Thermoacoustic Modeling of Injector Geometry and Performance

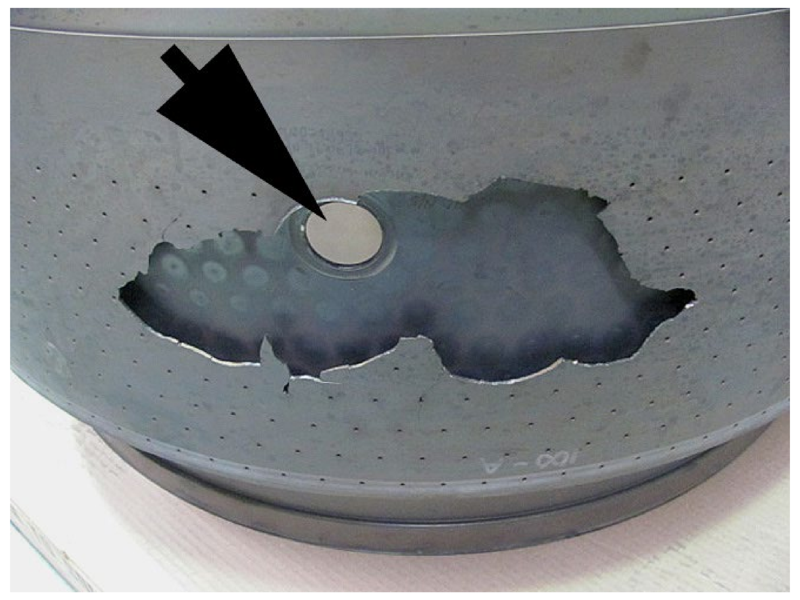
Solar Turbines
A Caterpillar Company

Austin Matthews, Jim Blust, Michel Akiki
Solar Turbines Inc.
2019 University Turbine System Research Gas Turbine Industrial Fellowship Program

SwRI
Southwest Research Institute

Introduction

Flame-induced thermoacoustic oscillations are a major challenge for the long-term reliable performance of gas turbine engines. These complex phenomena depend on a variety of different driving factors and can lead to high-cycle fatigue of combustor liners and injectors well before the mature component lifetime. Over the past several years, important advancements have been made in the modeling of these issues in order to mitigate performance issues. As a case study, a popular Low-NOx injector was analyzed in preparation for a manufacturing process change.



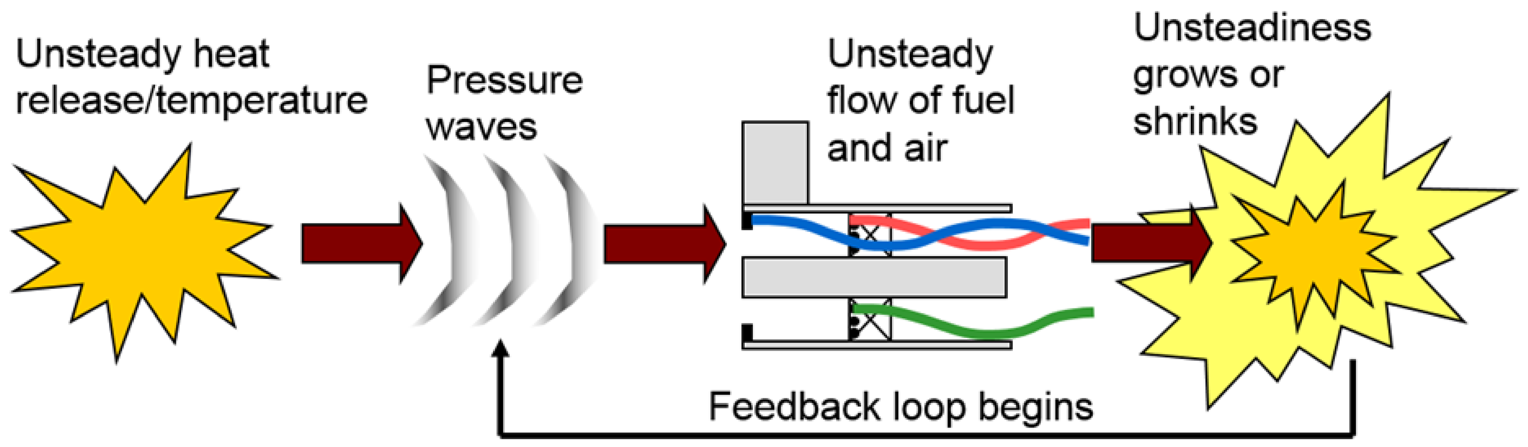
Combustor Liner Damage from Combustion-Induced Oscillations

Thermoacoustic Feedback

Oscillations are caused by a positive feedback loop between the flame front in the combustor and the flow of reactants being supplied to the primary zone

- Broadband noise caused by unsteadiness in combustion reaction
- Certain frequencies will grow due to geometry-based resonance in specific passageways of engine
- Resonance can grow to affect reactant flow, which further exacerbates original problem at flame front

