

# Three - Dimensional Modeling of The Rotating Detonation Engine

**Arkadiusz Kobiera, Michal Folusiak, Karol Swiderski, Jan Kindracki, Piotr Wolanski**

Warsaw University of Technology, Warsaw, Poland

## 1. Introduction

A continuously rotating detonation was firstly reported in the early sixties of the last century by Voitsekhovskii et al. [1]. But only recently a significant interest has been focused on development of the Rotating Detonation Engine, known also as Continuous Detonation Wave Engine, since it offers significant improvements of the cycle efficiency and simultaneous simplification of the design. Many experimental and numerical investigations in this field are conducted in many laboratories [2-4]. Despite many successful experiments into establishing of rotating detonation in different chamber's geometries and for different mixture compositions there is still a great need for a numerical simulation which can provide detailed data about the flow's structure and allows better understanding of the ongoing processes. The work presents the results of three-dimensional simulations of a detonation propagating in continuously flowing gas. The simulations show the large scale structure of the detonation and the flow in a ring-shaped, cylindrical detonation chamber.

## 2 Mathematical and numerical model

The simulations are based on the classical Euler equations describing the motion of a reacting inviscid gas. The model is capable of simulating of a detailed chemistry, however a simple single or two-step mechanisms are utilized in this work. The model is implemented in a in-house code CFD-ZSL. The code works on structural grids. The Euler equations and the grids can be defined in the Cartesian system or cylindrical systems. The structural grids can be combined in order to simulate relatively complex geometries close to that tested in the experiments. The program utilizes HLLC-WAF, a second order in space and time solver, for the advective fluxes [5]. The advective terms are integrated in time by use of the Runge Kutta 4th order scheme. The chemical source terms are integrated by the quasi-equilibrium solver Chemeq2 [6].

## 3 Three dimensional simulations

The geometry of the computational domain is similar to the geometry of the real detonation chamber used in the experiments conducted by Wolanski et al. [2] (Figure 1). The chamber is supplied with a premixed mixture of air and hydrogen. The mass flow rate is controlled by the throat section of the chamber. Then, the flow behind it expands and becomes supersonic (Figure 2).

After ignition, the rotating detonation develops and it propagates along the channel. The first analysis of the results showed that the structure of the detonation front is three dimensional and highly influenced by the structure of the initial supersonic flow of the mixture (Figure 3). The numerical diffusion causes a quite significant mixing of the fresh mixture with combustion products behind the front of detonation wave. It leads to unphysical "burning" which is similar to deflagrative one but it is very fast. To avoid it, the reactions rate is set to zero below certain pressure threshold. This approach was successfully used by Davidenko et al. [7].

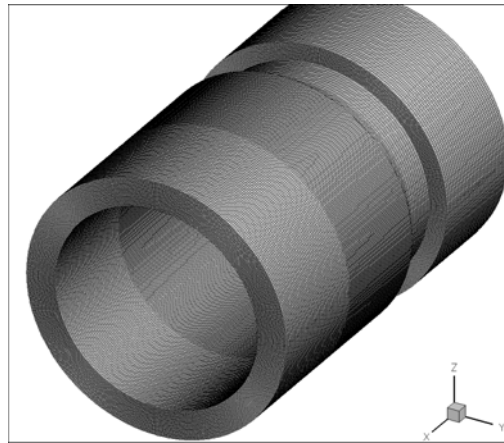


Figure 1. Geometry of the computational domain.

