Hydrogen for Aviation Propulsion: A computational study applied to rotating detonation engine combustion

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Overview

- There is strong interest in Hydrogen as a sustainable fuel for aviation. Power density available in gas turbines will remain the leading technology
- Hydrogen as a fuel presents opportunities for new cycles with improved efficiency
- This work present a numerical study of an annular rotating detonation combustor operating on hydrogen-air.
- A numerical approach, balancing precision with computational load with fidelity, is developed.
- Implementation of a 4-step chemical kinetic mechanism for hydrogen-air combustion that includes pressure dependence.
- This mechanism is applied to a unit cell, a two-dimensional model and a three-dimensional model.
- 2D and 3D transient, reacting CFD simulations were performed to yield insight into the combustion :s and key operating characteristics of an RDE.

Rotating Detonation Combustion

- Extremely high heat release rate – shorter combustion chambers
- Pressure gain combustion – more efficient cycle
- Reactivity of hydrogen fuel makes it favorable for wide detonation limits

Computational Approach

- Computational approach is time-unsteady, reacting computational fluid dynamics (CFD) using solver that can solve compressible flows and incompressible flows, including both single and multispecies treatment, reacting flows, multiphase flows, and steady and unsteady flows.
- Compuational platform is a Linux HCP with 128 cores and 500 GB RAM

Chemical Kinetic Model

- A 4-step reduced chemical mechanism for hydrogen-air.
- This mechanism models hydrogen-air combustion characteristics over a wide range of combustion regimes including low pressure and high pressure.
- Compared to simpler one-step or two-step mechanisms often used in CFD simulations, this mechanism captures a much broader range of conditions at not much more computational cost

$$3H_2 + O_2 \overset{I}{\rightleftharpoons} 2H_2O + 2H$$

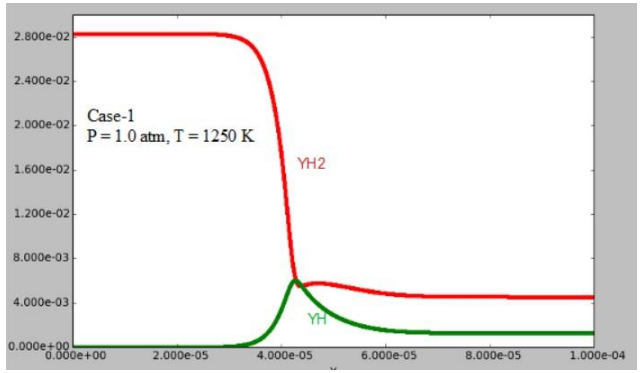
$$H + H + M \overset{II}{\rightleftharpoons} H_2 + M$$

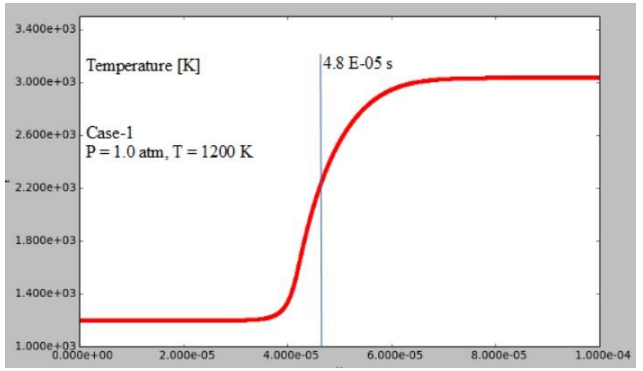
$$H_2 + O_2 \overset{III}{\rightleftharpoons} HO_2 + H$$

$$H_2 + O_2 \overset{IV}{\rightleftharpoons} H_2O_2$$

Sanchez, A.L., Williams, F.A., “Recent Advances in understanding of flammability characteristics of Progress in Energy and Combustion Science 41 (2014), 1-55.

Implementation of the 4-step chemical mechanism





Unit Cell calculations of species and temperature over time using 4-step mechanism.