By focusing analytical efforts around natural (geometry-based) frequencies, the problematic modes are more likely to be identified and mitigated



Thermoacoustic Oscillation Feedback Diagram

Simulation Workflow

Single injector Model

Geometric data is derived from drawings and models

- Length and diameter of all injector passages
- Sharp changes modeled as discrete flow restriction
- Surface roughness included

One Dimensional Flow Model

Simplified network used to calculate theoretical flow spits

- Ducts, nodes, and restrictions
- Iteratively calculates mass and velocity in each circuit
- Boundary conditions based on production test data

Flow Calibration

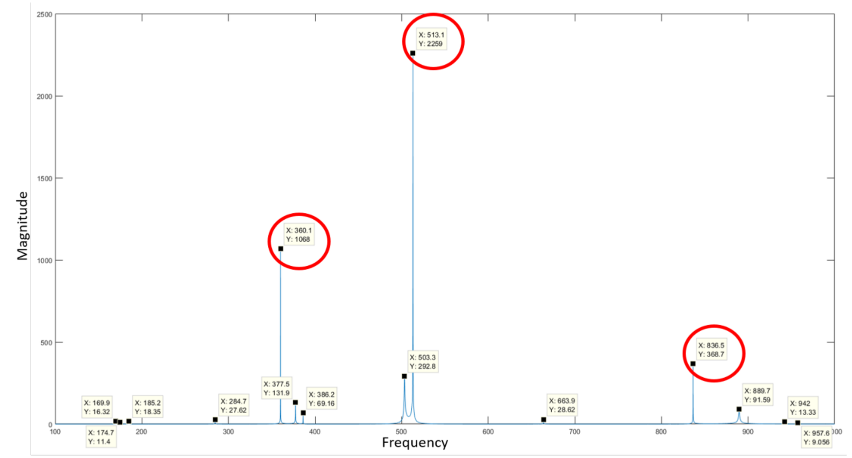
Parameters are adjusted based on various existing data

- Discharge coefficients, swirler parameters adjusted
- Multiple sources: Aero Specs, CFD, real and sim test data

Forced Excitation

Frequency domain is swept to find areas of interest

- Domain discretized into intervals
- Solver "forces" the system to vibrate at each frequency
- Yield FFT-style plot- spikes have high likelihood of yielding problematic frequencies when coupled with flame