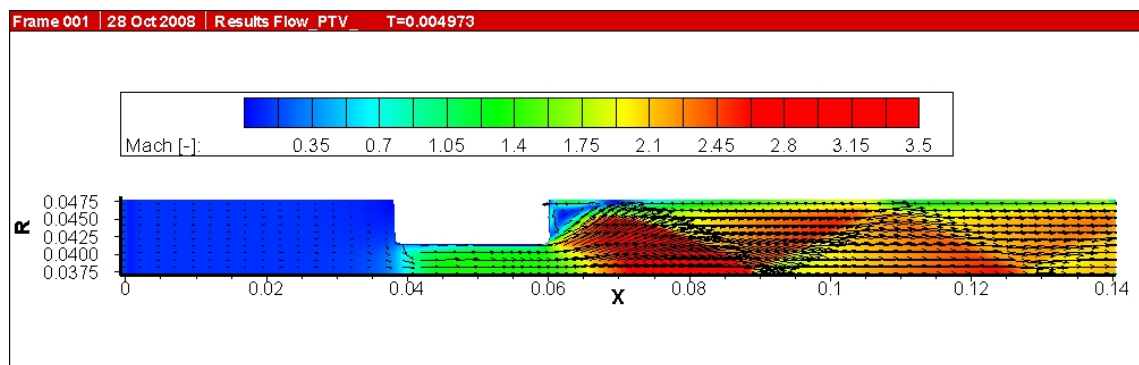


Figure 2. The frozen flow structure (Mach number) in the RDE (no reactions).

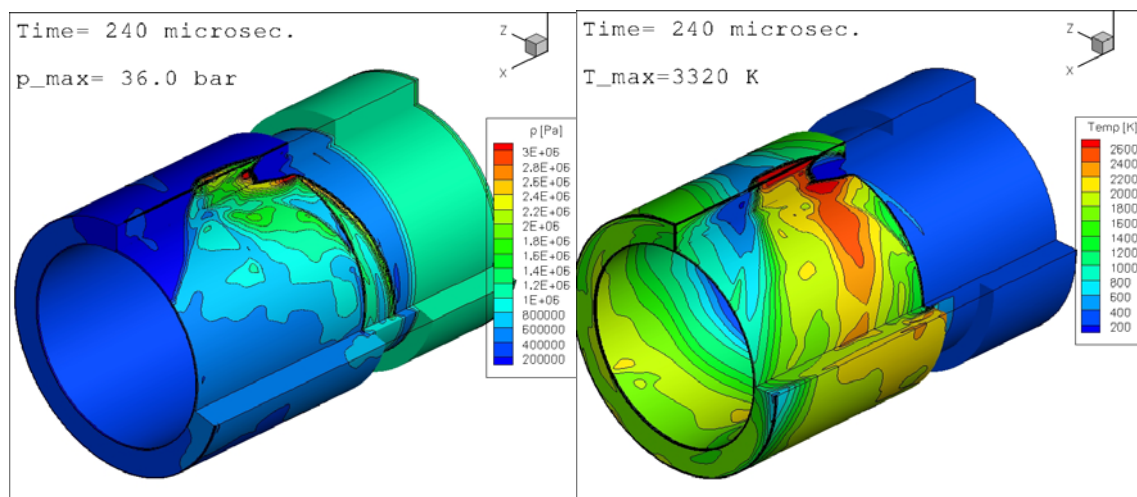


Figure 3. Propagation of the detonation in RDE left: the pressure field, right: the temperature field.

For better understanding of the phenomena occurring in the flow, the two dimensional structure of the wave is also studied. Here, the structure of the wave at the inner wall is presented in Figure 4. The LD wave is the leading detonation wave and sometimes it is referred as a detonation head. One can see Mach stem wave (MS), resulting from the intersection of other two waves at trippl point A: the

detonation front LD and transverse shock TS. The Mach stem MS is enforced by the influence of the chemistry limiting line. The chemical reactions are switched off upstream the line. In real systems the reaction region is limited to the place of injection of the fuel. In more complex simulations, the shape of MS wave will depend on the injection method and the mixing process of the fuel and the air. The point A is a triple point in this case. However, it is not the same triple point like in cellular structure of detonation, which cannot be observed in macroscale simulation. At the right end of LD wave, one can observe another wave. This short wave propagates downstream, however the interaction with “long-tail” wave LT causes that it vanishes rapidly.

