Flame Response to Transverse Acoustic Forcing

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Background

Gas turbine engines are widely used in aircraft, marine, and electrical power generation systems for clean, efficient power source. These machines are capable of combined cycles efficiencies up to 60%.

Emission reduction strategies for power generation gas turbines utilize lean combustion where combustion instabilities are more prominent. The result of coupling between resonant combustor acoustics and flame heat release oscillations (Figure 1), combustion instabilities are responsible for component fatigue, reduced engine operability, and increased toxic emissions.

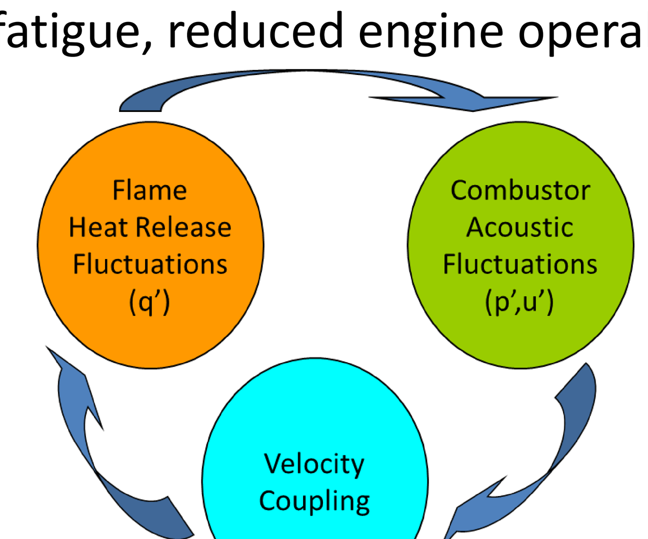

Figure 1a. Coupling process during combustion instabilities.

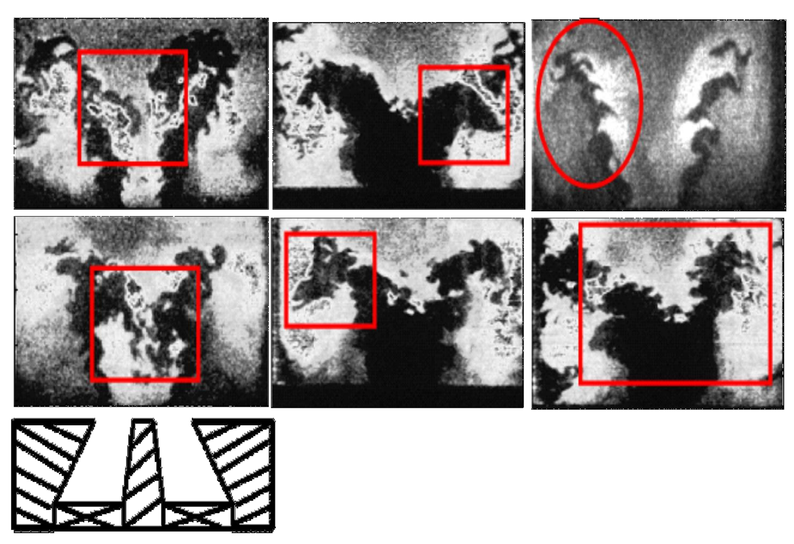

Figure 1b. Planar-laser induced fluorescence (PLIF) depicting flame wrinkling from acoustics excitation[1].

For annular combustor geometries, heat release oscillations can couple with the azimuthal acoustic mode represented in Figure 2a. For an azimuthal standing wave mode, transverse oscillations are produced in the vicinity of the nozzle in accordance with the nozzle location relative to the acoustic nodes.

