The Effect of Side Relief on Detonation Propagation in a Rotating Detonation Engine

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Rotating Detonation Engines (RDEs) have emerged as an important concept that, with further development, could provide major increases in jet and rocket engine performance. An RDE is based on an annular chamber. Reactants, such as hydrogen and air, are ignited to create a detonation which travels around the annulus. The detonation is continuously sustained by the injection of fresh reactants ahead of the wave. Thrust is generated by expanding the detonation products out the exhaust end of the RDE.

Experimentally observed detonation wave speeds are measured to be approximately 80 to 85% of the Chapman-Jouguet value. There are various mechanisms that may account for the measured wave speed. Possible sources are the curvature associated with the RDE geometry, counter-flow into the detonation, poor mixing, heat conduction and viscosity, and the side relief due to the lack of a solid wall at the top of the detonation.

This work focuses on isolating and quantifying the effect of side relief or area divergence due to the top of the wave being bounded by a compressible gas instead of a solid wall. The effect of side relief is studied in a simpler, canonical system of just a detonation wave bounded by an inert gas. This system was studied in the 1960s and 70s both experimentally and analytically. It is found that the detonation velocity deficit due to side relief within an RDE may be approximated by computing the deficit for a detonation wave bounded by an inert gas with a low acoustic impedance. The bounding gas in an RDE is hot detonation products which have a much lower acoustic impedance than air at low temperatures. Some previous experiments with helium as a bounding gas were conducted but the majority of the focus was on using low temperature air as the bounding gas.

A quasi-1D ZND analysis of a detonation wave with area divergence is used to estimate the velocity deficit based on the wave height. A variety of different models for the area divergence through the reaction zone are used and compared with each other. Currently, there are few experimental results and no computational results for detonations bounded by a low acoustic impedance inert gas. Future work should provide data to determine the validity of the analytical model. Experiments pose a challenge due to the requirement of using a very thin membrane (approximately 50 nm) to separate the detonable material from the inert. A new analysis based off of previous work is conducted to better quantify the effect of this membrane on the detonation propagation.

This research presents the first steps on isolating and analytically studying the effect of side relief on detonation propagation in an RDE. There are many potential mechanisms affecting wave speed and this seeks to quantify one of the effects and determine its contribution to the experimentally measured speeds.