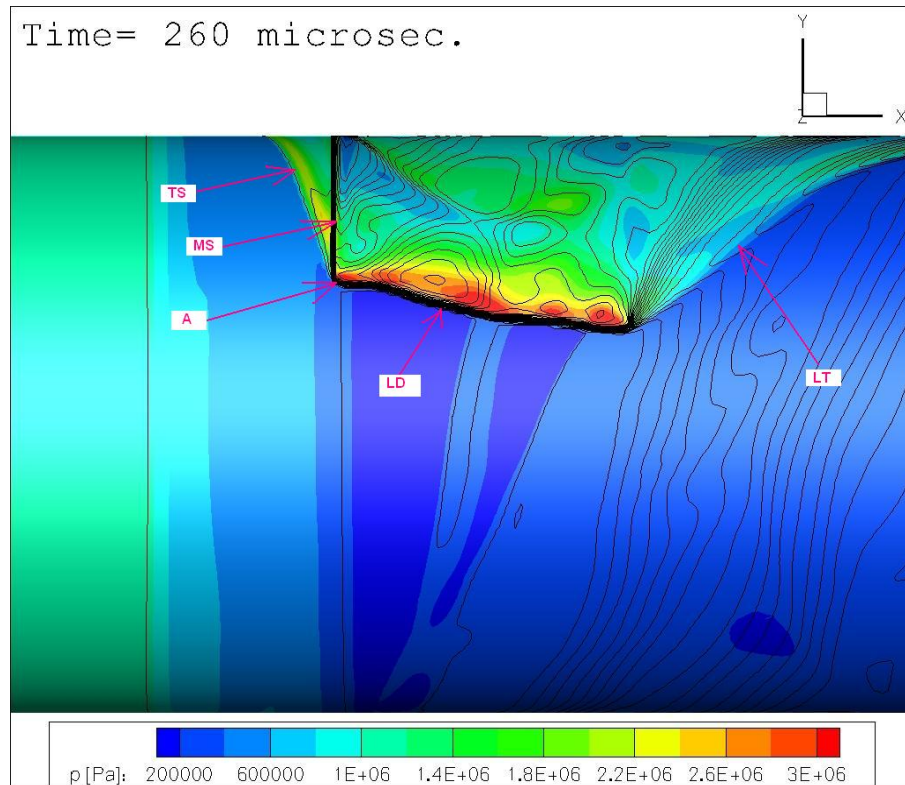


Figure 4. Structure of the waves at the inner wall of the ring shaped chamber.

## 4 Summary

The presented results show that the developed model works well, and it is the useful tool for simulation of the propagation of detonation in the RDE. The preliminary results of the three dimensional simulation of the RDE have given some information about the structure of this complicated reactive flow with incorporated detonation wave. Performed computations have risen important questions about the role of deflagrative combustion in the region of mixing of the hot gases with the fresh mixture. The simulations have also shown that special attention must be paid to the interactions of the numerical diffusion and proper mechanism of the chemical reactions. Certainly, more advanced model of combustion at the contact surface is necessary.

## References

- [1] Voitsekhovskii, B.V., Mitrofanov, V.V. and Topchiyan, M.E.: *Structure of the detonation front in gases*, Izdatielstvo SO AN SSSR, Novosibirsk, 1963 (in Russian). Wolanski P,

- [2] Kindracki J, Fujiwara T. (2006). An experimental study of small rotating detonation engine, in: Pulsed and continuous detonation. Torus Press.
- [3] Bykovskii FA, Zhdan SA, Vedernikov EF. (2008). Continuous spin detonation of H<sub>2</sub>-O<sub>2</sub> mixture in a flow-type combustor. Proc. ISHPMIE7.
- [4] Tsuboi N, Daimon Y, Hayashi A. (2008). Three-dimensional numerical simulation of detonations in coaxial tubes. Shock Waves. 18: 379-392.
- [5] Toro EF. (2001). Riemann solvers and numerical methods for fluid dynamics. Springer.
- [6] Mott DR, Oran ES. (2001). Chemeq2: A solver for the stiff ordinary differential equations of chemical kinetics. Naval Research Laboratory (NRL/MR/6400-01-8553).
- [7] Davidenko DM, Gökalp I, Kudryavtsev AN. (2008). Numerical study of the continuous detonation wave rocket engine. 15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference.