Validation of a combustion oscillation model

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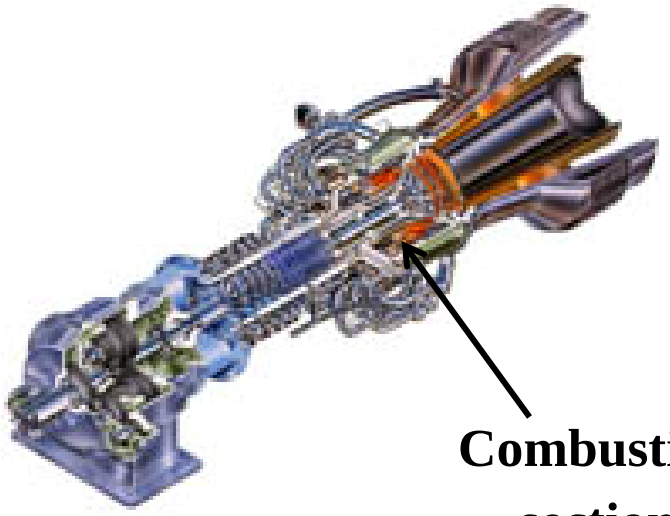
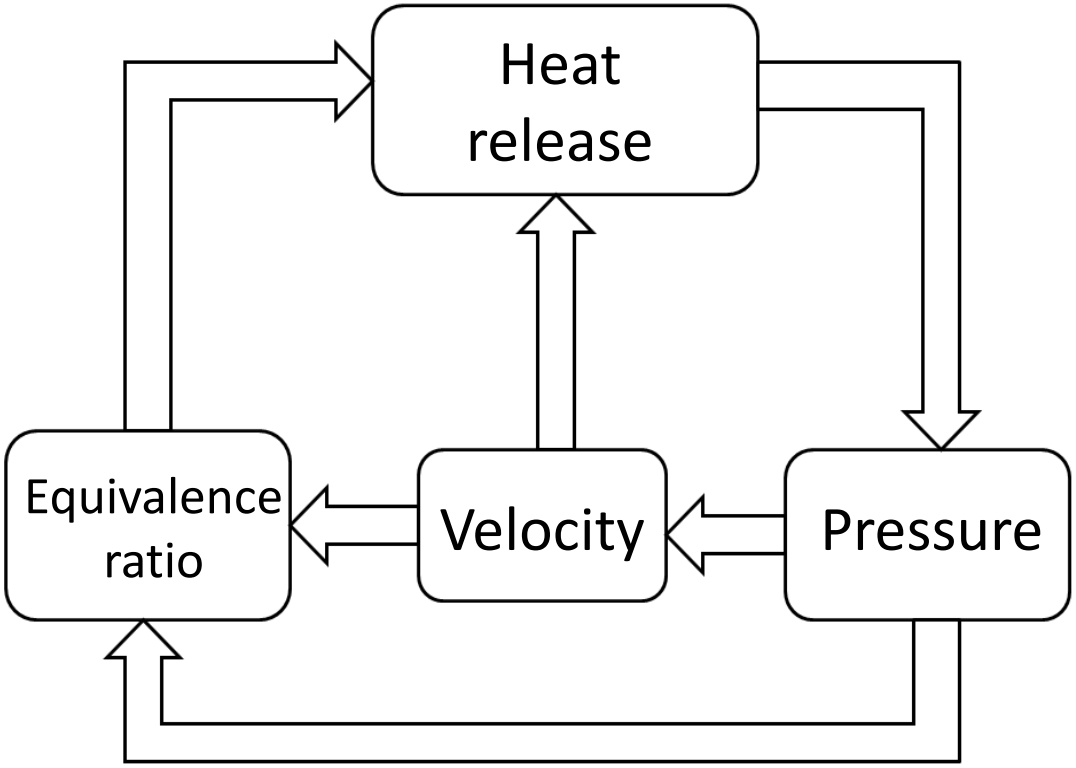
Introduction



- PhD research in experimental study of combustion oscillations
- Validated an oscillations model with experimental data during internship with Solar Turbines

