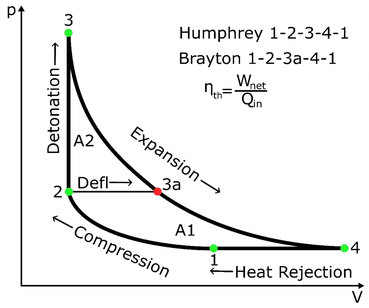
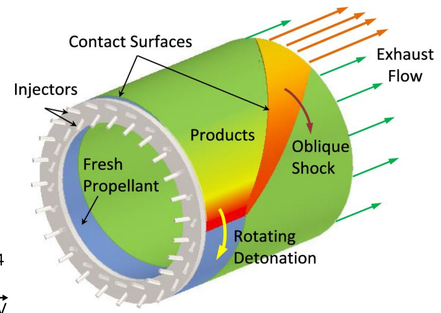
Acoustic Analysis on Small-Scale Rotating Detonation Engines (RDE)

Researcher: H. J. Shipman, PI: C. Knowlen, W.E.B. Department of Aeronautics and Astronautics

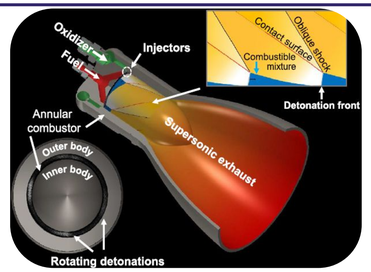
Background

Detonative combustion in RDEs extracts more work from propellants than conventional combustion in rocket engines. Current RDE modeling does not match experimental results nor predicts operational limits; characterizing the acoustic properties of running RDEs will inform engine parameter optimizations.





In small RDEs, pressure gain realization permits lower propellant injection pressures and simpler thruster systems.



Innovation

Motivation:

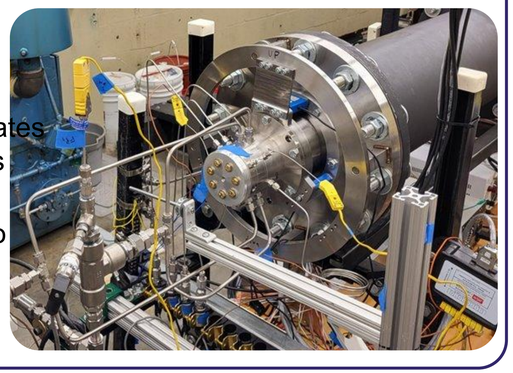
- *Hollow RDE*: Hollow or Coreless RDEs may perform better than the traditional annular RDE designs.
- *Complexity*: Acoustic analysis has not been fully outlined on RDEs; combines rocket engine acoustics with shock and detonation wave physics.

Acoustic Analysis:

- *Acoustics*: Sound propagation in RDEs must account for kHz-level frequencies.

Acoustic Modes:

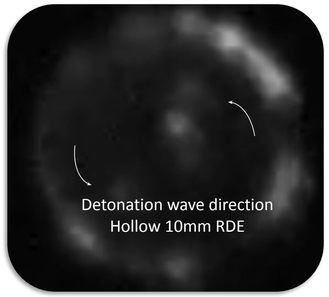
- *Radial*: Symmetric
- *Tangential*: Non-symmetric, oscillates across an axis or axes
- *Transverse*: Any combination of the two modes listed above
- *Longitudinal*: Not considered here

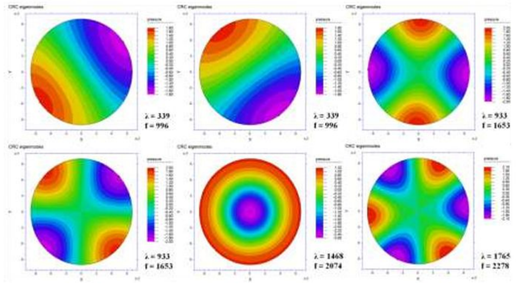


Project Description

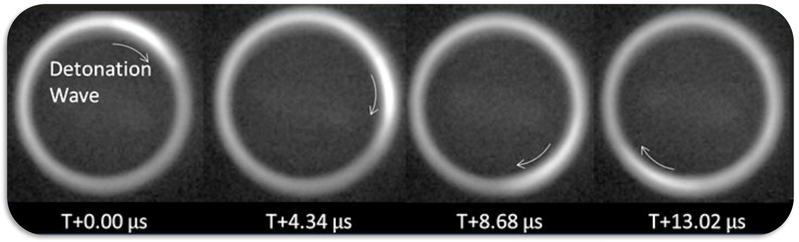
Tested 10 & 25 mm RDEs, gathered data → Studied acoustic analysis and RDE literature → Integrated theory and experiment to create MATLAB code → Ran code for 10&25 mm RDE on H2 and CH4, charted results → Chart results with annular RDEs and with T variations

- *Transverse Mode Numbers*: *m* is for radial modes, *n* for tangential, *q* for longitudinal modes; transverse modes are 2T, 1R, 1T1R, etc.

