Research of the Rocket Engine with Detonation Chamber

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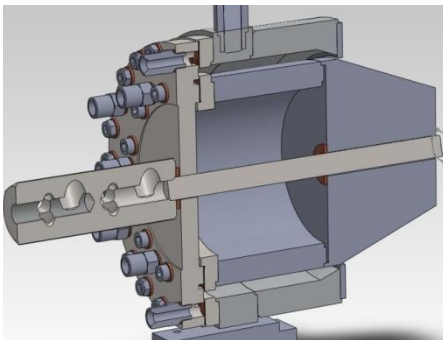
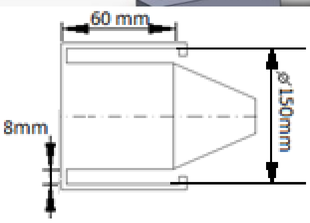
Introduction

The possibility of improving the thermodynamic cycle by the application of detonative combustion instead of deflagration was first proposed by Zeldovich [1]. The first stationary spinning detonation was successfully achieved by Voitsekhovskii et al. [2] and the first attempts to develop engine based on the rotating detonation was initiated by Nicholls J.A., et al.[3]. Since that time, many different possible ways of implementation of detonative combustion to the propulsion systems were studied. Extensive survey of such research can be found in [4]. But only recently more intensive research on the applications of the continuously rotating detonation (CRD) in the propulsion system was undertaken. It has demonstrated that it is possible to improve the engine efficiency by 3-7% [5-6]. The simplest engine utilizing a continuously rotating detonation is the rocket engine. In Rotating Detonation Rocket Engines (RDRE), the fuel and the oxidizer are injected into a cylindrical detonation chamber, and the rotating detonation continuously propagates as long as the fuel and oxygen are supplied to the chamber. Since the products from the detonation chamber are flowing out with supersonic velocity, there is no need to apply a converging–diverging nozzle and the aerospike nozzle can be attached directly to the detonation chamber [4]. In this paper, the research on application of the CRD to rocket engine is presented.

Experimental testing stand

The special testing stand to conduct research of a rocket engine with a detonation combustion chamber with the diameter of 150mm was built in the Institute of Aviation. The engine was manufactured with aluminum alloys - as they are easily exchangeable, which facilitated the research on influence of a different geometrical elements. The aero-spike nozzle was connected to the engine. The engine's critical cross-section is designed in such a way that it could be modified by a special throttle ring. Combustible mixture is produced by specially designed 168 holes impinging injectors which allows to mix gaseous oxygen and gaseous fuel. The engine is fixed on the test trolley with linear bearing. It allows for measuring the thrust by dynamometer.





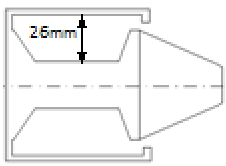


Figure 1. a) Cross-section of the engine, b) Engine on the testing stand, c) The main dimensions of engines: detonation mode and deflagration mode.

Measuring system

The measuring system is equipped with pressure sensors and thermocouples for oxygen and fuel supply system as well as piezoelectric pressure sensors for measurements of the pressure variations in the combustion chamber and pressure sensors for measured averaged pressure of combustion. Measurement of the mixture mass flow is calculated from the measurement of a difference of the amount of gases in the bottles before and after the experiment.

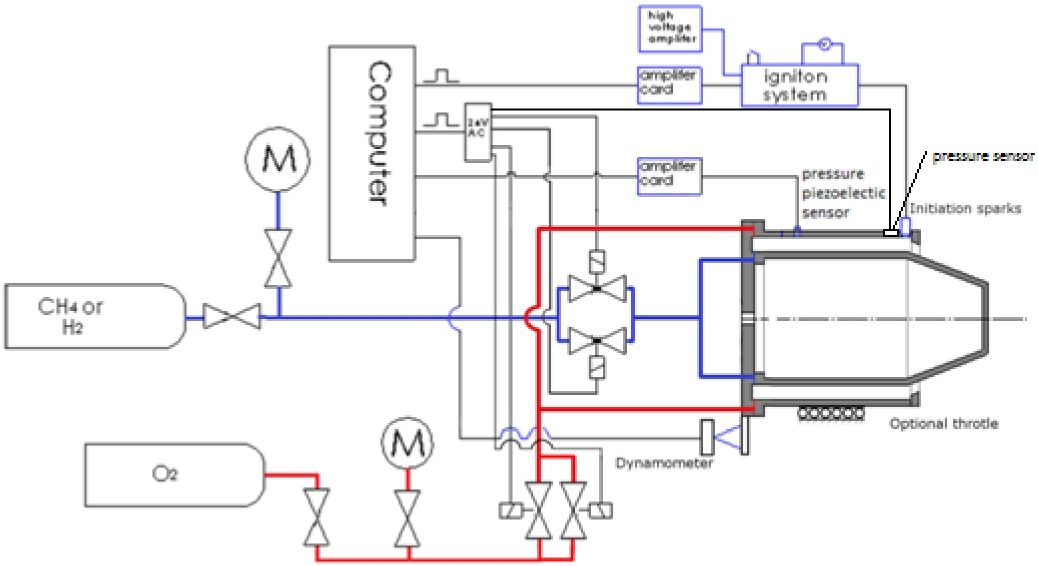


Figure 2. Scheme of the testing stand with elements of measuring system

Experiments

In the initial research which were carried out for methane-oxygen mixture, we aimed to determine the detonability range of the tested mixtures for different initial pressure in the experimental rocket combustion chamber.