Combustion Oscillations Feedback Loop

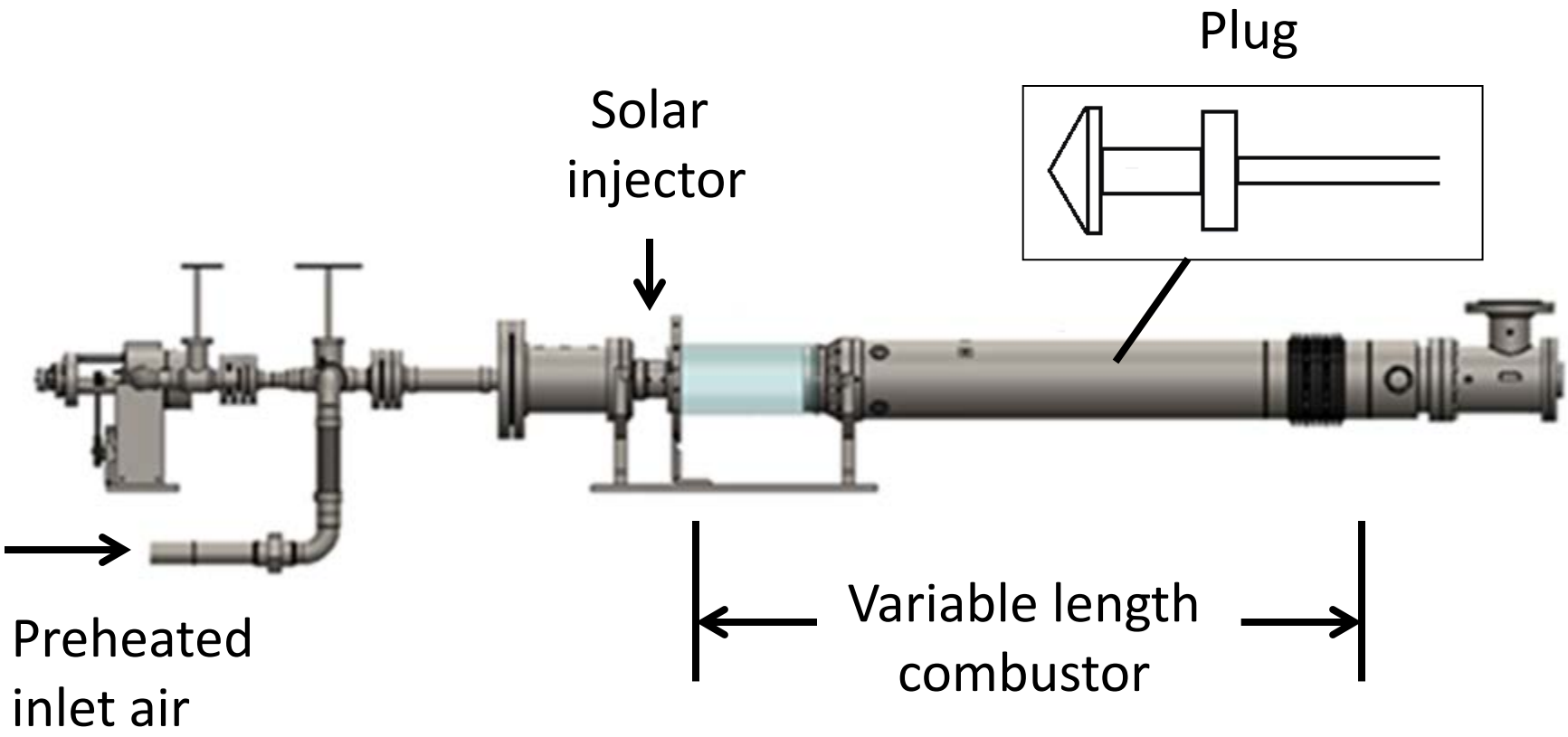


Motivation for acoustic network model

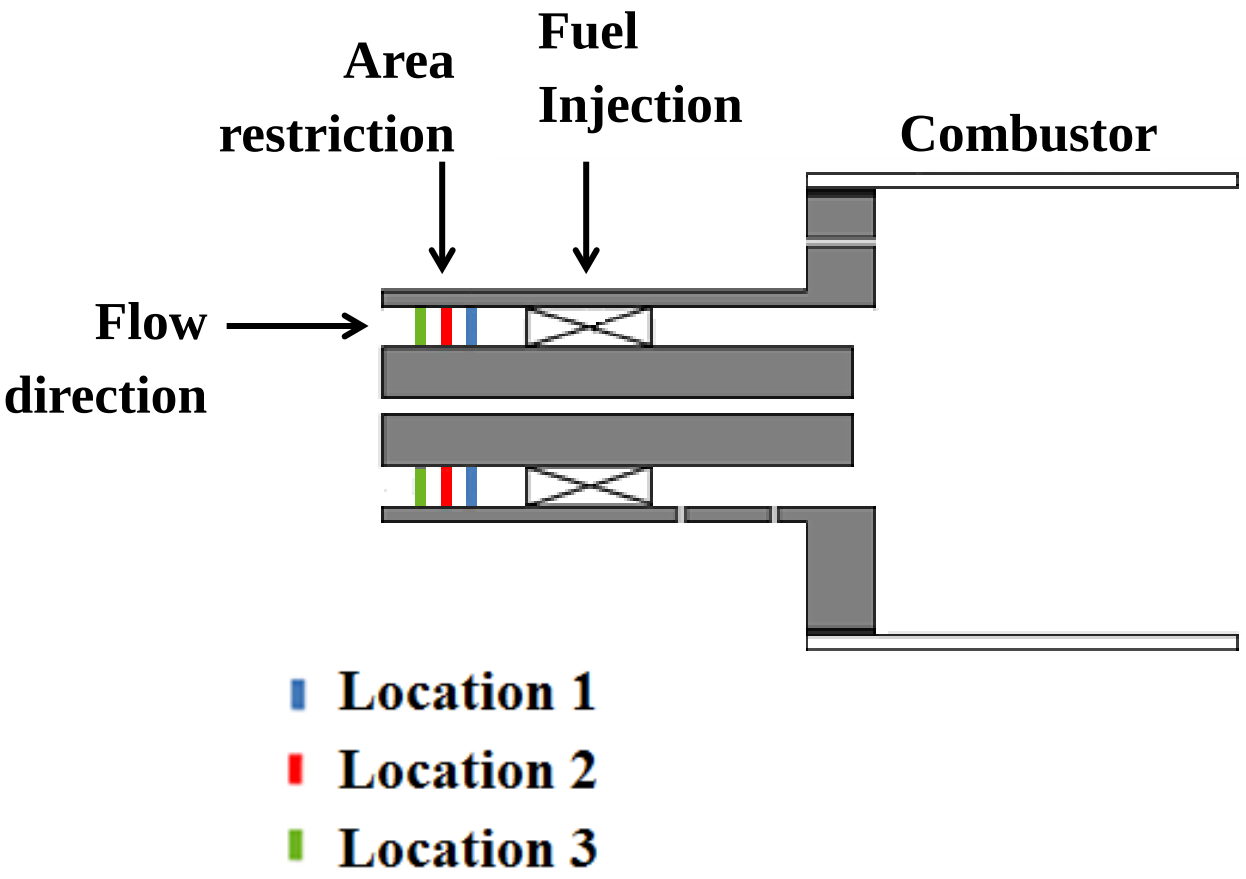
- Large oscillations can cause flame flashback, blowout, reduced efficiency, and damage of the combustion system

