Dynamic Instability Limits in the Testing of an Advanced Premixed Combustor

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PRINCETON
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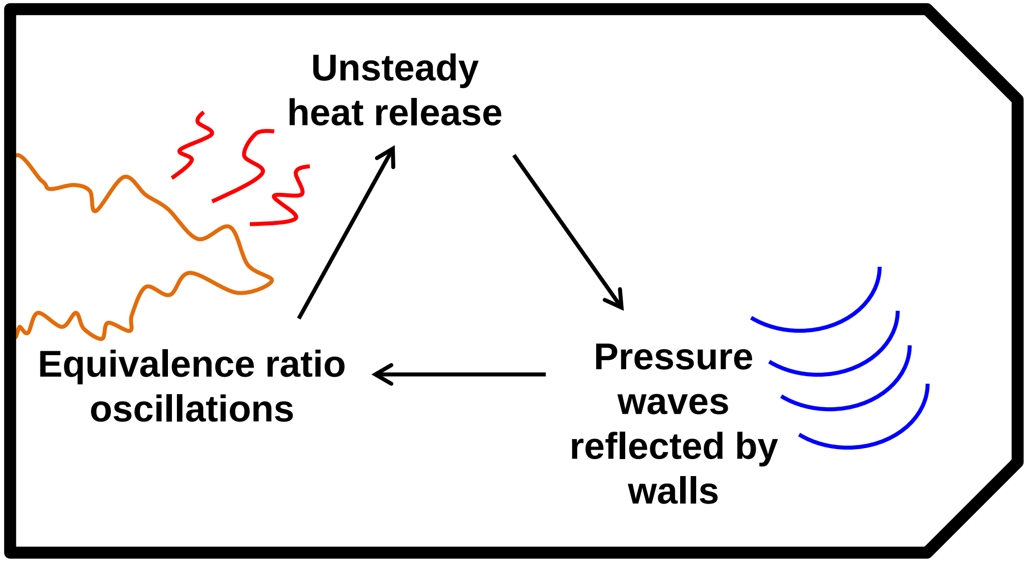
Background

Personal Background

- Grew up in New Orleans, LA
- Undergraduate education at the University of Virginia
  - Aerospace Engineering major
- Graduate studies at Princeton University
  - Department of Mechanical and Aerospace Engineering
  - Prof. Yiguang Ju’s Combustion Lab

Lean Premixed Combustion

- For gas turbines, premixed combustion offers reduced emissions (particularly NO_x) compared to nonpremixed techniques
  - Using lean premixtures can allow for lower maximum flame temperatures
- However, lean premixed combustion is more susceptible to combustion instabilities as a result of interactions between heat release, pressure, and mixing
- New premixed combustors must be able to control these instabilities to operate safely and effectively



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Siemens Combustor Development

- Many paths exist to improve gas turbines: new combustion techniques, material advances, more effective cooling methods
- Siemens has recently been investigating several concepts to improve mixing characteristics in premixed combustors
  - Better mixing results in fewer temperature gradients and therefore less NO_x
  - However, the trade-off is a higher susceptibility to combustion instabilities
- Multi-step technology development process
  - Initial design, laboratory tests, detailed design, rig tests, etc.
- After rig testing, two designs (Design #1 and Design #2) were chosen for full-scale engine tests this past summer