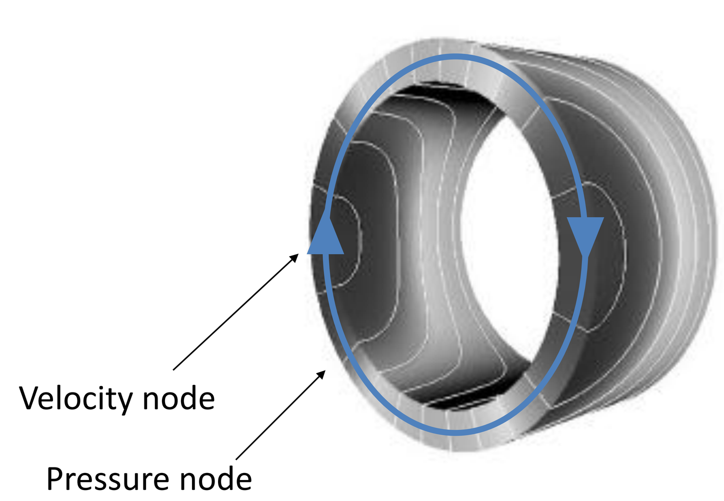

Figure 2a. Acoustic model for an annular geometry[2].

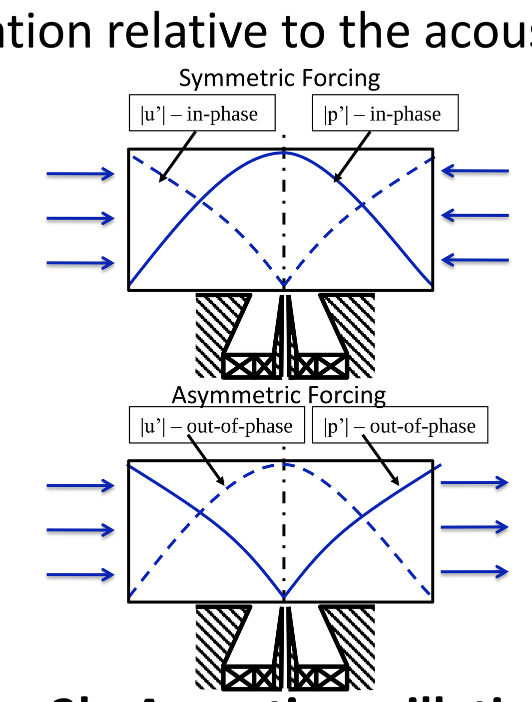

Figure 2b. Acoustic oscillations for pressure anti-node (top) and pressure node (bottom) .

Experimental Facility

Figure 3. Facility for transverse combustion instabilities.

The transverse forcing facility is shown in Figure 3. The facility is equipped with 3 speakers on each side to establish strong transverse acoustic waves that disturb the flow field and subsequently the flame. Large windows grant access for laser and imaging diagnostics.

High speed particle image velocimetry (HSPIV) is used to measure the time-resolved velocity field. This technique, Figure 4, uses paired seeded particle images to calculate the velocity field. Example results are shown in Figure 5.

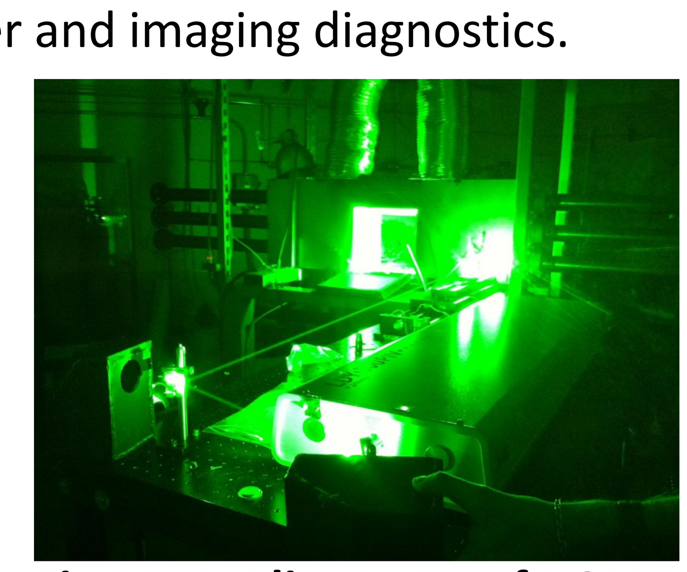

Figure 4. Alignment of HSPIV laser for use as a laser diagnostic tool.