	Initial Conditions			Autoignition Time		
	Temperature	Pressure	Eq. Ratio	Ref. 4	Unit Cell Prediction	% Diff
	(K)	(bar)		(usec)	(usec)	
Case-1	1200	1	1	45	48	7
Case-2	1500	10	1	1.2	1.1	-8
Case-3	1800	50	1	0.13	0.09	-31

Comparison of Unit Cell ignition delay time

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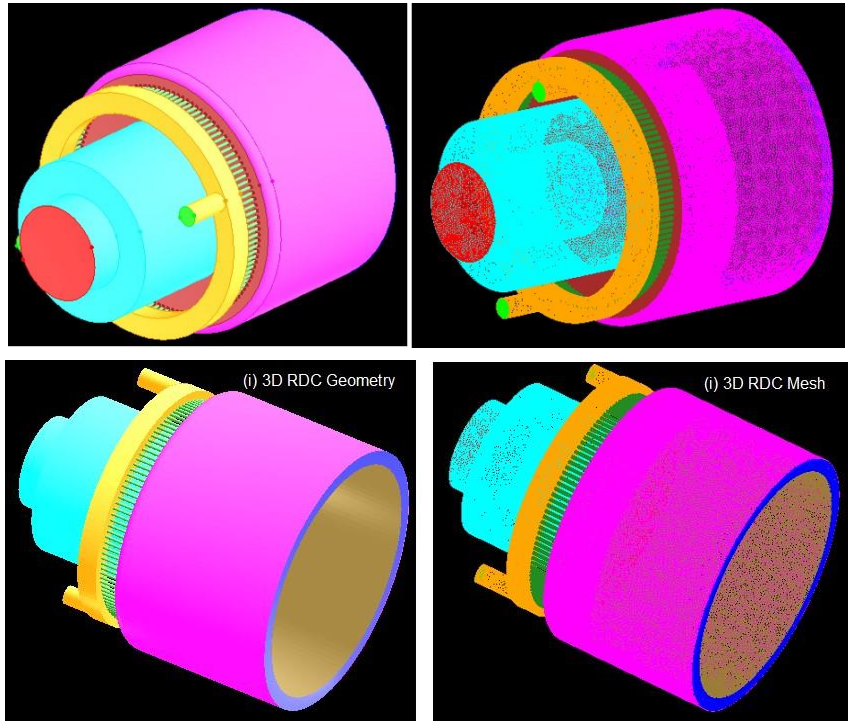
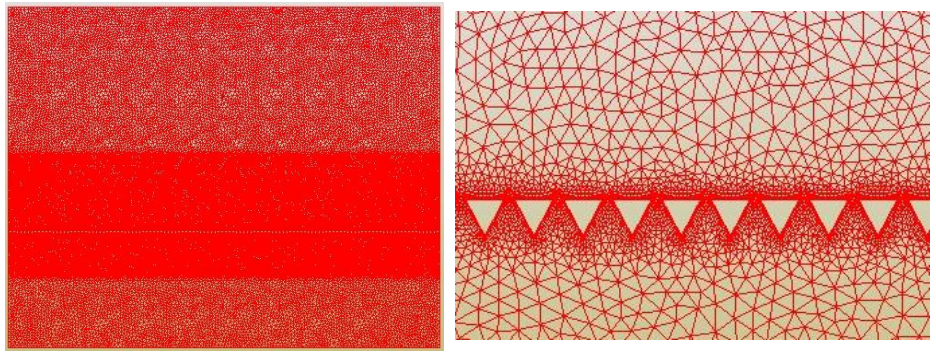
Geometry and Mesh

A reference case of an annular RDC with 150 mm diameter, and reaction zone 250 mm long