- Ability to predict instabilities would be extremely useful for gas turbine design

Penn State test rig schematic

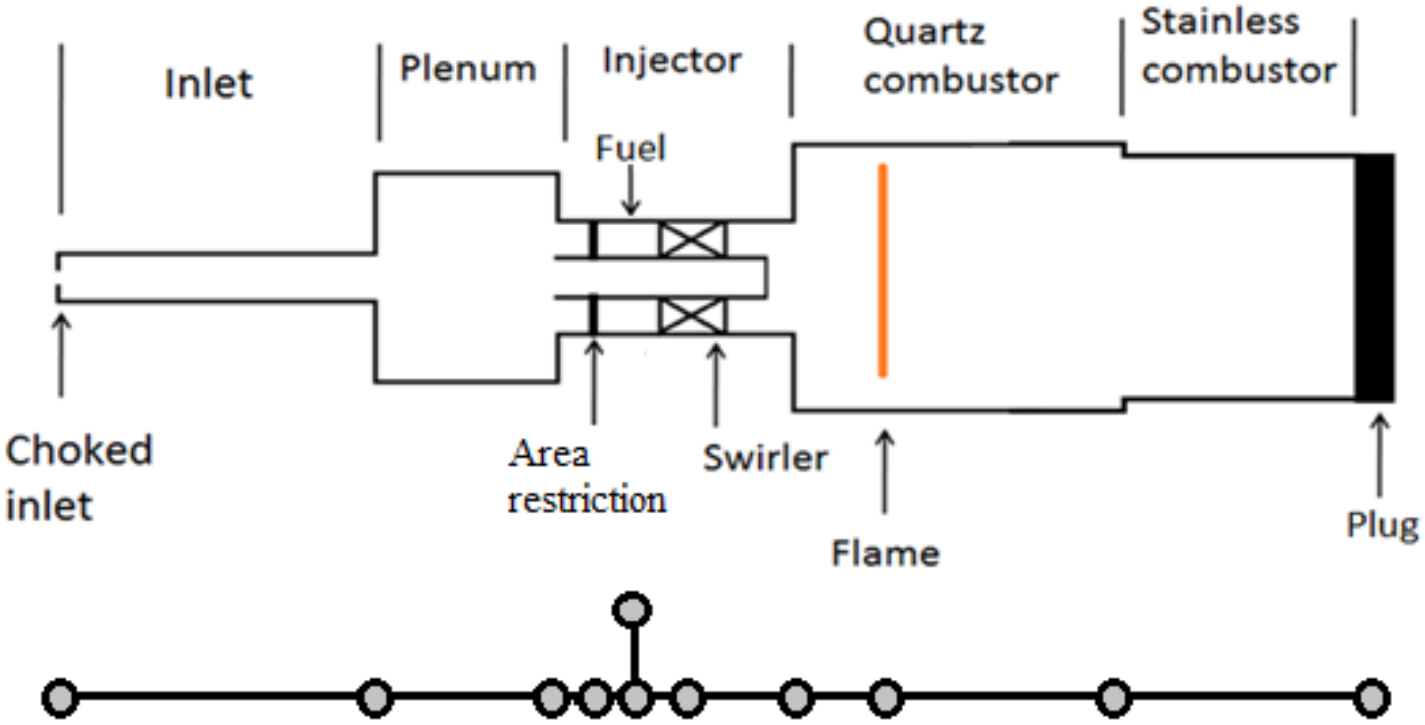


Penn State test rig schematic: Injector



Acoustic network model

- 1D acoustic network model
- Geometry of Penn State rig divided into a series of ducts and junctions