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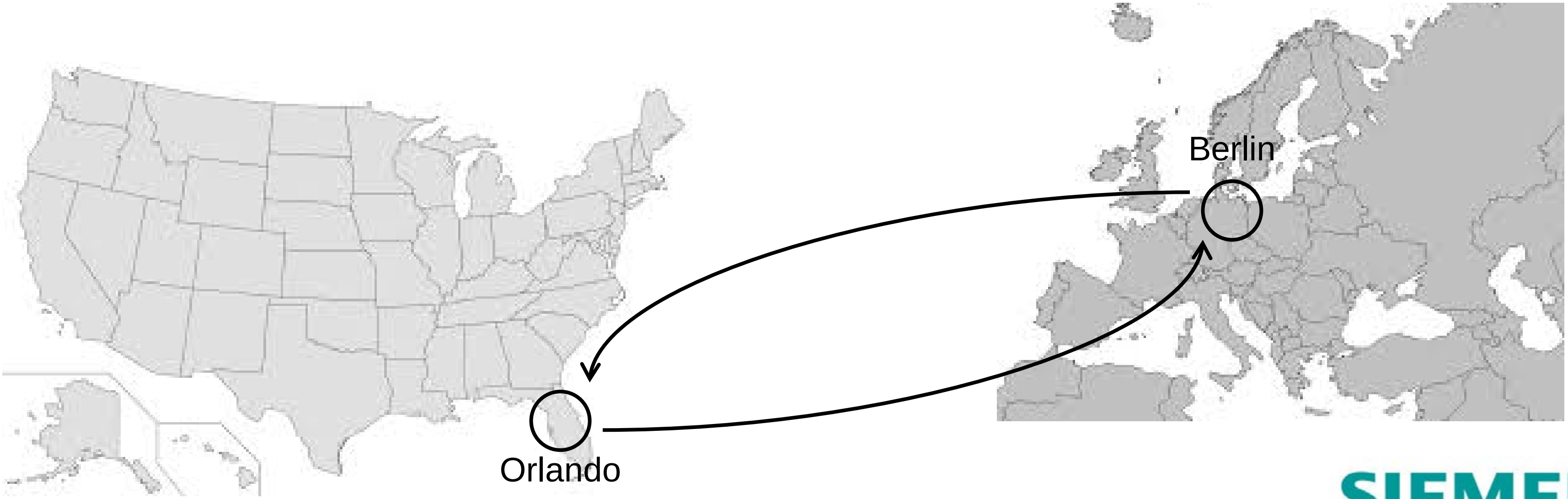
Siemens Combustor Testing

- Full-scale engine set-up in Berlin Test Facility
  - Extensive diagnostics: thermocouples, pressure transducers, gas analyzers
- Expensive test due to its scale but extremely valuable in advancing the understanding of a design
- Some goals of the testing period (June-August 2015):
  - Confirm the emissions benefits of the new designs
  - Evaluate combustor behavior at engine operating conditions and off-design conditions
- Data was analyzed by engineers in both Germany and the United States



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My Tasks

- Data processing:
  - (1) Convert raw data to useable form
  - (2) Compile analyzed data once testing period was complete
- Data analysis:
  - (3) Examine correlations between measurements (CO emissions vs load, NO_x emissions vs various tuning parameters, etc.) to better understand how the engine performs under various conditions
  - (4) Check quality of steady-state data measurements
  - (5) Examine various points of interest during testing (engine trip, unstable pressure spikes, flame blow-off, etc.) to find possible causes behind events

