High-fidelity Simulations of Rotating Detonation Engines

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Introduction

Rotating detonation engines (RDEs) are geometrically complex devices that are not easily accessible using conventional diagnostic tools. Moreover, the performance of RDEs is fundamentally linked to specific design choices. For this reason, any insight gained from studying geometrically simple canonical flows will have limited use in practical systems. In order to enable fast and inexpensive design of such systems, reliable full scale simulation tools are necessary. The focus of this study is to demonstrate such full scale RDE simulations for a select fuel-air injection design that has been developed at UM by Gamba and co-workers.

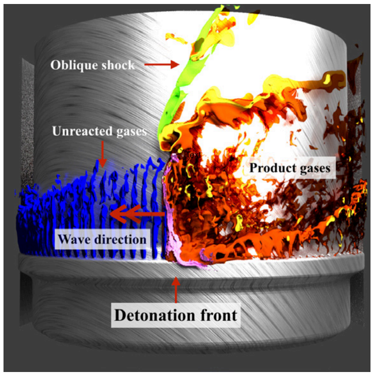
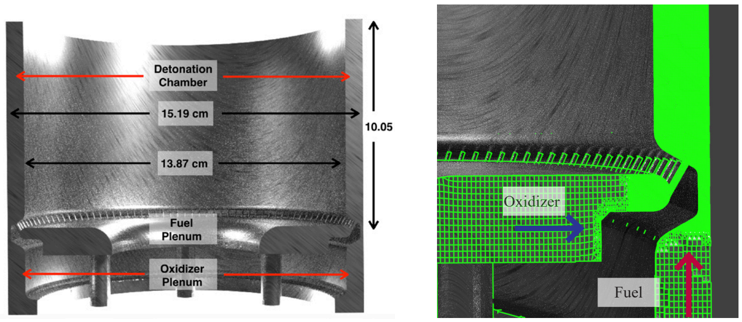


Figure 1. General detonation structure in numerical simulation of UM RDE

UM RDEs facility simulations

The full system simulatios were conducted using a new open source platform based solver developed at UM. Termed UMdetFOAM, this solver a) uses detailed chemical kinetics by integration with CANTERA chemistry package, b) is capable of handling complex geometry through unstructured grid formulation, and c) is highly scalable on heterogeneous machines and has been shown to scale to 250K cores and 4096 GPUs with 80% efficiency, Figure 1 shows a general detonation structure within a sample RDE design computed using this solver.



Fiure 2. Mesh of RDE facility at UM. Left: cross-sectional view, Right: injection scheme.

Figure 3 shows the detailed species behavior at the shock front. It reveals that the detonation product gases from the previous cycle remain in the pre-detonation region. This causes the incomplete detonation process as implied by the lower peak pressure compared to the ideal process.

Global quantities such as thrust and specific impulse can be extracted from the full system simulations. The number of waves in the chamber matches with the experimental value while the wave speed is computed slightly faster than the experiment.

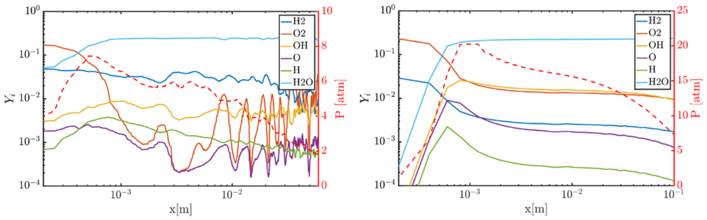


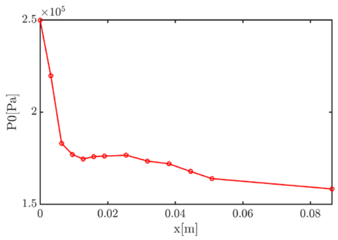
Figure 3. Detailed species behavior at the shock front.
Left: annulus centerline detonation region, Right: ideal process in 1D detonation tube.

Air pressure (kPa)	H2 pressure (kPa)	Expt. # of waves	Sim. # of waves	Expt. wave speed (m/s)	Sim. wave speed (m/s)	Sim. Thrust (N)	Sim. Isp (s)
235.1	395.3	1	1	1562	1938	326	2576

Table 1. Simulation conditions and computed global results.

Pressure gain analysis

To determine the variation of total pressure in the chamber, the axial total/ static pressure and kinetic energy are shown in Figure 4. The total pressure significantly decreases after the injector region due to the expansion process but reaches a plateau due to the detonation wave. Specifically, the static pressure increases while the kinetic energy decreases during this process. After the detonation region, the total pressure continues to decrease due to gas expansion. In this process, the kinetic energy in the axial direction increases to 80% of the total kinetic energy.



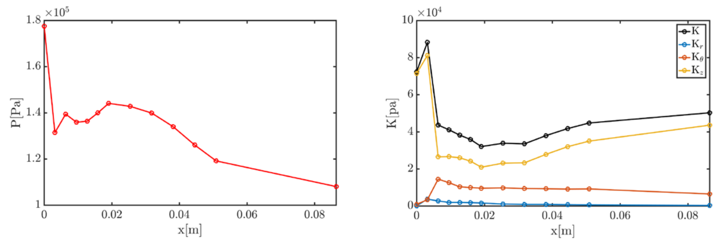


Figure 4. Axial total pressure, static pressure and kinetic energy
x = 0 corresponds to the throat of the oxidizer injector.

Conclusion & acknowledgement

Full system simulations of UM's RDEs facility were performed. The combustion within the chamber is inefficient possibly due to the residual product gases from the previous cycle. Total pressure is lost mostly during the injection expansion process. The flow is expanded after the detonation process, and the flow becomes predominantly axial further downstream. This work is financially supported through DOE Grant No. DE-FE0031228 and DOE Grant No. DE-FE0023983.