Acoustic network model

- Model calculates natural frequencies of the combustor

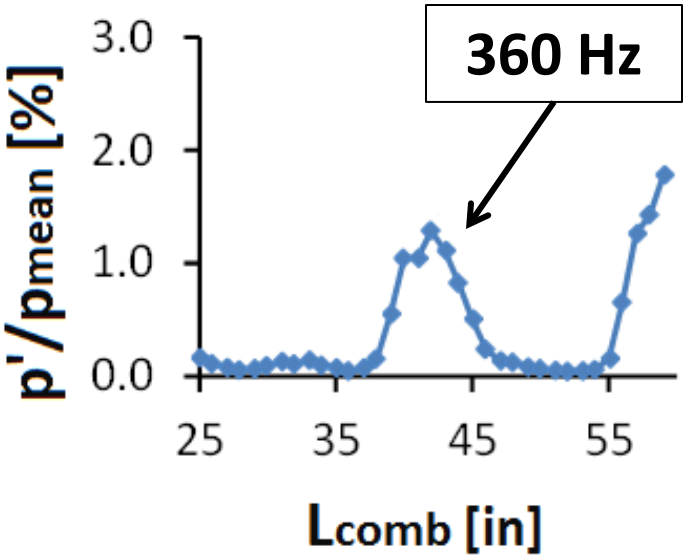
- Includes heat release model to predict frequencies and growth rates
  - Positive growth rates -> instability grows
  - Negative growth rate -> instability damped