Test Results

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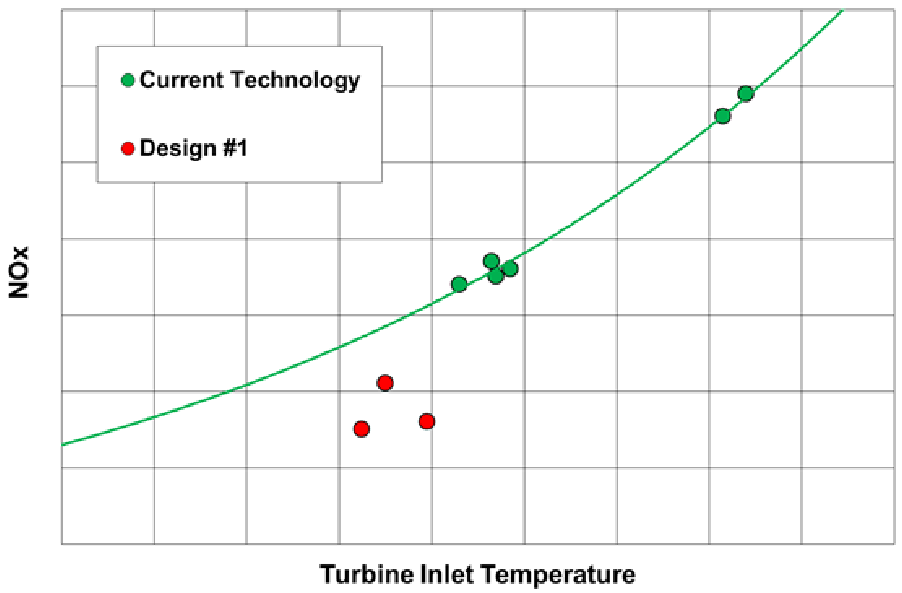
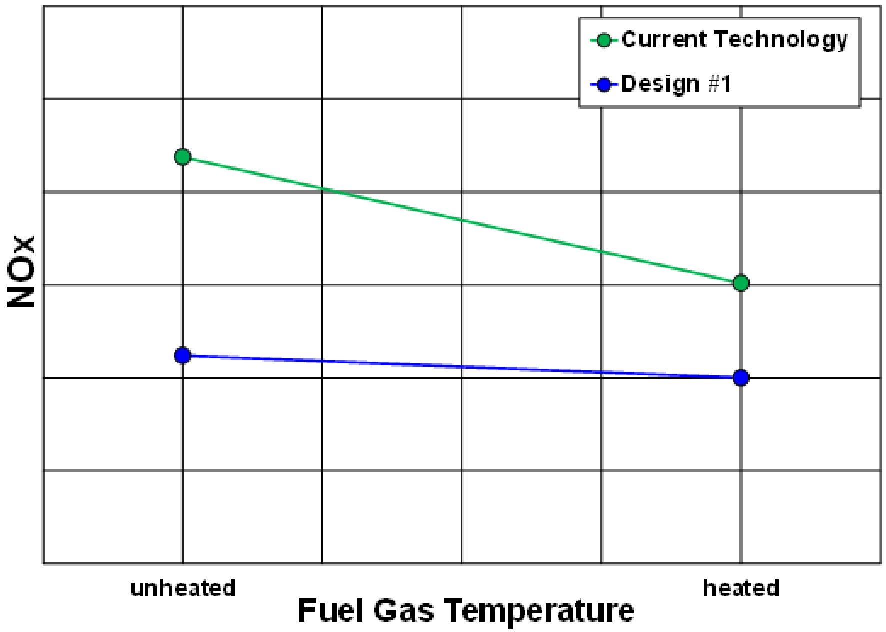
Design #1 Test: NO_x

- Full-scale engine test showed a NO_x decrease for Design #1 compared to the current technology (a different premixed combustor design)
- Trend agreed with results from smaller rig tests
- At these points, Design #1 could reach a higher turbine inlet temperature (higher efficiency) for the same NO_x limit



Design #1 Test: NO_x

- Design #1 also appeared less susceptible to outside conditions such as fuel or air temperature than the current technology
- Fuel gas temperature showed little effect on NO_x emissions
- Potential for Design #1's ease of use in a wide variety of markets (hot climates, cold climates, etc.)