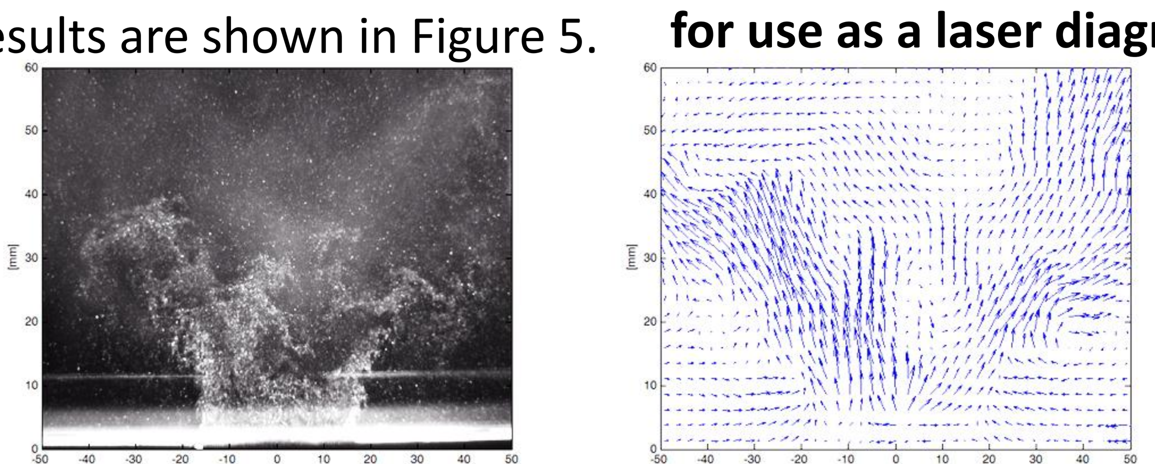

Figure 5. Raw particle image (left) and vector field (right) from HSPIV laser diagnostic tool.