Experimental Results: Effect of equivalence ratio

Φ = 0.55

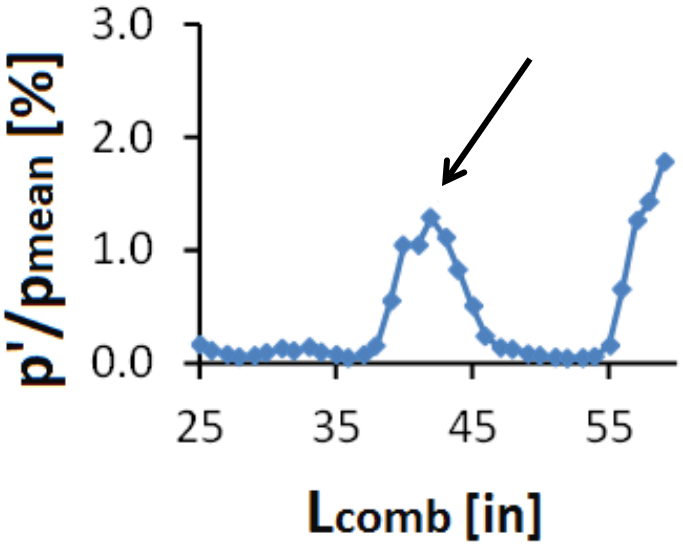
Tin = 250C

Uin = 40 m/s

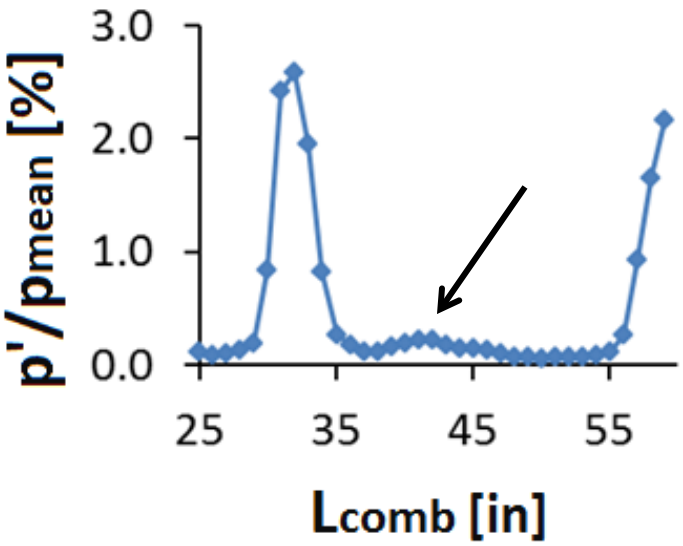


Experimental Results: Effect of equivalence ratio

Φ = 0.55



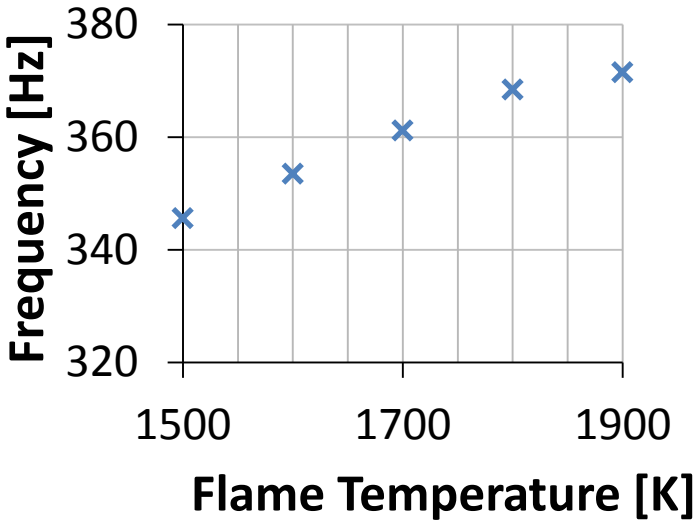
Φ = 0.60

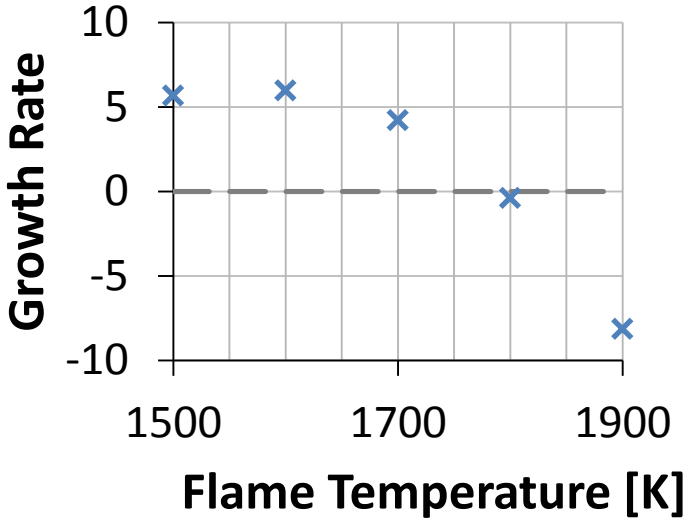


Model validation

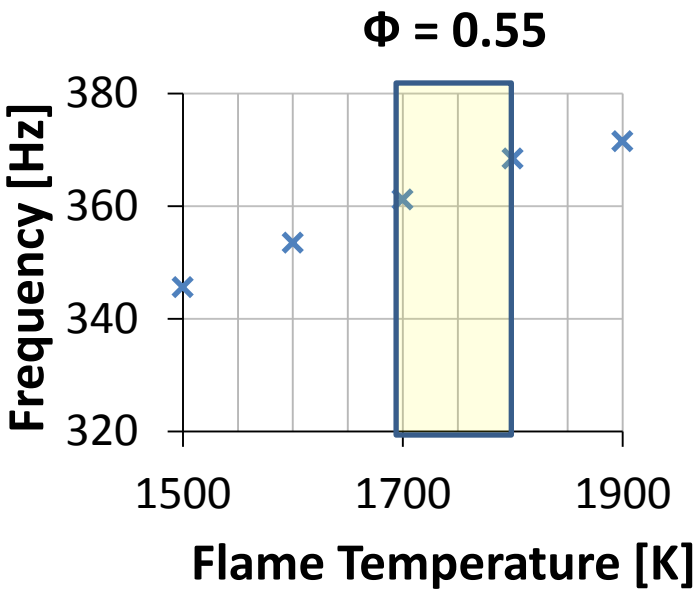
- Higher equivalence ratios result in higher flame temperatures
- Sensitivity of model to flame temperature was tested
- Expect to see an instability for low flame temperatures but not for high flame temperatures

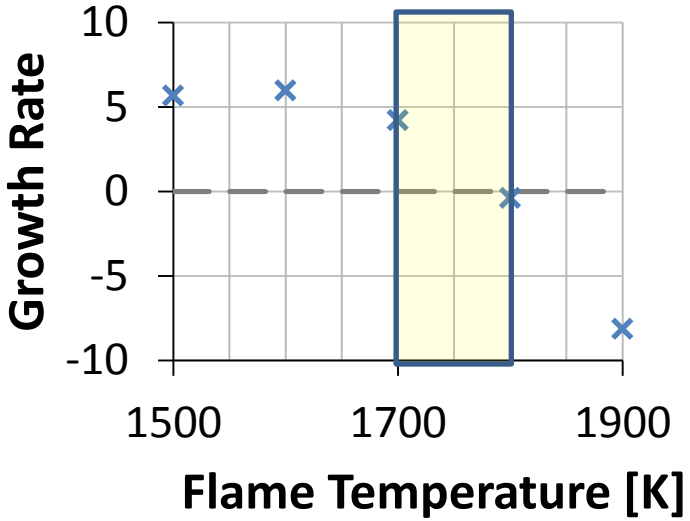
Model validation: Effect of equivalence ratio





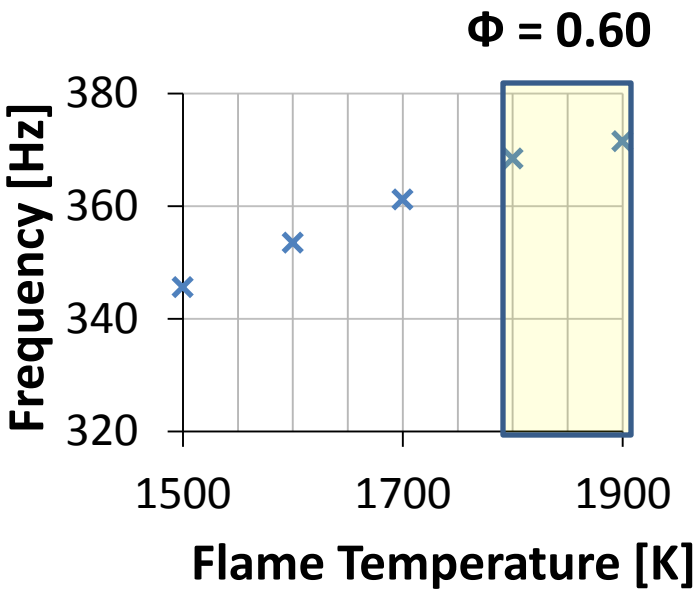
Model validation: Effect of equivalence ratio

