Air/Fuel Mixing Control of Acoustic Emission from a Rijke-Tube Combustor

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Motivation

- Acoustic resonance in combustion can be advantageous or detrimental; control of this resonance is therefore useful.
- Actuation for combustion control is most effective before heat release, since combustion is a natural amplifier.
- Rijke-tube combustors have a well-characterized geometry for the study of acoustic resonance.
UCI Rijke-Tube

- 3.1 meter tall, 21.5 cm diameter resonance tube
- Thermocouple ports at each section flange
- Viewport approximately 1 meter from base of tube
- 0.7 m per side cube decoupling chamber
Rijke Tube Combustor

Three standard propane camp stove burners
Propane Burner

- 2.34 kW per stovetop
- Air fed to partial premixing chamber
- Vertical traverse
Premixing Levels

- Fully Premixed
- No Premixing
- Partial Premixing
Experimental Apparatus

- Exhaust vent
- Microphone
- Preamplifier
- Spectrum analyzer
- DVM
- Propane tank
- Fuel manifold
- Flowmeters
- Air manifold
Observations

- Single burner does not resonate
- Triple burner operating as designed does not resonate
- Triple burner operating non-premixed does not resonate
- Triple burner operating partially premixed causes resonance
- Both total heat release and mixing affect resonance condition
Resonant Flames

Resonance requires:
- High flow rates
- Partial premixing

Outside tube

Inside tube
Acoustic Emission

Viewport open

Sound Level (dB) vs. Fraction of Stoichiometric Air Flow Rate

- 2.06 slpm fuel
- 1.93 slpm fuel
- 1.85 slpm fuel
- 1.68 slpm fuel
Observations

- Resonance occurs around equivalence ratio 0.8
- Resonance band narrows with decreasing fuel flow rate
- Secondary broad resonance band under rich conditions with viewport open
- Control of acoustic emission is possible, but its effect on combustion is not yet known
Combustion Driven Acoustic Resonance

Rayleigh condition

\[ \int Qp \, dt > 0 \]

\( Q(t) \) -- heat release
\( p(t) \) -- acoustic pressure

What mechanism brings the heat release in phase with the pressure fluctuation?

- Changes in flame area
- Vortex shedding
- Equivalence ratio fluctuation
Heat Release Phasing

- Flame area--low pressure increases fuel flow rate; delay occurs as fuel convects to reaction zone, so that increase in flame area coincides with high pressure.
- Vortex shedding--vortices shed by burners wrap fuel into core, phasing heat release with pressure.
- Equivalence ratio fluctuation--low pressure increases fuel flow, enriching system locally; convective delay until mixture reaches the reaction zone where higher heat release coincides with high pressure.
Approximate Scales

- Speed of sound = 400 m/s
- Length of tube = 3.1 m
- Burner diameter = 8.6 cm
- Oscillation frequency = 120 Hz (harmonic)
- Approximate buoyant flow velocity = 1.1 m/s
- Entrained air flow = 0.032 m³/s
- Max. propane heating value (2 slpm) = 3kW
- Convective delay to reaction zone = 8 ms
  (5 m/s past burners to 4 cm)
Summary

• Rijke tube combustor as a model resonating system to study control
• Level of premixing can control the acoustic emission
  – maximum acoustic emission occurs around equivalence ratio 0.8
  – band of resonance narrows with decreasing fuel flow rate
• Geometric changes (e.g., viewport) changes resonance sensitivity
Future Work

- Measure emissions
  - efficiency
  - pollutants
- Increase fuel and air flow rates to reach lean premixed conditions
- Explore the role of the open viewport in controlling resonance
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