Experimental Research of Liquid Fueled Continuously Rotating Detonation Chamber

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1 Introduction

Most important development needed for successful application of the continuously rotating detonation to propulsion systems is to achieve operation of such engines on liquid jet fuels. First attempts to study liquid fuels application to propulsion system were carried at the University of Michigan [1-2]. Many attempts in these directions have not been successful yet, however, research is continuously conducted in many different laboratories. There are few basic requirements needed to obtain successful operation of combustion chamber supplied with liquid aviation fuel. One of the most important condition is a very good atomization of the liquid fuel. Additionally fuel-mixture has to be uniform and dimension of the detonation channel should also be relatively large. This is due to the fact that the detonation cell size for liquid fuel-air mixtures is usually relatively large as compared to most gaseous fuel-air mixtures, excluding methane-air mixture, since methane is also very difficult to detonate. Operation of elevated pressure is usually helpful, since detonation cell size is usually smaller for higher initial pressure, so for higher initial pressure size of detonation chamber in which detonation can propagate stationary can also be smaller. All these conditions are very difficult to fulfill and up to now successful, stable continuously rotating detonation in cylindrical chamber for atmospheric conditions of jet fuel-air mixtures has not yet been achieved. Unstable detonation of the jet fuel-air mixture was already achieved in the Institute of Aviation in Warsaw, but not all atomized fuel was consumed in rotating detonation and efficiency of such combustion process was relatively low [3]. So in some laboratories research was initiated to obtain better conditions of fuel-air mixture preparation, which can allow successful propagation of continuously rotating detonation in cylindrical chamber [4-5]. The aim of this research was to prepare uniform liquid fuel-air mixture which eventually will allow stable detonation of liquid fuel-air mixture in the chamber of reasonable size and in initial atmospheric conditions. So special system was developed and now it is under patent applications [6].

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2 Experimental Test Stand

Experiments were conducted in a specially adopted detonation chamber used in [3] with a newly designed injector of an over-enriched fuel -air mixture as described in patent application [6]. Main air, preheated to about 100C, is supplied to detonation chamber from high pressure installation at carefully controlled rate. Before the main chamber, pitot tube is used to measure air velocity and thermocouple to measure its temperature. The flow rate is measured by specially calibrated flowmeter. Just before main section of cylindrical detonation chamber injectors of very rich fuel-air mixture are located. This mixture is prepared in a special mixing chamber where preheated liquid fuel is mixed with preheated high pressure air from a different supply system. Both liquid fuel and air supply rate are very carefully monitored, since created rich fuel-air mixture should be above flammability limit. It is also very important to keep all parameters under very tight control to allow liquid fuel to evaporate but to prevent it from cracking. To reach such conditions not only temperature of both air and liquid fuel is under strict control but also occupied time of created very rich mixture in mixing chamber should be properly adjusted. Such created very rich mixture is injected into the main stream of air just before critical section of the detonation chamber. Cylindrical detonation chamber of outside diameter of 225 mm, is equipped with pressure and temperature sensors as well as the special ignition system. The chamber can also be trothed at the exit to allow pressure increase. To conduct experiments main air rate and temperature is adjusted and then rich fuel-air mixture is injected to the main chamber and ignition is initiated. The conducted experiments usually last from 1s to 4s and the process is controlled by special sequencer and all data are recorded by Data Acquisition System and stored in a PC computer.