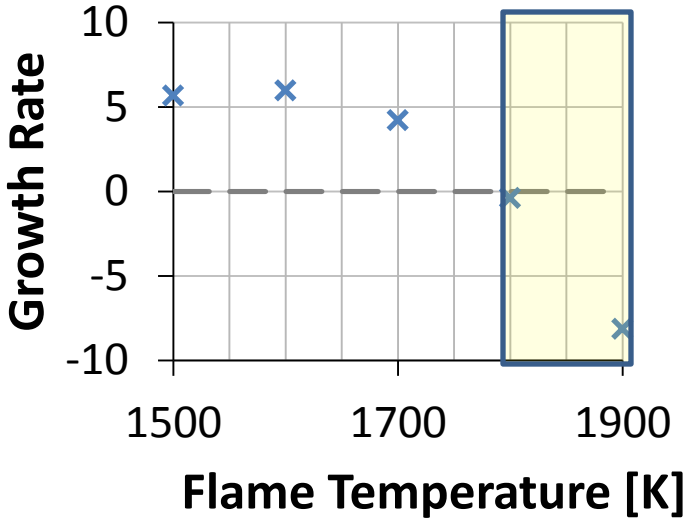




- At lower flame temperatures, the model predicts a positive growth rate (instability will grow)

Model validation: Effect of equivalence ratio

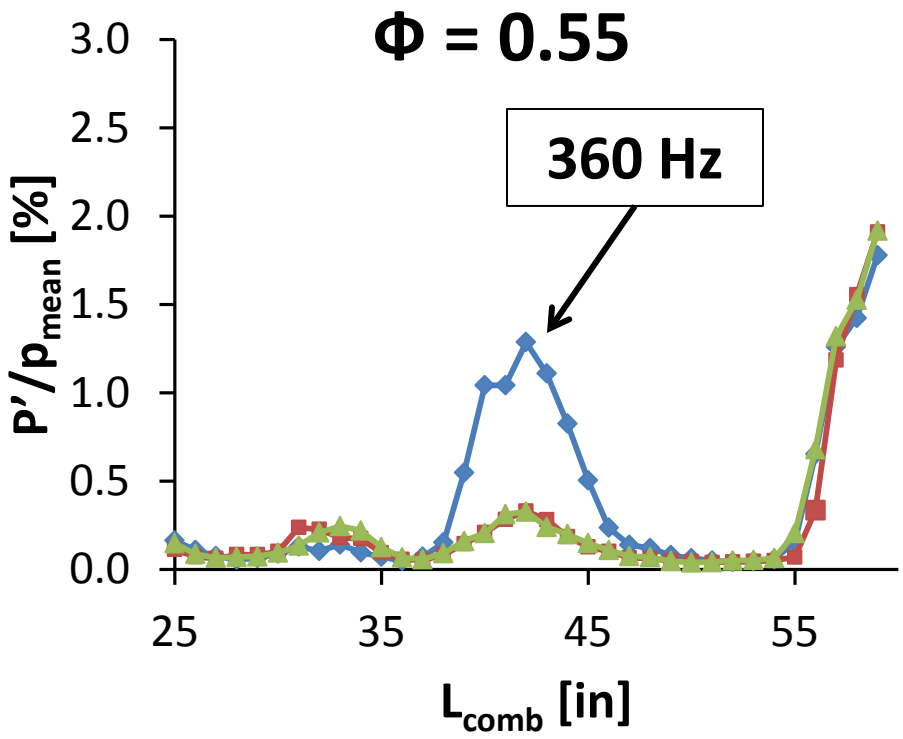




- At higher flame temperatures, the model predicts a negative growth rate (instability will be damped)

