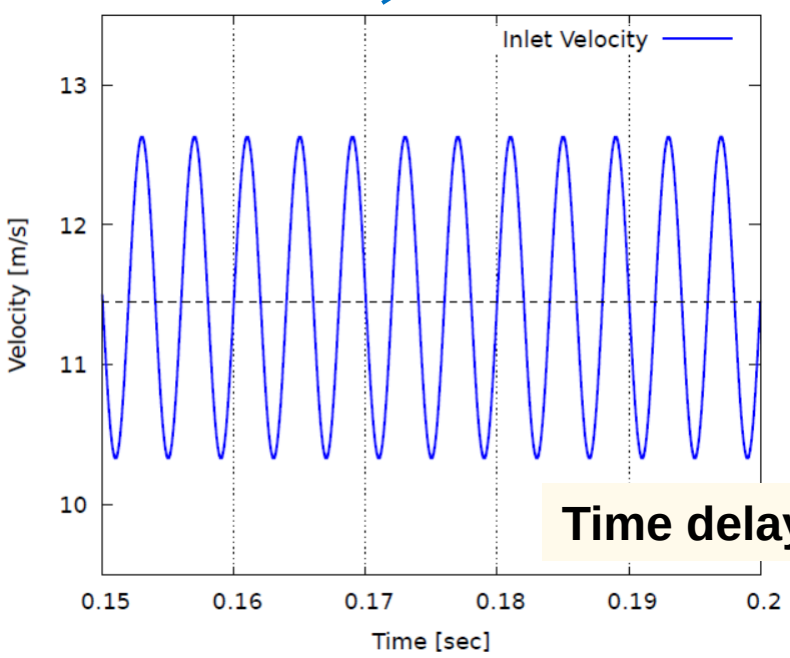
Time: 0.2000 s

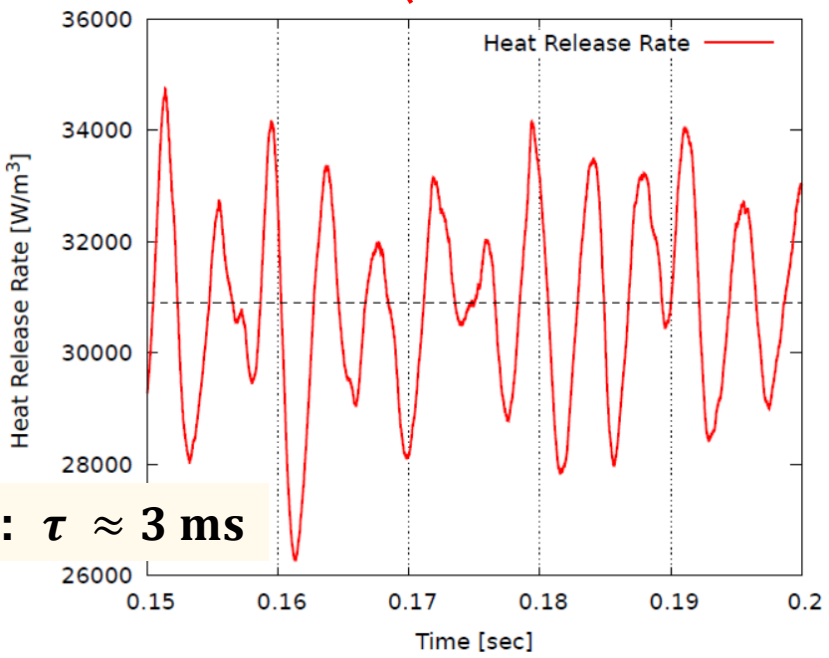
HRR

Results

- **Acquisition FTF**

- LS02, 250Hz

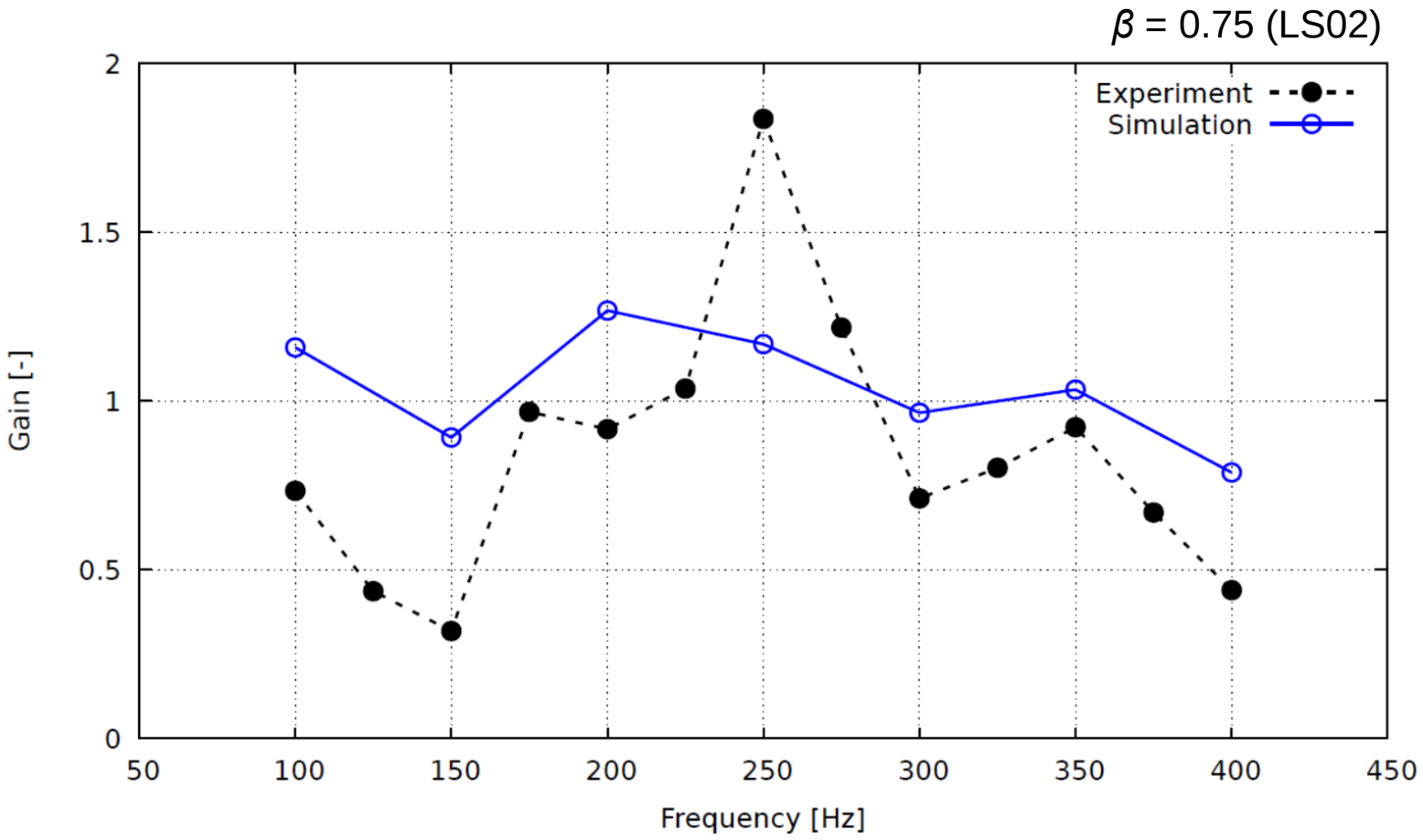




Time delay: $\tau \approx 3$ **ms**

Results

- **Low swirl injector - FTF**



Conclusion & Future work

- **Velocity excitation** and **non-reflecting** boundary conditions and **FGM** technique were applied.
- **Attached flame** of HS and **lifted flame** of LS were observed.
- The FTF results of simulation on LS02 tend to be similar to the **experimental** results.
- Simulation of HS and LS04 will be performed.

Thank you for your attention.