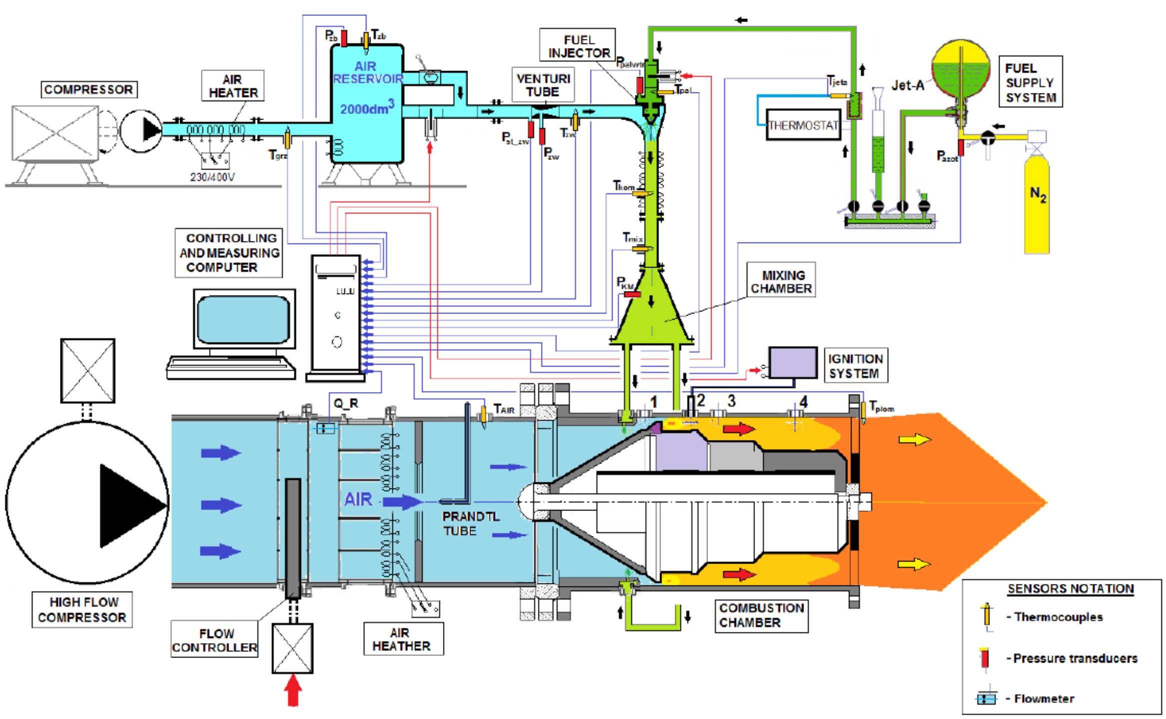


Figure 1. Schematic diagram of experimental test stand.

3 Results

Experiments were conducted for gasoline-air and Jet-A-air mixtures. The exemplary results are presented on Fig. 2 – 6. On Fig 2 we could observe strong evidence of single wave stable rotating detonation with velocity of 1045 m/s, but on some other experiments, shown on Fig.3, two counter rotating waves with similar velocity were recorded. For gasoline air mixtures longest run last about 4 s (Fig.4), and the picture of the detonation chamber with visible flame, outside chamber, is presented on Fig.5.

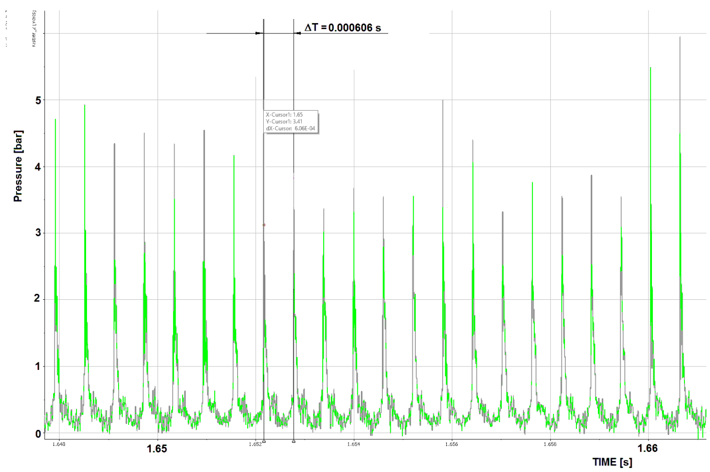


Fig.2. Measured pressure variation (a) for gasoline-air mixture of equivalence ratio equal to 1.14, rotating detonation velocity equal to 1045 m/s.

