Research on Application of Continuously Rotating Detonation Combustion Chamber to Turbine Engine

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Abstract

The paper summarizes conducted research on the possibility of application of continuously rotating detonation to gas turbine engine. Test stand and tested detonation chambers are described. Experiments were conducted for a different mixtures compositions. Gaseous hydrogen as well as Jet-A or combination of both were used as the fuel. A few different initiator was tested and experientially recorded pressure waves generated by the continuously rotating detonation of fuel-air mixtures and temperatures were also recorded. Obtained results are briefly discussed.

1.Introduction

The possibility of establishment of the continuously rotating detonation was first demonstrated in early sixties of last century by Voitsekhovskii at all for the oxy-acetylene mixture [1], but continuous detonative combustion for fuel-air mixtures was demonstrated only at the end of XX Century [2]. More recently successful experimental research on CRD has been started initially in Russia, Poland, and France, and later in USA, Japan and China. In 2004, Tobita, Fujiwara and Wolanski applied for a patent on the Rotating Detonation Engine (RDE) and the patent was issued in 2009 [3].

The RDE is based on the formation of continuously propagating detonation in cylindrical combustion chamber. The schematic diagram of such chamber is presented in Fig.1. Air is supplied through a narrow slit at critical conditions and fuel is injected through a numbers of small holes. Later many research on rotating detonation were conducted for air mixtures with different gaseous fuels [4-10], but no conclusive results were reported for liquid fuels-air mixtures. Recently research on application of the continuously rotating detonation combustion chamber to the turbine engine where conducted at the Institute of Aviation (IoA) in Warsaw, both for gaseous, liquid and dual fuels (gas + liquid).

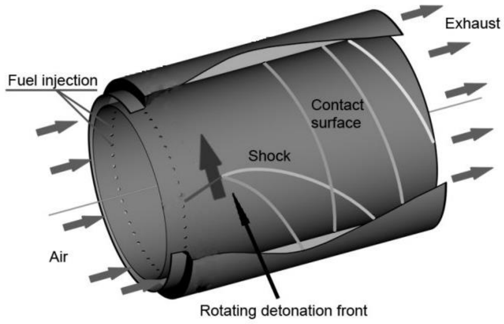


Fig.1. Schematic diagram of detonation chamber for basic research of RDE.

2. Experimental Research

Since 2010 in Institute of Aviation in Warsaw research aimed to develop combustion chamber with rotating detonation for turbine engine has been carried out. Special test stand equipped with preheated compress air supply system was designed. The system allows to supply a few kg/s of air preheated to temperature over hundred degree and pressure of a few atmospheres. Schematic diagram of the test stand with attaches GTD-350 gas turbine is presented on Fig.2, and diagrams of test chambers are presented on Fig. 3 and the fuel supply system on Fig.4.

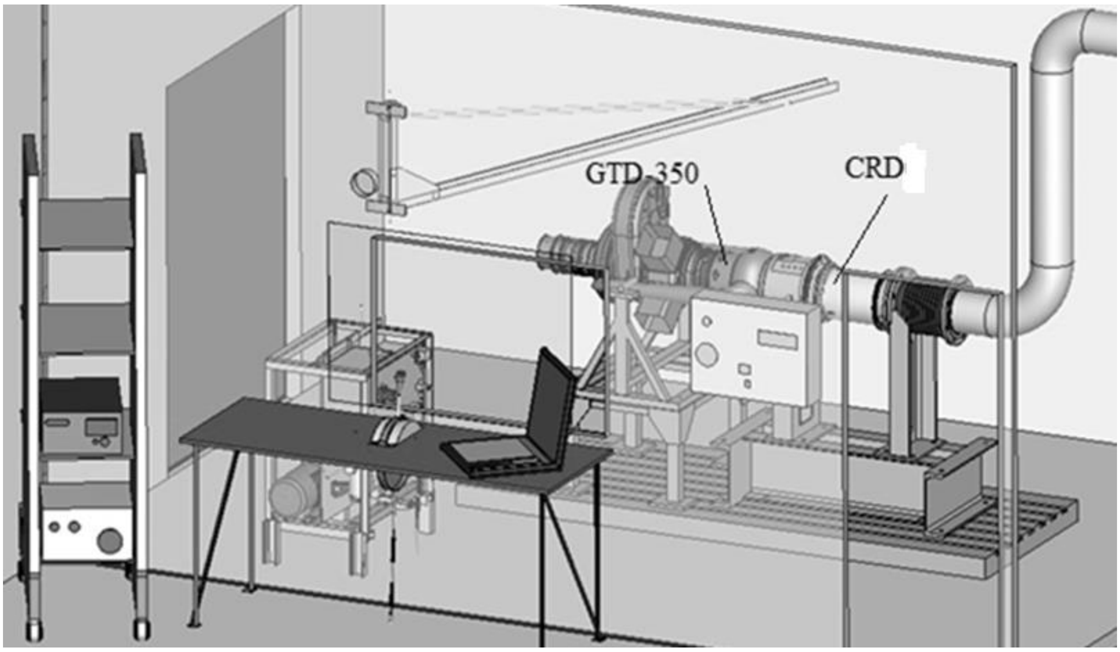


Fig.2. Schematic diagram of the test stand with Continuous Rotating Detonation (CRD) combustion chamber and attached GTD-350 gas turbine.