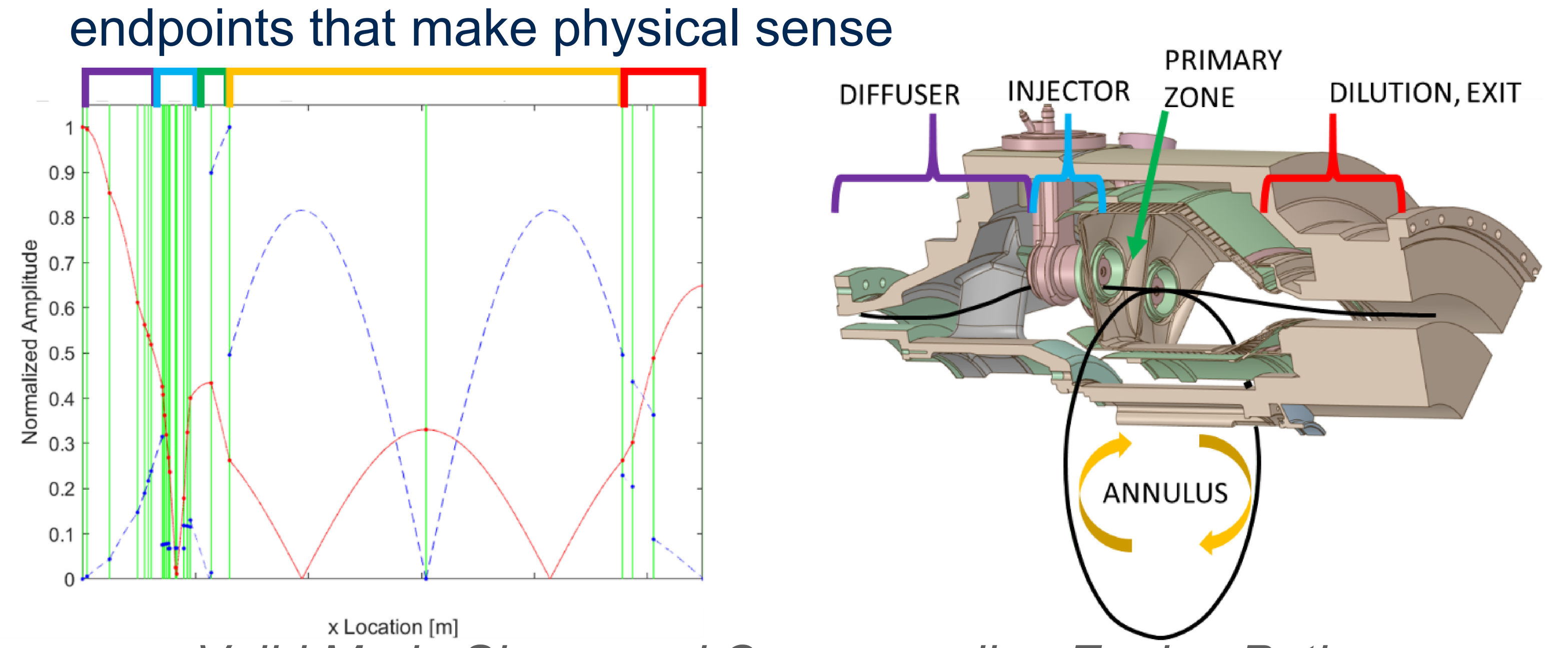


Forced response output example with frequencies of interest circled in red

Self-Excited Frequencies and Mode Shapes

Eigenvalue solver used to determine problem frequencies

- Complex-valued solutions have an imaginary component corresponding to growth rate
- Pressure and volume-velocity fields plotted with respect to 1-dimensional routes through the engine
- Valid mode shapes have a continuous wave structure and endpoints that make physical sense



Valid Mode Shape and Corresponding Engine Path

Test Cell Validation

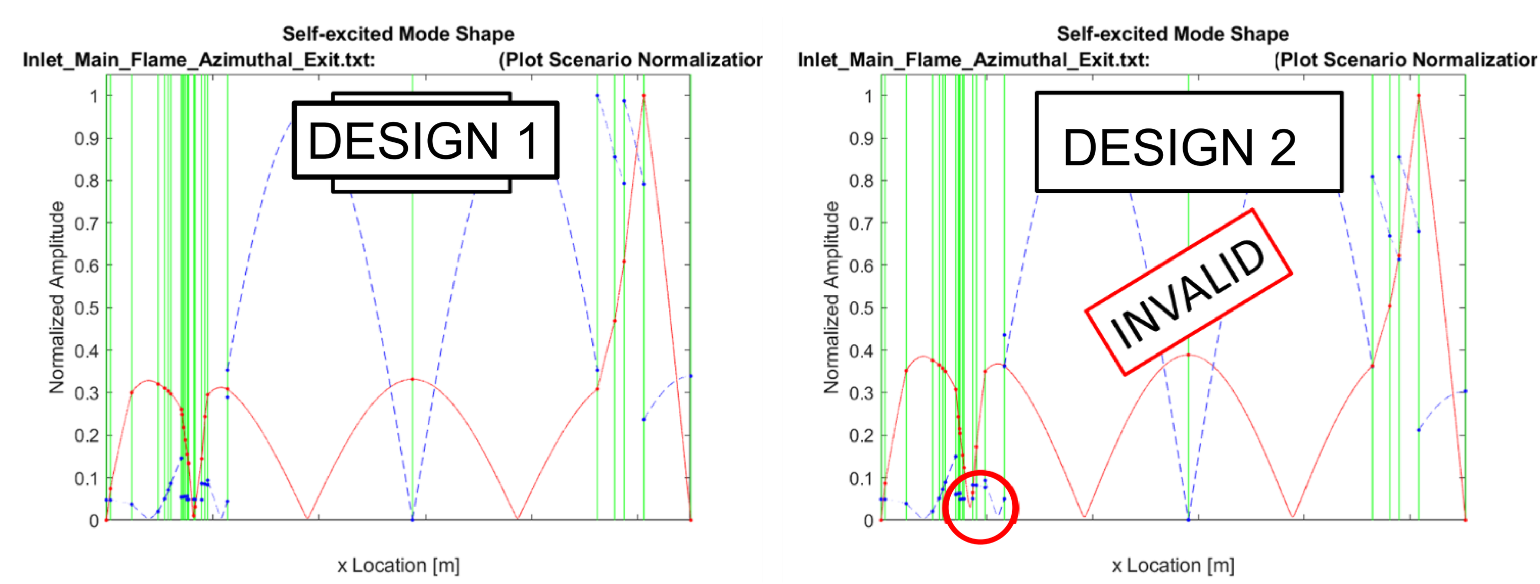
- Out of hundreds of complex-valued solutions, only four yield valid mode shapes
- Strong correlation to production engine oscillations spectrum- indicates validity
- Large last spike on spectrum corresponds to circumference of main combustor annulus

Spectral Test Results for Model Validation

Use in Design Process

Conclusions derived from analysis process can be used to guide iterative design decisions

- Lessons learned can be used to develop "best practices" when designing liners and injectors
- Analysis applied to existing problematic engines can be used to size and locate attenuation devices
- Seemingly insignificant design changes can cause large differences in oscillations performance



Specific solution becomes invalid as result of small design change (no longer creates complete waveform)