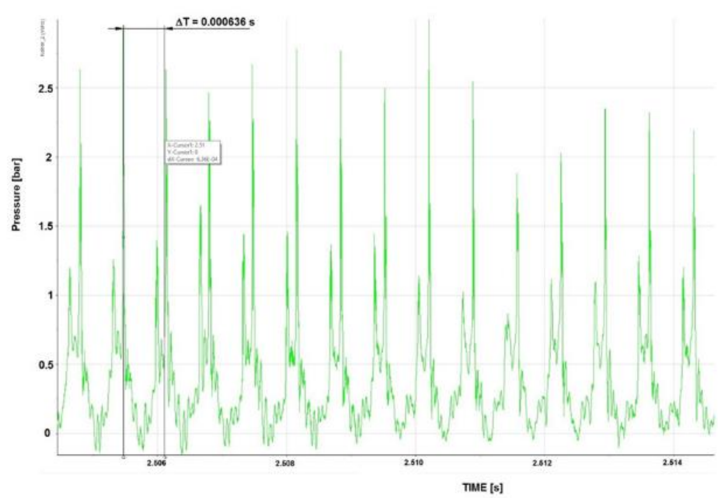
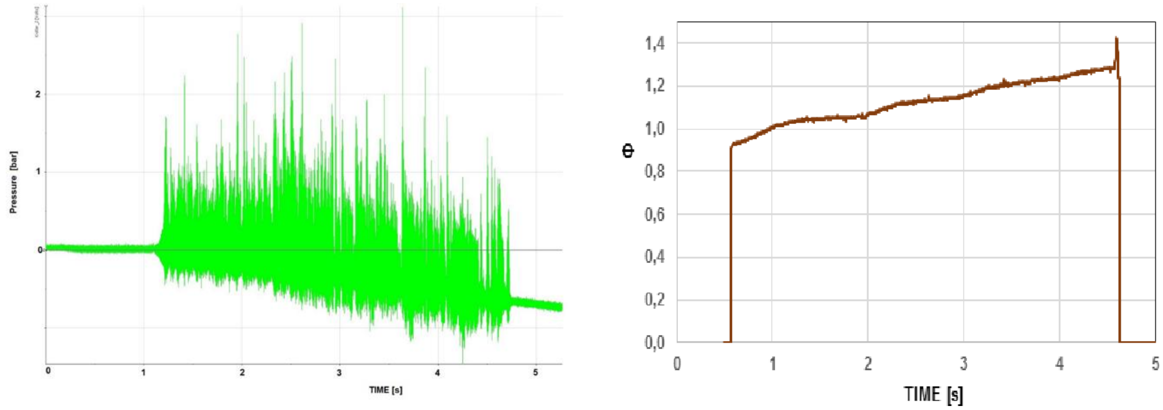


Fig.3. Measured pressure variation for gasoline-air mixture of equivalence ratio equal to 1.13, rotating detonation wave equal to 1110 m/s.



a) b)

Fig.4. Variation of pressure (a) and equivalence ratio (b) during test of gasoline-air mixture.

Fig.5. Typical picture of the flame emerging from rotating detonation chamber.

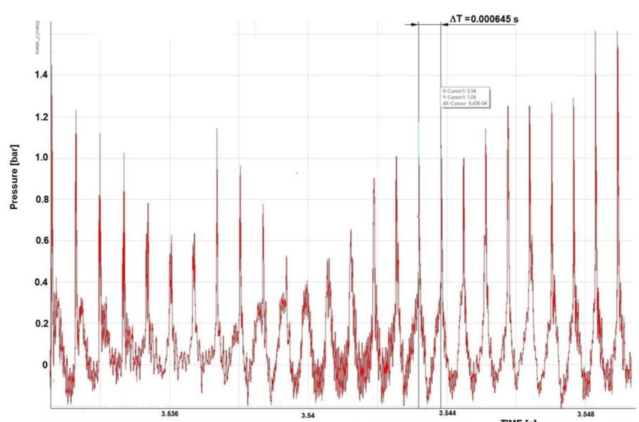


Fig.6. Measured pressure variation for Jet-A-air mixture of equivalence ratio equal to 1.6, rotating detonation wave equal to 1096 m/s

For the case of jet fuel Jet-A mixture with air up to now we have been able to obtain only quasi stable detonation propagating with velocity on 1096 m/s, but it should be, in near future, to obtain stable detonation for such kind mixture, but only flow rate and initial temperature of air should be increased. As it can be seen from experimental results continuously rotating detonation, at tested condition, can propagate with stable or unstable mode depending on mixture supply rate as well as on the equivalence ratio, but at the present arrangement detonation of gasoline-air mixture can detonate without any additive of gaseous hydrogen or other substances which may make mixture more sensitive to detonation combustion.

4 Discussion and conclusions

On the base of conducted experiments it is clearly seen that if the fuel-air mixture is properly prepared, stable continuously rotating detonation in cylindrical chamber can be achieved. Evaporation of liquid fuel before injection to the detonation chamber is most important to provide appropriate conditions to support stable detonation in the chamber. Obviously, chamber/channel dimensions, initial pressure and rate of supply mixtures play also crucial role in supporting stable continuously rotating detonation. Even at this research conditions stable detonation was achieved only for gasoline –air mixtures and for Jet-A-air mixture unstable detonation was achieved, but nothing fundamental stands in the way of accomplishment of stable, continuously rotating detonation in cylindrical chambers of turbine or turbojet engines operating on typically available jet fuels.

References

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