Velocity Coupled Flame Response

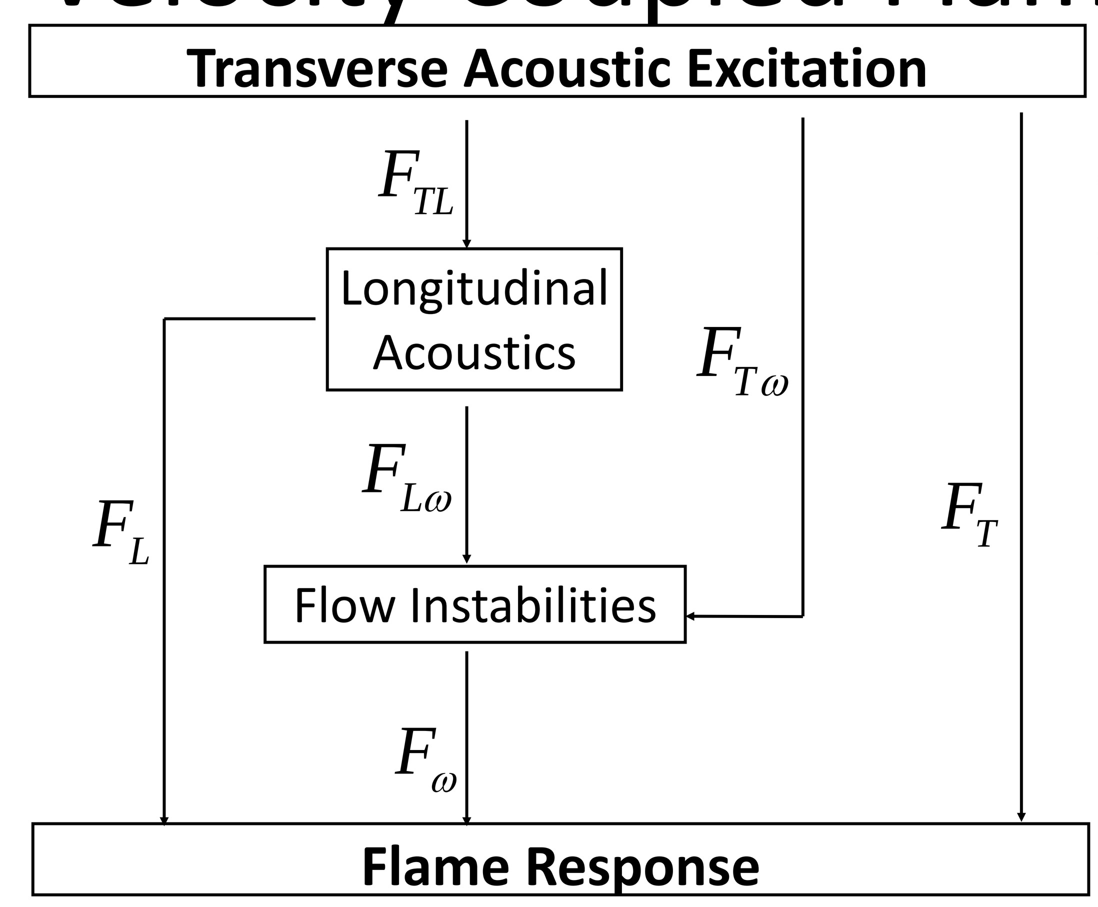

Figure 6. Possible flame response pathways during transverse forcing for swirl-stabilized flames.

Known disturbance pathways for velocity coupled flame response are shown in Figure 6:

- Direct excitation from transverse acoustics.
- Coupling between transverse acoustics and longitudinal acoustics localized around the nozzle.
- Longitudinal excitation of flame
- Excitation of natural flow instabilities from both transverse and longitudinal acoustics perturbations

Flame Leading Point Motion

- Aerodynamic stabilization of the flame , Figure 7, presents an additional source for flame wrinkles as the flame is not anchored.
- The natural motion of the flame leading point is dominated by the motion of the stagnation point in the recirculation zone.
- The forced motion of the flame leading point, $\langle \xi_{b,1} \rangle_{ph}$ is comparable to particle motion induced from acoustic excitation, $\xi_{b,m} = |u_{n,1}|_F / 2\pi f$ known to induce flame wrinkles.

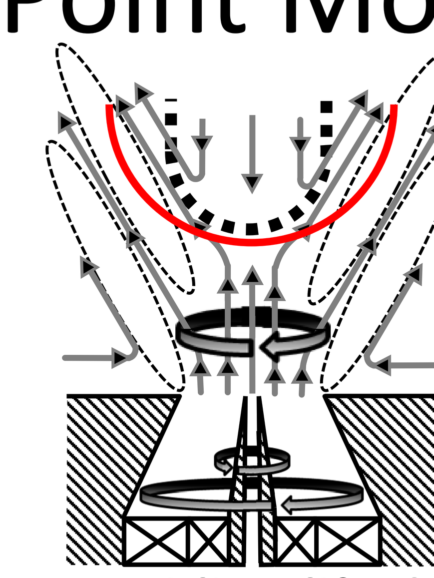

Figure 7. Swirling, lifted flame topology.

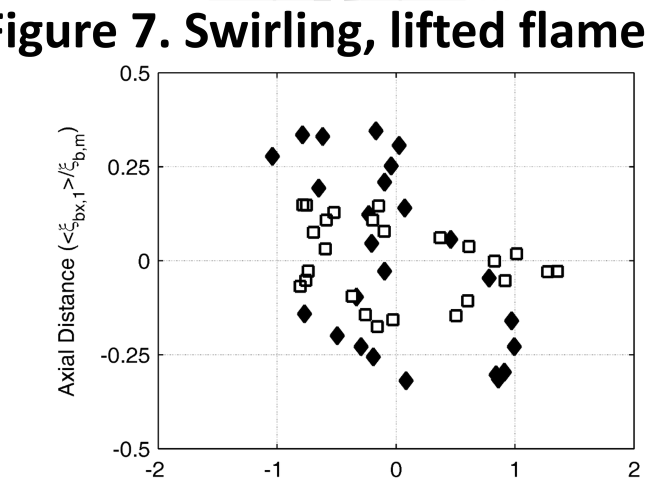

Figure 8. Forced flame motion normalized by particle motion for symmetric forcing(solid) and asymmetric forcing (open).