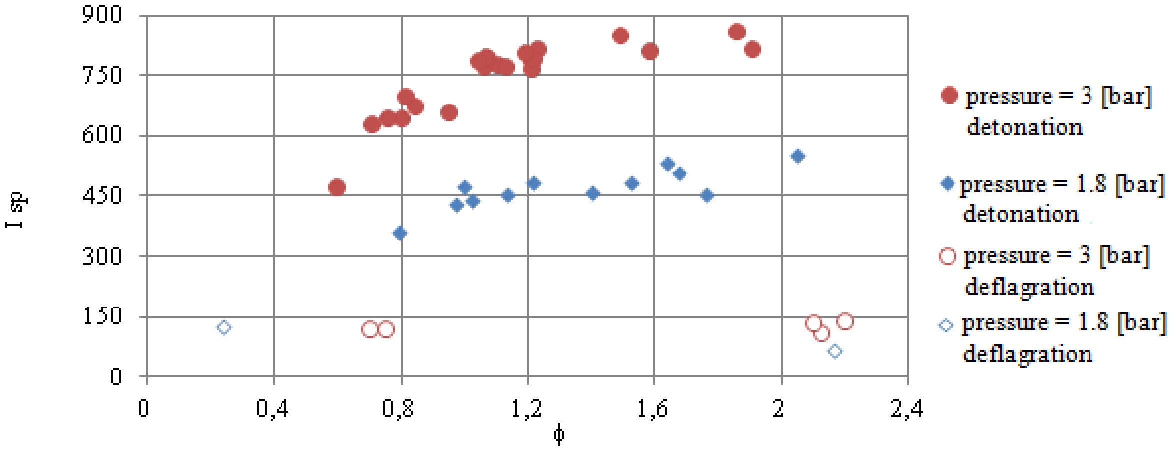


Figure 3. Dependence between mixture composition and specific impulse.

The conducted experiments show that the highest specific impulse is obtained for mixture stoichiometric coefficient between 0,8 and 2. Outside this range the detonation is difficult to initiate and sustain.

The best way to control the pressure in the chamber is by applying different throttling under the same supply rate of the mixtures. Influence of throttling on specific impulse as function of the chamber pressure is presented in Fig.4. The tests with throttling were performed without the aerospike nozzle.

Also, the research on influence of chamber geometry was conducted. For chamber with relatively small differences of inner and outer diameter continuously rotating detonation was easily sustained, while for the chamber in which inner diameter was much smaller, only the deflagrative combustion could be achieved. Figure 5 presents variations of the specific impulse as a function of the chamber pressure. Conducted experiments prove that in very similar conditions, the detonation mode produces higher specific impulse. The difference of specific impulse between detonation and deflagration combustion modes was up to 7%. Deflagration mode was attained by increasing the height of the combustion chamber and modifying the injector.
In a higher combustion chamber the speed of the mixture is lower. Lower speed of the mixture creates a combustion cell too short for detonation to occur.

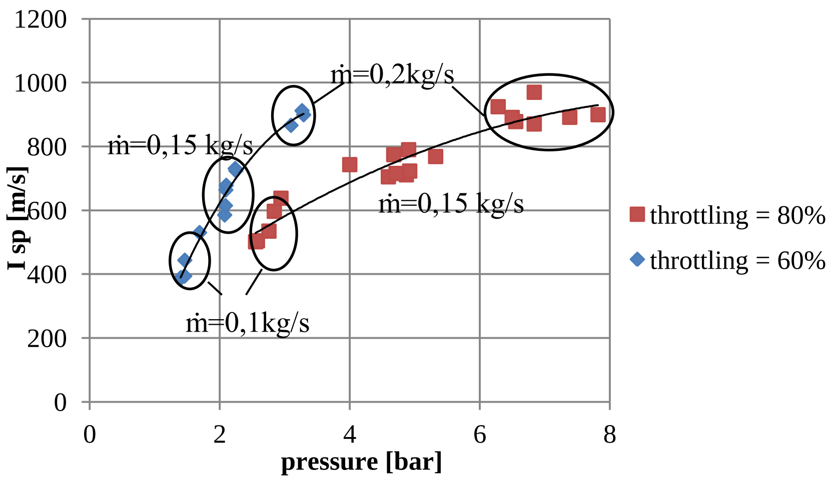


Figure 4. Dependence between the pressure of combustion and the specific impulse in rocket engine.