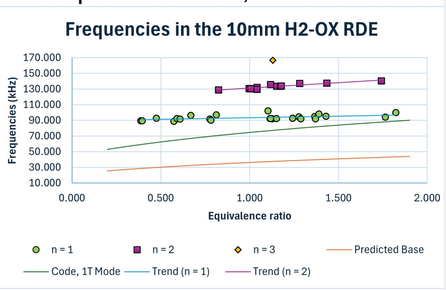


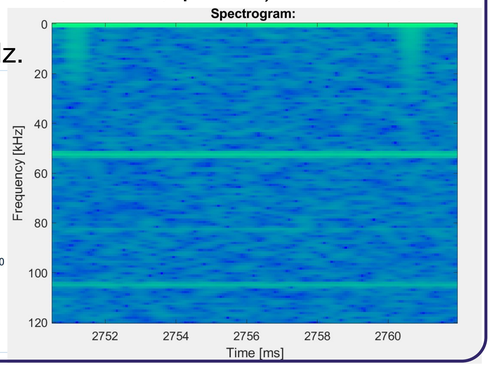


- *Hollow RDE*: Engine-level frequencies found by $f_{mnq}=\frac{a}{2}\sqrt{\frac{\alpha_{mn}}{r}+\frac{q}{L}}$; here *a* is acoustic sound speed, *r* is radius, *L* is length, and α_{mn} is the *m*th root of the derivative of the first Bessel function: $\frac{d\mathcal{J}_n}{dr}=0$.



- *Annular RDE*: Similar to hollow, $f_{mnq}=\frac{a}{2}\sqrt{\frac{\kappa_{mn}}{r}+\frac{q}{L}}$, but κ_{mn} includes both the first and second Bessel function $\mathcal{J}_n$ and $\mathcal{Y}_n$.
- *Wave Dynamics*: High speed video and piezoelectric pressure data were used to determine wave speed, frequency and count.
- *Example*: Run 53 (10mm hollow RDE, H2-OX, φ ≈ 1.8) has *n* = 1, average freq. 95 kHz, but base frequencies. ~57, 83 and 105 kHz.

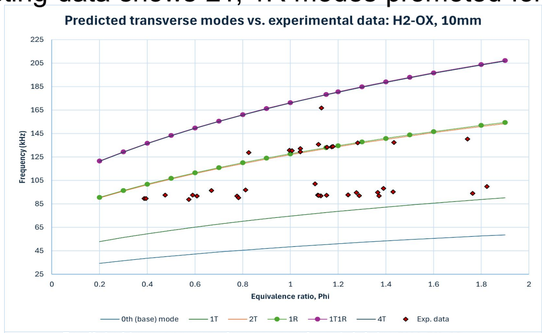


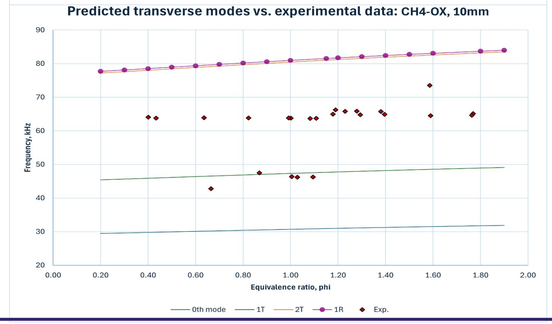


Initial Results

Computed and Experimental Frequencies

- *Choice of Variables*: Temperature, pressure and equivalence ratio influence acoustic sound speed
- *MATLAB Coding*: multiple iterations needed to correctly compute α_{mn} and frequencies
- *Graphs using p = 3 bar, T = 1000 K*: Correlation to existing data shows 2T, 1R modes promoted for n =2





Next Steps

Trends in CH4-OX propellant & 25mm RDE

- *Temperature dependence*: Verify initial temperature choice by comparing 10mm RDE experimental data with updated code results
- *25 mm (1") RDE*: extend analysis to the larger RDE
- *Investigate Effects of Variable Mass Flux*: increases in mass flux causes higher detonation wave numbers, and may have other effects as well
- *Annular RDEs*: The code developed for annular engines will allow comparison to the more extensive annular RDE experiment database