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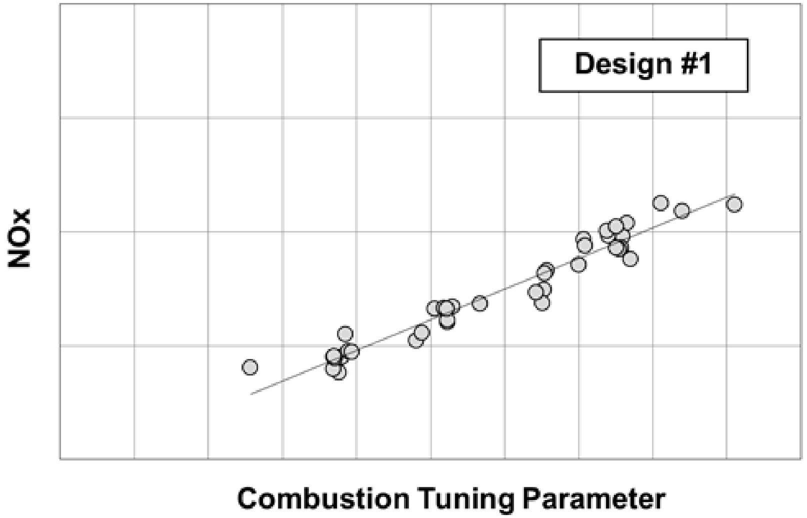
Design #1 Test: Tuning

- In order to optimize engine performance at a given load, various tuning parameters are utilized

- Several parameters can be shown to correlate with NO_x emissions (through linear regression or other types of analysis), but one specific tuning parameter was most strongly correlated with NO_x in Design #1

- However, thorough tuning of this parameter was limited during testing…



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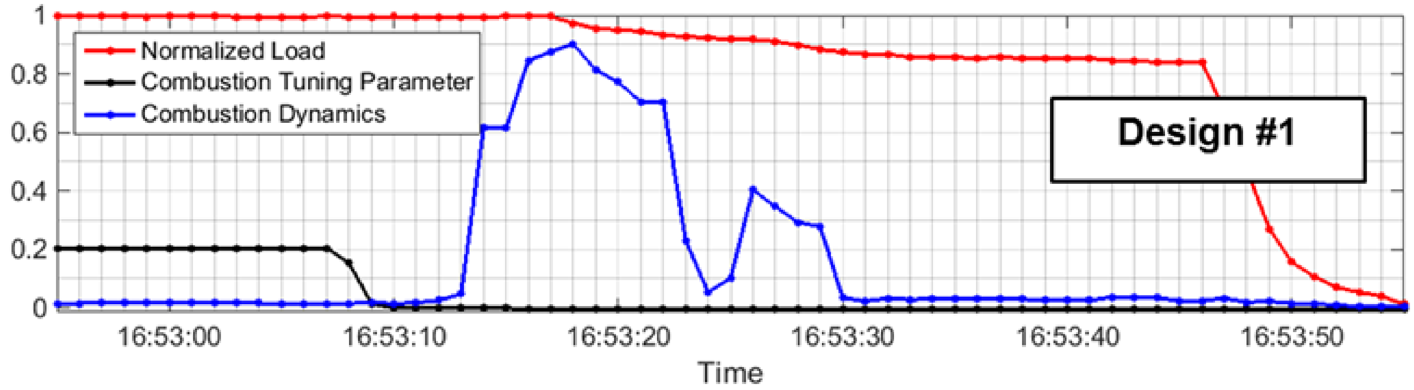
Design #1 Test: Tuning



- Tuning in Design #1 was often limited by combustion instabilities
- In several instances, reduction in a tuning parameter led to large pressure spikes caused by the dominant instability mode
  - Importance of this mode was somewhat suspected from thermoacoustic calculations
- These instability events often resulted in an engine trip a few seconds later
- As a result, the operational range of the Design #1 engine was restricted by these inherent instabilities throughout the testing period