3D Model



2D Model

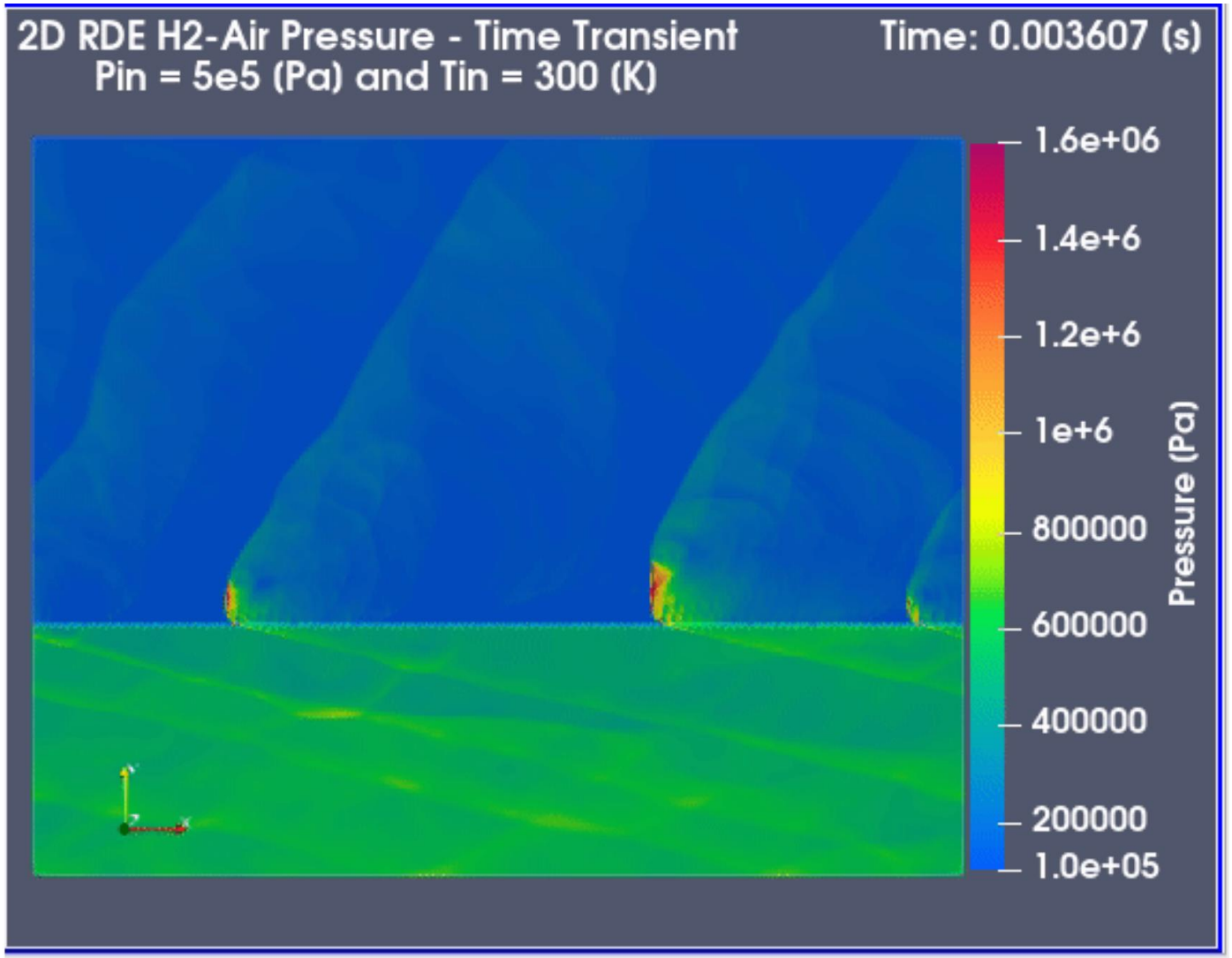


A 2D model of an “unrolled” anullar combustor with an inlet mixing region

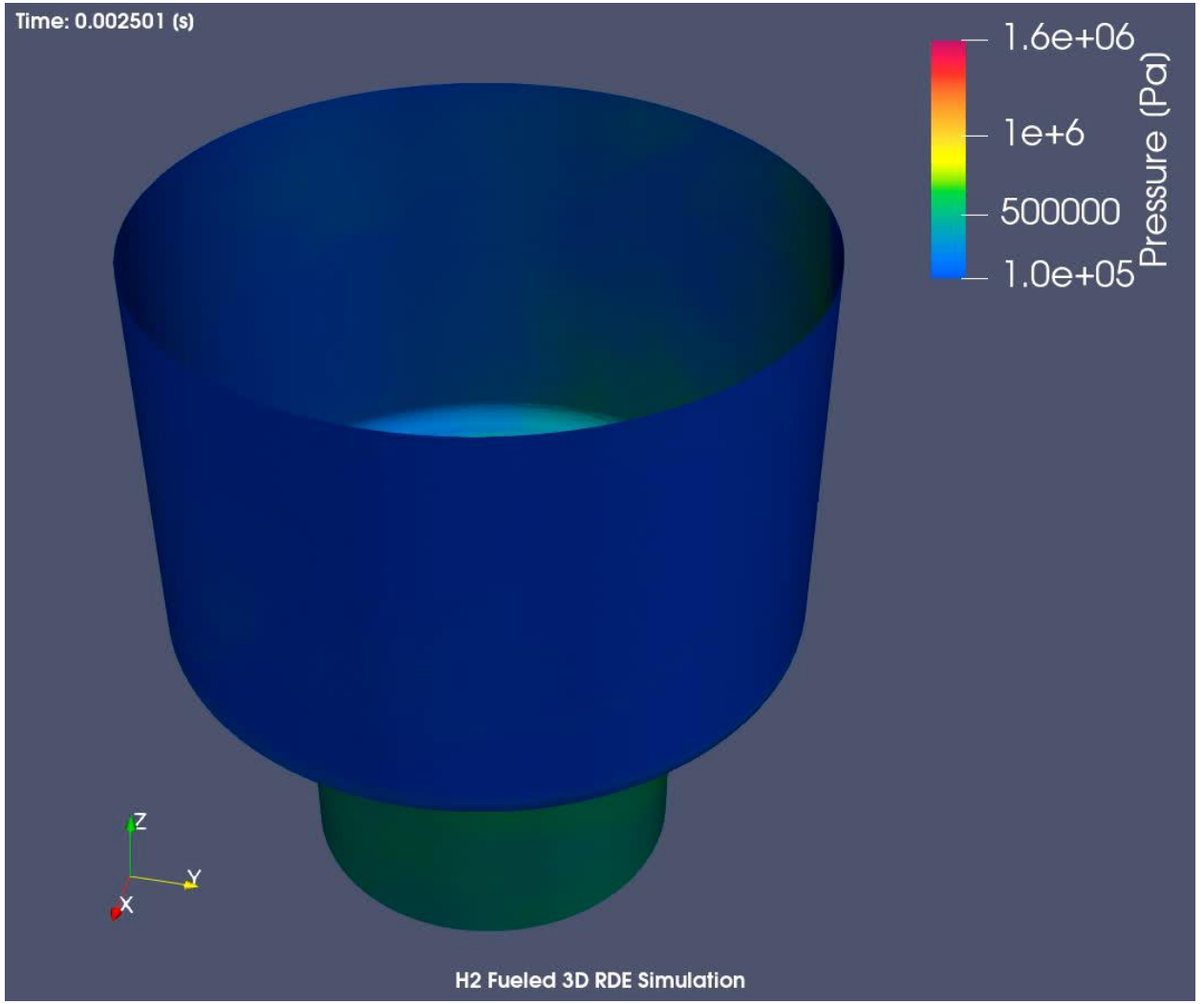
Ref: Rankin, B.A., Fotia, M.L., Paxson, D.E., Hoke, J.L., Schauer, F.R., “Experimental and Numerical Evaluation of Pressure Gain Combustion in a Rotating Detonation Engine”, AIAA-2015-0877.

Results of 2D simulations

- Transient start behavior



Results of 3D simulations



Conclusions and Next Steps

- Developed a computational approach to explore hydrogen-air combustion over a wide range of conditions.
- Numerically explored the combustion behavior in 2D and 3D Rotating Detonation Combustor geometries and produced results consistent with experiments.
- Applying this numerical approach to new geometries with focus on improving performance:
  - Reduction of pressure drop through the air and fuel system
  - Coupling of the exit of the combustor to downstream systems
  - Developing operability maps over a flight envelop