Experimental Results
Effect of area restriction location

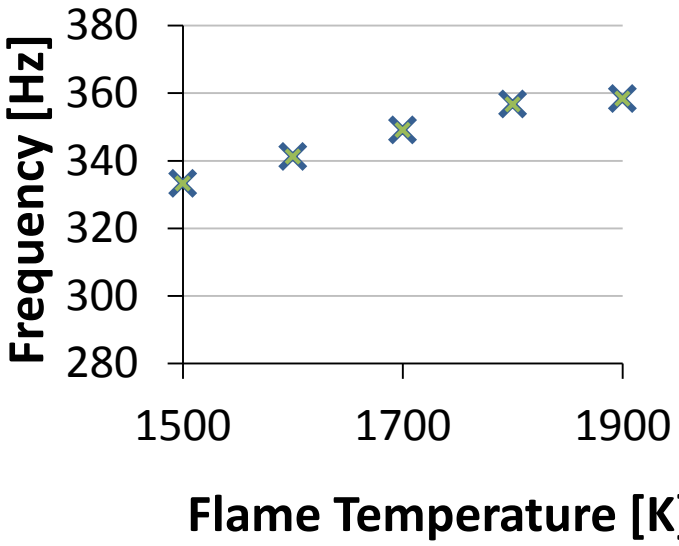
Baseline
1” upstream
2” upstream

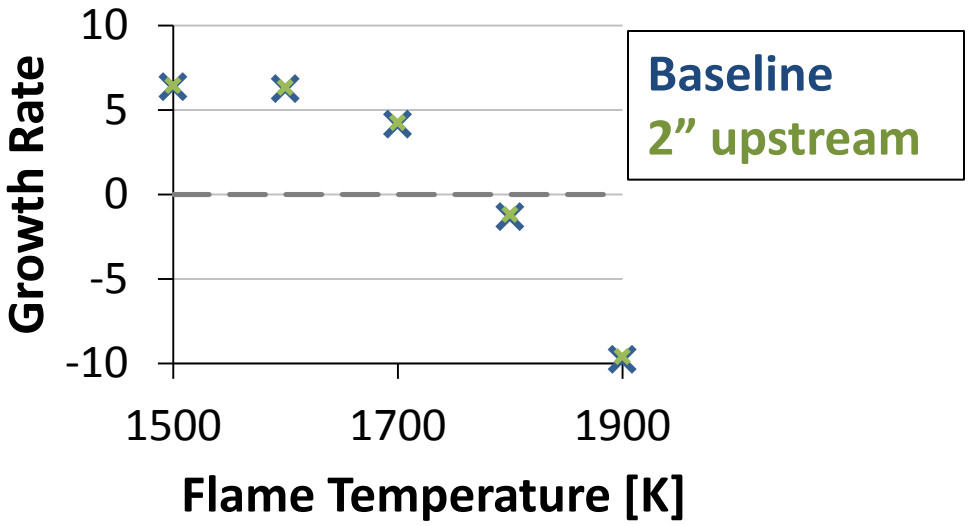


- Upstream locations reduce the instability

Model Results
Effect of area restriction location

- Restriction location was varied in the model

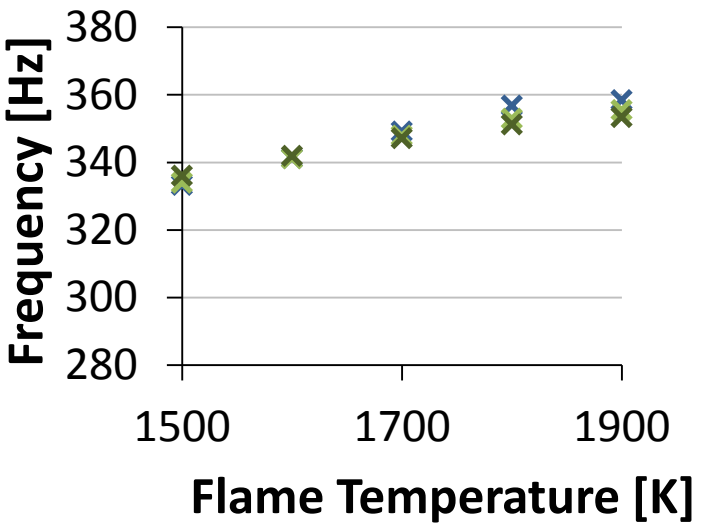


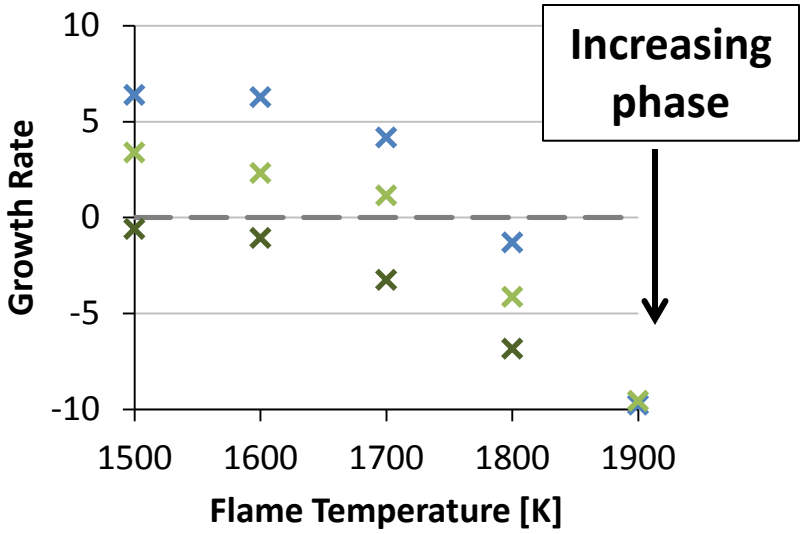


- Area restriction location does not change system acoustics
- Effect observed in experiment is not purely acoustic

Model Results
Effect of velocity oscillations phase

- Velocity oscillations phase varied from 0° to 40°



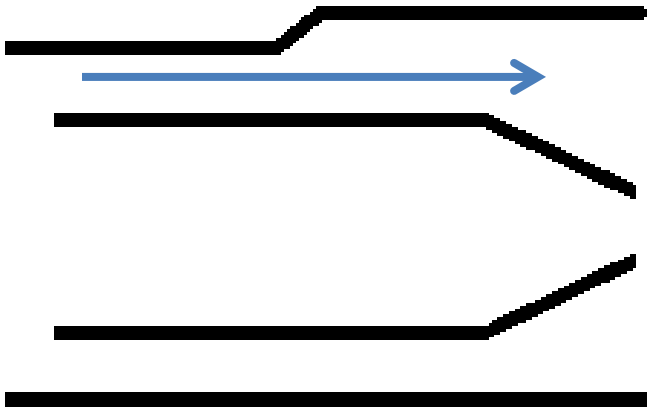


- Observed effect of area restriction likely due to change velocity oscillations phase

