Introduction
Motivation
Combustion instabilities are a leading cause of hardware damage.
- Combustion instabilities are poorly understood, particularly when coupled with hydrodynamic stability boundaries.
- Bluff body wake is common flame holding technique that is plagued with combustion instability.
- Bluff body wake is a simple, canonical flow field, well suited for fundamental combustion instability studies.

Bluff Body Flow Dynamics
Unforced bluff body flow fields exhibit Von Karman vortex street.
- Vortex street is the fluid’s natural dynamics-it is a global instability.
- Consists of alternating vortex shedding.
- Vortex shedding occurs at global mode frequency.

Reacting Flow Dynamics
Combustion may suppress the vortex street.
- High density ratio flames suppress vortex street: flow is globally stable.
- Low density ratio flames permit vortex street: flow is globally unstable.
- Flame density ratio is a stability parameter.
- Flame density ratio is particularly sensitive to preheat.

Methods
Combustor
- Vitiated bluff body burner
- Optically accessible

Diagnostics
- Measure velocity field with low-speed particle image velocimetry.
- Image the flame structure with high speed chemiluminescence.

Figure 1: Velocity and Density profile for reacting bluff body wake (1)

Figure 2: Nonreacting bluff body flowfield (2)

Figure 3: Global stability domains (1)

Figure 4: Reacting bluff body flowfield exhibiting base density asymmetry

Objectives
Determine the effect of base density and velocity asymmetry via parametric stability analysis on:
1. Global stability of the wake
2. Structure of the hydrodynamic global mode

Compare stability predictions to experimental observations.

Results
Test Conditions
Three cases
- One highly asymmetric condition predicted to be absolutely unstable.

χ = 0, S = 0.2
χ = 0.3, S = 0.3
χ = 1.1, S = 0.6

Figure 5: Generalized model profiles for base velocity (left) and base density (right)

Figure 6: Experimental test conditions

Magnitude of flame flapping
Highest density asymmetry case shows greatest flame flapping

Flapping of lean vs. rich branches
Highly asymmetric case shows greater oscillations of leaner flame branch.

Observations
1. Base density asymmetry increases absolute growth rate, reduces absolute frequency.
2. Base velocity asymmetry reduces absolute growth rate, increases absolute frequency.
3. Density asymmetry distorts hydrodynamic mode shape.
4. Flame branch with smaller density jump associated with greater hydrodynamic oscillations.

Figure 7: Magnitude of flame flapping

Figure 8: Flapping of lean/rich branches

Conclusion
1. Base density asymmetry is an important stability parameter.
2. Leaner flame oscillates more with higher base density asymmetry.

Analysis
Global stability analysis
Captures important qualitative trends.
- Does not quantitatively describe observed global stability boundaries.
- Wide range of stability-transition parameters reported in literature.
- Due to non-colocation of density jump and shear layer.

Generalized reacting wake model
Permits linearly-stratified base density in bluff body wake.
- S, χ characterize base density asymmetry.
- χ, S characterize base velocity asymmetry.

Generalized model predictions
Absolute frequency and growth rate strongly affected by base asymmetry.
- Base density (velocity) asymmetry increases (reduces) growth rates, reduces (increases) frequency.
- Hydrodynamic mode shapes distorted by density asymmetry.
- Small base density jump associated with large oscillations.

Figure 9: Generalized model profiles for base velocity (left) and base density (right)

Figure 10: Predicted generalized global stability domains

Figure 11: Hydrodynamic mode shapes with and without asymmetry.

Figure 12: Hydrodynamic flapping amplitude predictions

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