# A Study on Unsteady Responses of Flames – Calculation of Flame Transfer Function in a Subscale Combustor

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# 화염의 비정상 응답 특성 연구-화염 전달 함수 산출

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## ABSTRACT

The acoustic optimization of a swirl coaxial jet injector mounted upstream a combustion chamber is investigated to tackle combustion instabilities. The least damped modes are extracted with the help of the dynamic mode decomposition (DMD). The sensitivity of the heat release perturbation to the velocity perturbation for the second longitudinal mode is investigated by combining the Crocco's equation and the inhomogeneous wave equation and computing the flame transfer function (FTF). DMD and FTF results agree in terms of the optimized injector length.

**Key Words** : Half Wave Resonator, Dynamic Mode Decomposition, Flame Transfer Function, Inhomogeneous Wave Equation, Crocco's Model

Combustor design is achieved through several stages which take into account for instance the mechanical constraints and the needed power output. Apart from those main design requirements, an acoustic optimization is needed to avoid the so-called thermo-acoustic instabilities.

To address the thermo-acoustic instability problem, an acoustic optimization of the combustor is achieved by redesigning the cylinder shaped injectors. The injector is used as a device enabling the acoustic damping of potential dangerous thermo-acoustic modes. It has been shown in the previous works that injectors can act as a half wave resonator and damp pressure wave significantly [1].

In the present study, a range of injector lengths is investigated by performing dynamic mode decompositions. As a result, the adequate injector length is found with respect to an optimal acoustic damping. In addition to evaluating the sensitivity of the thermo-acoustic instabilities to the velocity fluctuation at the inlet of the combustor, the flame transfer function is computed.

The geometry of a combustion chamber is cylinder shaped with an injector at the inlet as shown in Fig 1. The length of the cylinder is calculated based on the geometry of a reference subscale combustion chamber and the acoustic similarity rule of the longitudinal modes. The injector is divided into 4 parts. The core of the injector consists of an inner passage. The other three parts added to the core are the inlet blockage, the induction bulge and the recess. In the present study, the recess length is modified as the injector length changes.

In a combustion chamber, Reynolds-Averaged Navier-Stokes equations are solved under the standard k-ε model assumption by the commercial software CFD-ACE+ [2]. Meanwhile, the turbulent-chemistry interaction is handled using the so-called eddy breakup model. The kerosene and the oxygen are injected thtough different inlet inside the injector and are changed into carbon dioxide and water according to an 1-step global scheme.

Dramatic changes in density, temperature, velocity and species mass fractions are expected where combustion occurs and as a result, it leads to changes in acoustic

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properties in the chamber. In order to compute the flame transfer function, one must access averaged quantities as well as fluctuating ones. The dynamic mode decomposition is used as a tool to compute frequency fixed density, pressure and velocity.

In order to extract the least damped modes through the dynamic mode decomposition, an acoustic excitation is imposed at a specific point outside the reaction zone in the domain and for a given time. Snapshots are recorded at a specific interval and for a two-dimensional plane. Then, the dynamic mode decomposition is performed and the density, velocity, and pressure fluctuations for the second longitudinal mode are extracted.

The flame transfer function is then computed by combining the inhomogeneous

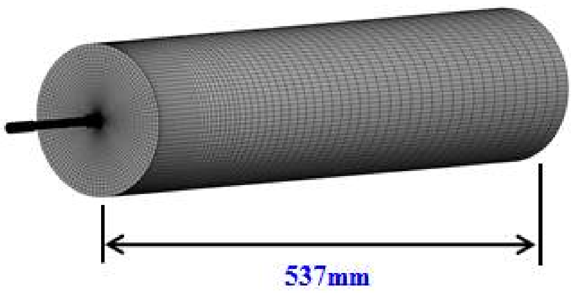


Fig.1: Geometry and computational grids of the model chamber and an injector

wave equation [3] and the Crocco's equation [4]. Mean quantities are computed based on CFD results and fluctuating quantities based on the DMD results [5]. The local phase and gain are computed and shown in Fig. 2. The local gain is large where the temperature gradient is large. The phase varies over a wide range in the flame zone.

The DMD damping coefficient reveals the acoustically optimal injector length for the second longitudinal mode. Similarly, the global gain for the second longitudinal mode was minimum for this injector length. This implies that a velocity fluctuation at the second longitudinal mode frequency generates a minimum heat release feedback fluctuation at this frequency for this injector length. The procedure based on Crocco's model, the inhomogeneous wave equation, and the dynamic mode decomposition shows thus promising results as a post process for

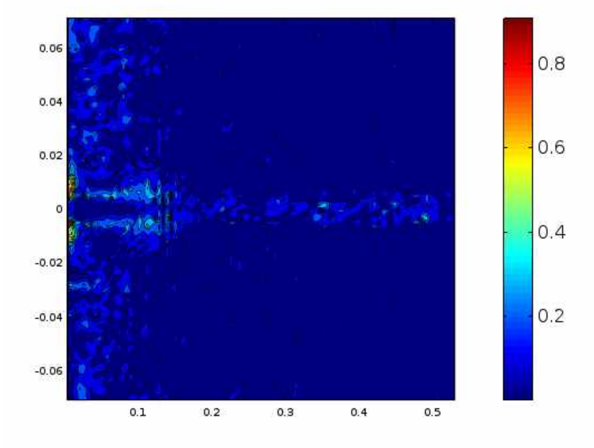


Fig.2: Local gain of FTF

stability evaluation tool.

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