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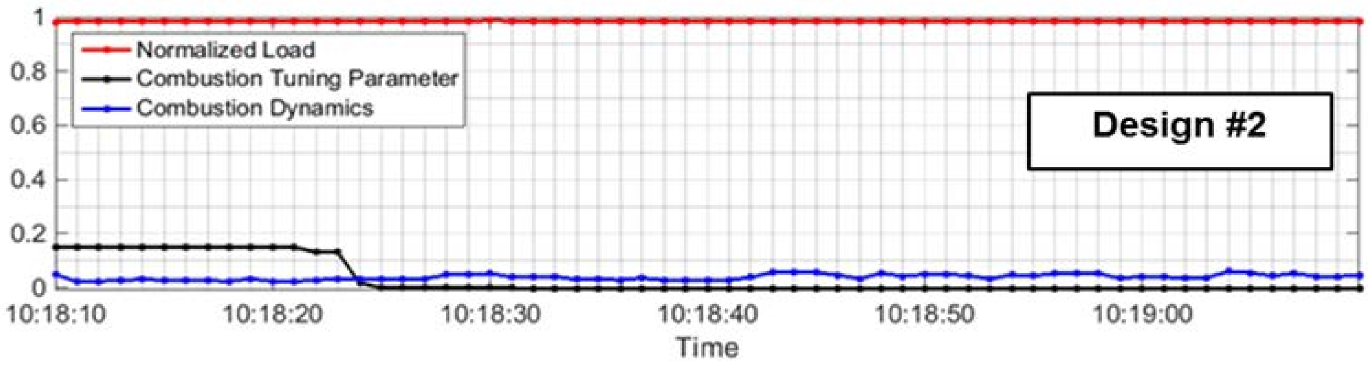
Design #2

- Design #2 followed the same overall mixing concept as Design #1 but possessed a different fuel nozzle design
  - Potential for improved combustion dynamics due to reduction of the dominant instability mode
  - Small NO_x penalty compared to Design #1 in rig tests
- Test results showed that for a drop in the same tuning parameter, no pressure spike was observed
- Larger degree of tuning possible for Design #2



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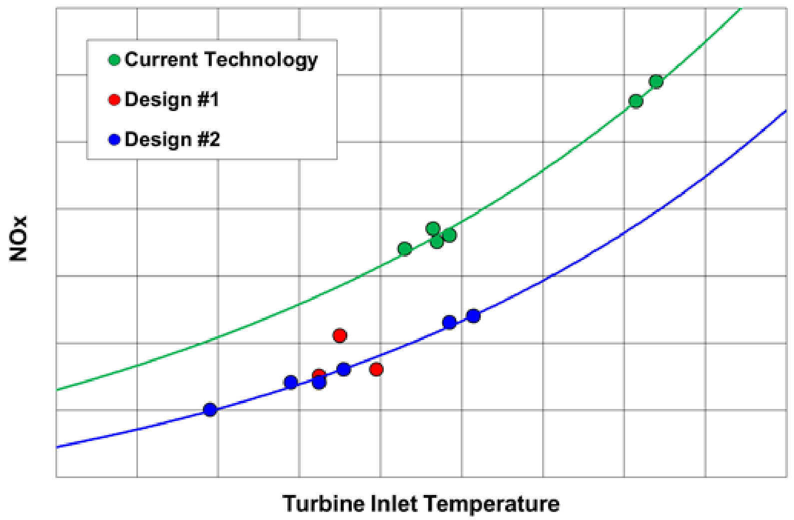
Design #2 Test: NO_x

- Like Design #1, Design #2 showed substantially lower NO_x emissions than the current premixed technology
- NO_x penalty compared to Design #1 proved to be insignificant (possibly due to more extensive tuning)
- Design #2's greater operational envelope allowed it to reach a wider range of conditions than Design #1 (both lower NO_x regions and higher temperature regions)



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Conclusions

- Combustion instabilities are not only important for their effects on engine lifetime but also in how they can affect combustion tuning and the overall operating envelope
  - Easy to underestimate importance of instabilities in smaller or unconfined experiments

- In the testing of Design #1, a reduction in NO_x was achieved, but combustion instabilities limited engine operation

- Design #2's modified fuel nozzles helped to control the problematic combustion instabilities, allowing the full potential of the new premixed system to be displayed

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Acknowledgements

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Siemens