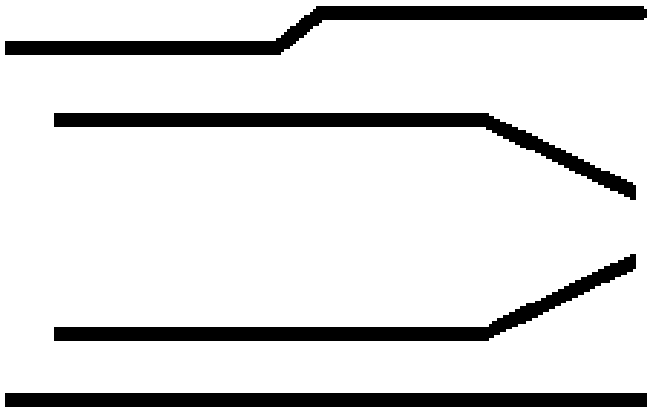
Applications to Solar turbine design

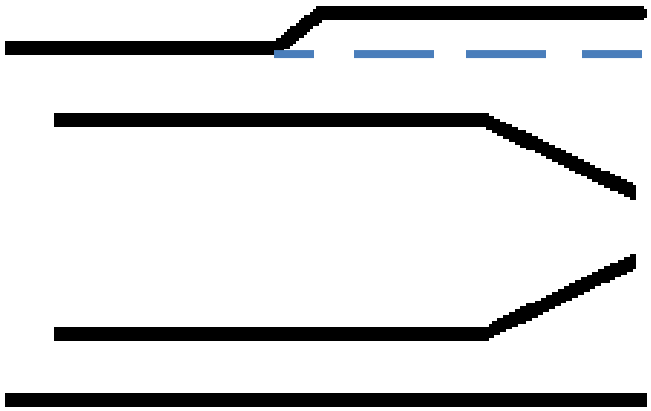
- Engine testing at Solar showed a 200 Hz instability
- The acoustic network model also shows 200 Hz natural frequency
- Plots of mode shapes show the instability is associated with the outer region of the combustor

Combustor schematic

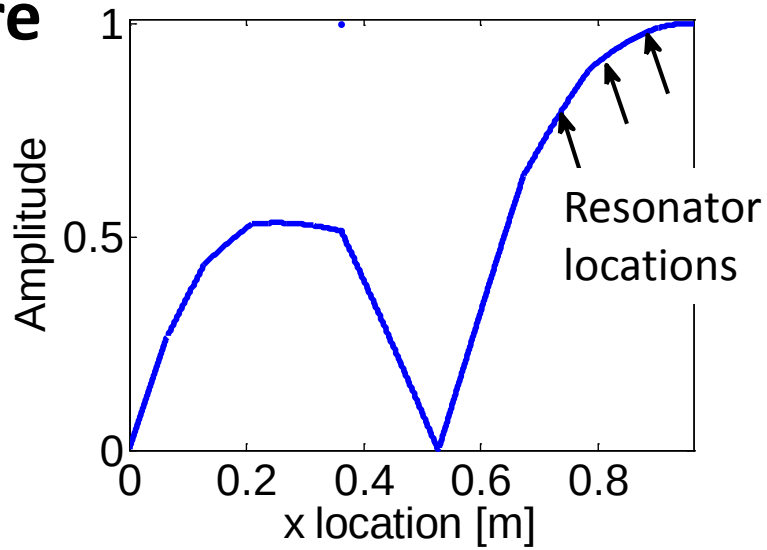


Effect of resonator on 200 Hz mode shape

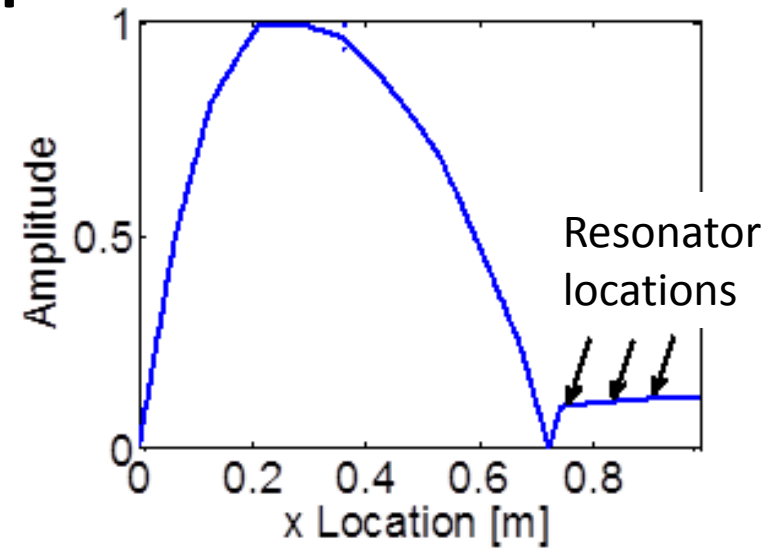




Before



After



Internship Take Aways

- Application of experimental results to problems currently facing Solar
- Experience in acoustic modeling
- Industry experience
- Summer in San Diego

Acknowledgements

PENNSTATE

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University Turbine Systems Research

Solar® Turbines
A Caterpillar Company