Multi-Nozzle Effects

Vortex-vortex interaction and flame-flame interaction may contribute significant differences to heat release oscillations between single and multi-nozzle facilities. Insight into these effects are paramount for application to gas turbine engines.

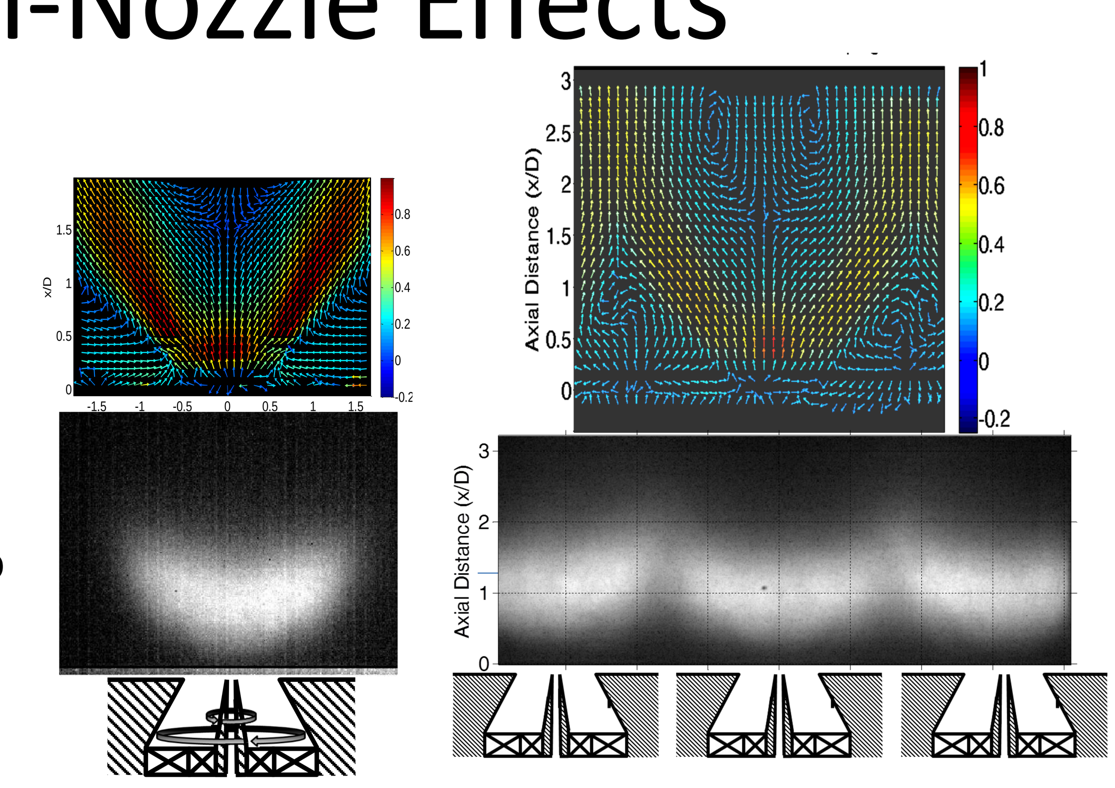

Figure 9. Time average single and multi-nozzle flame and flow field.

Impact: Investigation of the interactions between neighboring flames and flow structures and the flame response to transverse excitation increases the fidelity of flame response modeling allowing advancements in combustor design capabilities to avoid combustion instabilities.

1. Bellows, B.D. et al., *Flame transfer function saturation mechanisms in a swirl-stabilized combustor*. Proceedings of the Combustion Institute, 2007. **31(2): p. 3181-3188**
2. C. Sensiau *et al.*, International Journal of Aeroacoustics, 2009