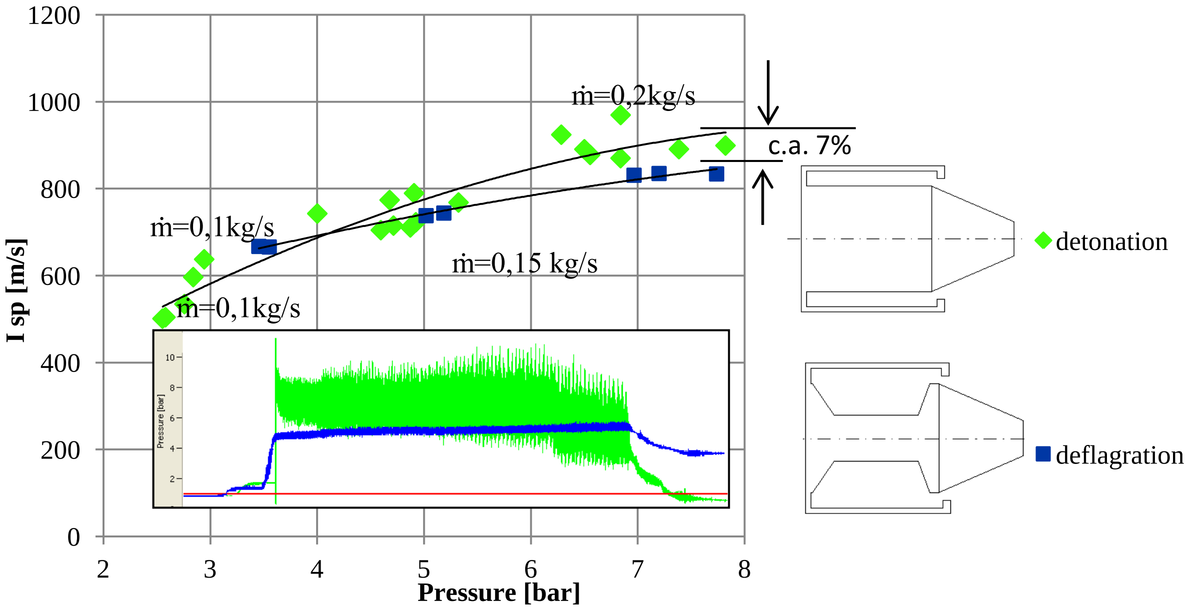


Figure 5. Difference between detonation and deflagration. Inserted records of pressure in both combustion chambers.

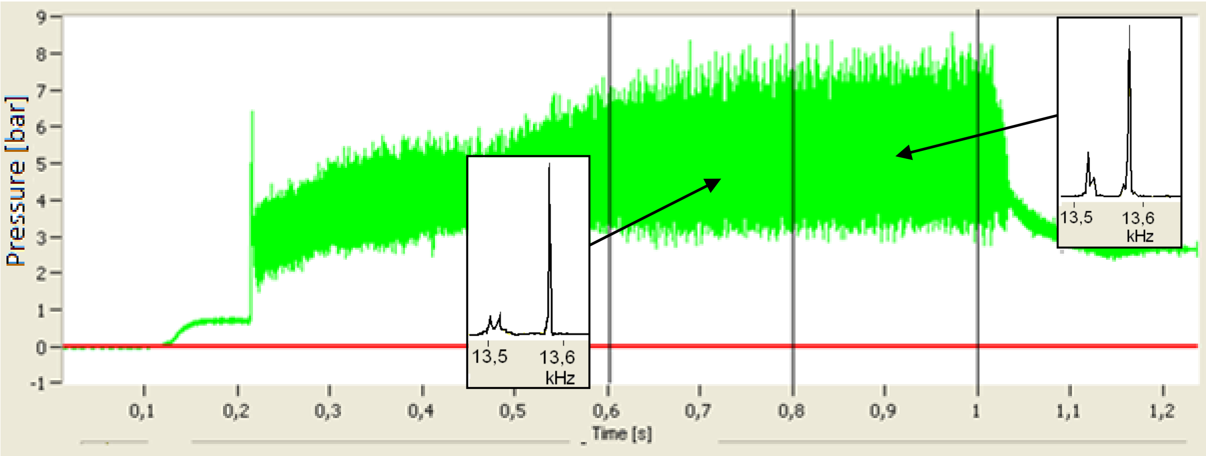


Figure 6. Pressure record from piezoelectric sensor and Fourier analysis for intervals where detonation exists.

The number of waves was determined by means of Fourier analysis, by DETON SPEED program [7-8]. The spectrum indicates the peak at 13,6 kHz. This frequency translates to a wave speed of 6195 m/s which is larger than the Chapman– Jouguet detonation velocity of 2670 m/s for methane and oxygen mixture, which indicates that more than one wave is rotating in the chamber. So it will be necessary to locate a few pressure transducers in the chamber in order to distinguish real number of waves, their actual velocity and direction. It will also be desirable to analyze the conditions under which the waves rotate in one or the other direction. This, however, will be the subject of future studies.

Conclusions

1. The optimum engine performance is for rich mixtures.
2. The highest engine performance was recorded for the detonation mode of combustion, and for the optimum conditions the value of specific impulse was up to 7% higher than for the deflagrative combustion mode.
3. Increasing of throttling to up to 80% causes the increase of the specific impulse, but for higher throttling detonation was extinguished mostly due to the decrease of mixture supply rate.

Acknowledgement

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