Geometric Scaling of Cylindrical Rotating Detonation Rocket Engine Combustors

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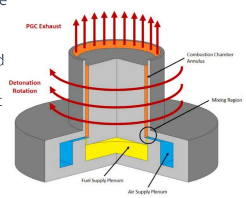
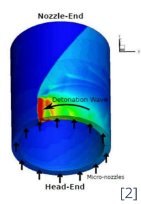
Rotating Detonation Engine (RDE)

- Propulsion device employing circumferentially-traveling detonation waves in annular channel
- Pressure Gain Combustor: unlike deflagration-based combustors, theoretical total pressure increase
- Furthermore, theoretical efficiency, and therefore size and weight, advantages over traditional rocket combustors
- Fundamentals of design and performance not well understood [1]





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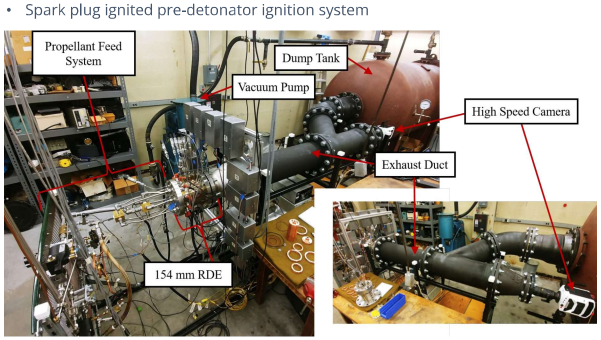
Experimental Goals

- Experiment-driven effort to obtain scaling laws and investigate small-scale RDRE dynamics by isolating combustor dimensions
- Radius of curvature study over three outer diameters
- Annulus gap width study over four configurations at smallest outer diameter
- Test conditions scaled by mass flux, and included equivalence ratio (ER) sweep

Facility Design

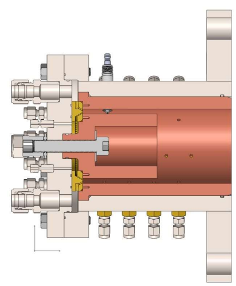
- Indoor facility with dump tank and vacuum pump captures combustion effluent and is dual-purposed for back pressure control
- Gaseous methane and oxygen delivered by calibrated critical flow nozzles partnered with regulators controlled by electro-pneumatic actuator units
- NI-based DAQ for valve control and recording of pressure and temperature
- Wave dynamics captured at 240,000 fps by Phantom v12.11 high-speed camera
- Secondary 1.25 MHZ DAQ for piezoelectric dynamic pressure sensors
- Spark plug ignited pre-detonator ignition system



Engine Design

- Three modular engines designed, built, and tested with major dimensions shown in table to right
- Six total configurations, with one shared by both studies
- Cutaway of 76-FI-5 configuration shown below

	76-FI-5	51-FI-5	25-FI-5	25-FI-3	25-FI-7	25-FI-12.7
Annulus OD	76.2 mm	50.8 mm	25.4 mm	25.4 mm	25.4 mm	25.4 mm
Annular Gap	5.0 mm	5.0 mm	5.0 mm	3.0 mm	7.0 mm	12.7 mm
Annulus Length	76.2 mm	50.8 mm	25.4 mm	25.4 mm	25.4 mm	25.4 mm
Injector Pairs	72	72	**48**	**48**	**48**	**48**
Fuel Inj. Dia.	0.79 mm	0.64 mm	0.51 mm	0.51 mm	0.51 mm	0.51 mm
Oxidizer Inj. Dia.	1.24 mm	0.99 mm	0.81 mm	0.81 mm	0.81 mm	0.81 mm
Injection-to-Annulus AR	0.110	0.110	0.110	**0.164**	**0.0856**	**0.0684**
Fuel Inj. Feed	Radial	Radial	**Axial**	**Axial**	**Axial**	**Axial**
Oxidizer Inj. Feed	Radial	Radial	Radial	Radial	Radial	Radial

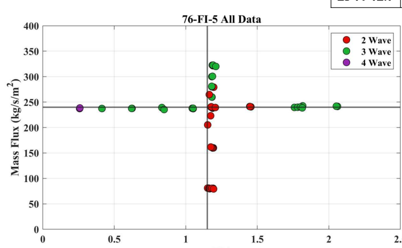


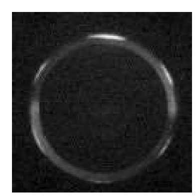
- 25-FI-12.7 is a "coreless" configuration
- Flat-faced impinging injector design
- Impingement at center of annulus corresponding to 5-mm gap width and at constant height of 2.16-mm
- Oxidizer and fuel injectors inclined 30 deg. from axis
- Same injector used in all 25-FI configurations
- OFHC copper used for inner and outer cores, 360 Brass used in injectors, and 316 stainless steel used in remaining components

Results Overview

- Summary of data set, including operational differences between configurations shown in table to right
- Example of "cross" formed by mass flux and equivalence ratio ("Phi") sweeps in 76-FI-5 configuration, with wave number results, shown in plot below.

	Hot Fires	Core Losses	Nitrogen Pre-Purge Duration	Starting Back Pressure
76-FI-5	63	0	0.3 s	62 to 80 kPa
51-FI-5	108	0	0.3 s	44 or 83 kPa
25-FI-5	115	3	None	50 kPa
25-FI-3	30	1	None	50 kPa
25-FI-7	9	1	None	50 kPa
25-FI-12.7	82	N/A	None	50 kPa

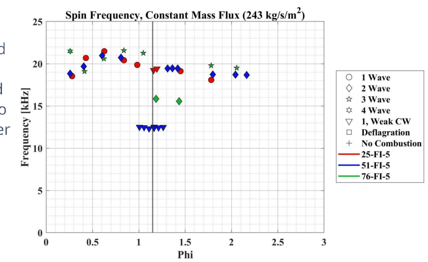




Example of 2-wave system from 76-FI-5

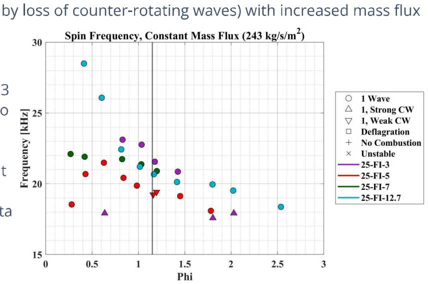
Radius of Curvature Results

- Wave number rose with mass flux increase, and decreased with diameter reduction
- Combustor pressure independent of diameter and wave number
- Wave frequency increased with mass flux
- Wave frequency and speed discontinuity at wave number change. Increased wave number correlated to higher frequency, but lower speed
- Wave number minimum and combustor pressure maximum near ER = 1.3
- Wave speed local maxima near ER = 0.6



Annular Gap Width Results

- No wave number changes
- Increased stability (shown by loss of counter-rotating waves) with increased mass flux
- Combustor pressure independent of gap width and wave stability, with maxima again near ER = 1.3
- Wave stability insensitive to ER except at operability limits
- Wave frequency maxima at low ER, with coreless reporting highest of **all** data



Future Work, References, and Acknowledgments

- Operability mapping and transition criteria
- Correlation to detonation cell size (Cantera modeling)
- Application of theorized geometric ratios (e.g. ratio of inner-to-outer radius and injection-to-annulus area ratio)
- Uncertainty analysis

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[1] Hargus, W. A., Schumaker, S. A., and Paulson, E. J. "Air Force Research Laboratory Rotating Detonation Rocket Engine Development," AIAA 2018–4876. *2018 Joint Propulsion Conference*. July 2018
[2] Andrew C. St. George, et al. "Development of a Rotating Detonation Engine Facility at the University of Cincinnati," AIAA 2015–0635. *53rd AIAA Aerospace Sciences Meeting*. January 2015.

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SPONSORS: AFOSR Grant FA 9550-18-1-9-0076

Office of Naval Research funding document N0001417MP00398