A few different types of detonation chambers with different geometry and different fuels, and different fuel-air ratio were tested. As a fuel both gaseous hydrogen and Jet-A fuel were used. Fuel was supply by the large number of injectors. Different injectors locations were tested and the optimum placement of injector was selected. Both fuels were injected into the chamber at high pressure. Schematic diagram of the fuel injection system is shown on the Fig. 4. Gaseous hydrogen was injected into the chamber from the high pressure bottles. To ensure sufficient and controllable rate of fuel supply a few high pressure hydrogen bottles with pressure reduction device were used. Electromagnetic valve was used to open and stop of hydrogen supply to the chamber. For the Jet-A fuel high pressure nitrogen feeding system was used. In some cases Jet-A fuel was preheated up to 170 ^{o}C.

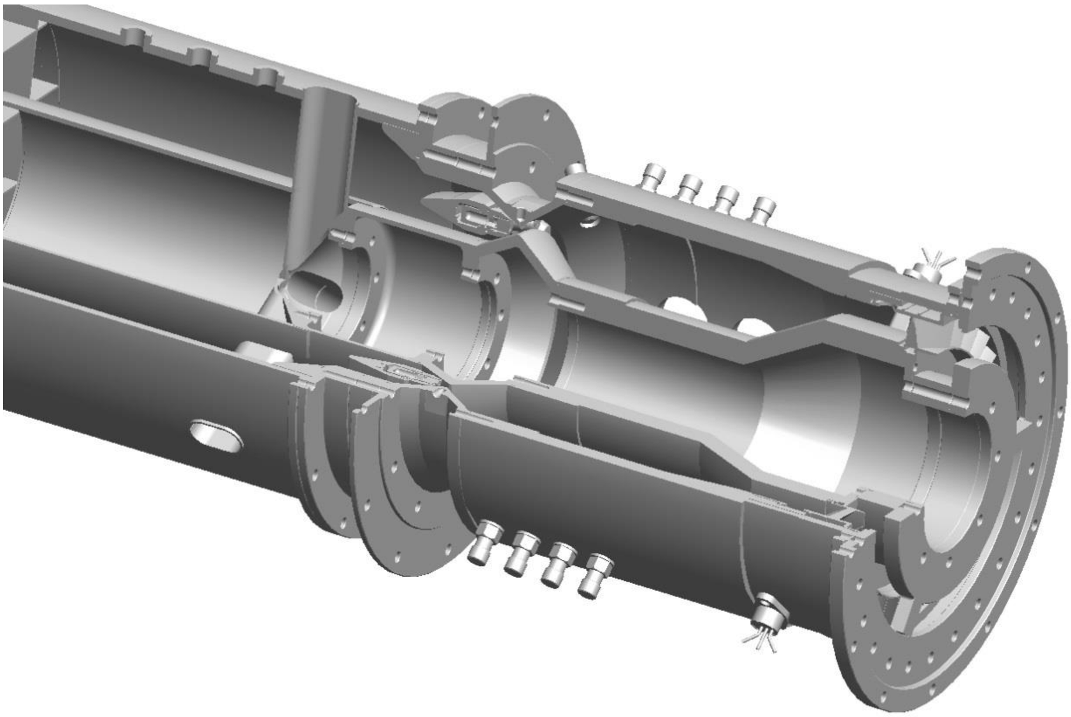
For the initiation of continuously rotating detonation several different types of devices were used in the experiments, such as:

a) spark discharge in air,
b) plasma electric discharge (the so-called "exploding wire"),
c) micro-explosive charges,
d) pyrotechnic cartridges,
e) gas initiator (with detonation of acetylene-oxygen stoichiometric mixture induced by spark electric discharge).

It was found that basically all kind of initiators can successfully initiate process of continuously rotating detonation, but from practical reasons strong electrical spark or gas generator was most frequently used as initiator of detonation. Basically there are no limits of duration of the test, but due to the heating of pressures transducers, most of experiments was limited to about one second duration. Longest duration of test, up to 10 s, was performed without Kistler pressure transducers.

Before experiments air flow was initiated and the air preheater was switch on. When the temperature of air reach desirable value, experiment was initiated. Fuel (or fuels) supply system, initiator as well as data recording were controlled by specially programed sequencer operated by the computer. Picture of continuously rotating detonation obtained for hydrogen-air mixture is shown on Fig. 5. In the case when detonation was initiated short flame emerging from the chamber was clearly visible. For the deflagrated combustion very long flame appear at the chamber exit.

Typical pressure records obtained for different fuels and different flow conditions are presented on Fig.6-8. In the pictures the record from the whole duration of the experiment are presented, but extracted, more detailed pressure variations are also shown. If the pressure transducer was directly exposed to rotating detonation (placed at inside wall of detonation chamber) the pressure signal is strongly affected by the increasing temperature of the pressure gauge. Such significant signal drift is very well seen on the Fig.6. Due to this reason for most of experiments pressure transducers were placed in a special cooled adapters. This, however, significantly modified recorded pressure profile, so such measurements were basically used to monitor frequency of rotating detonation.



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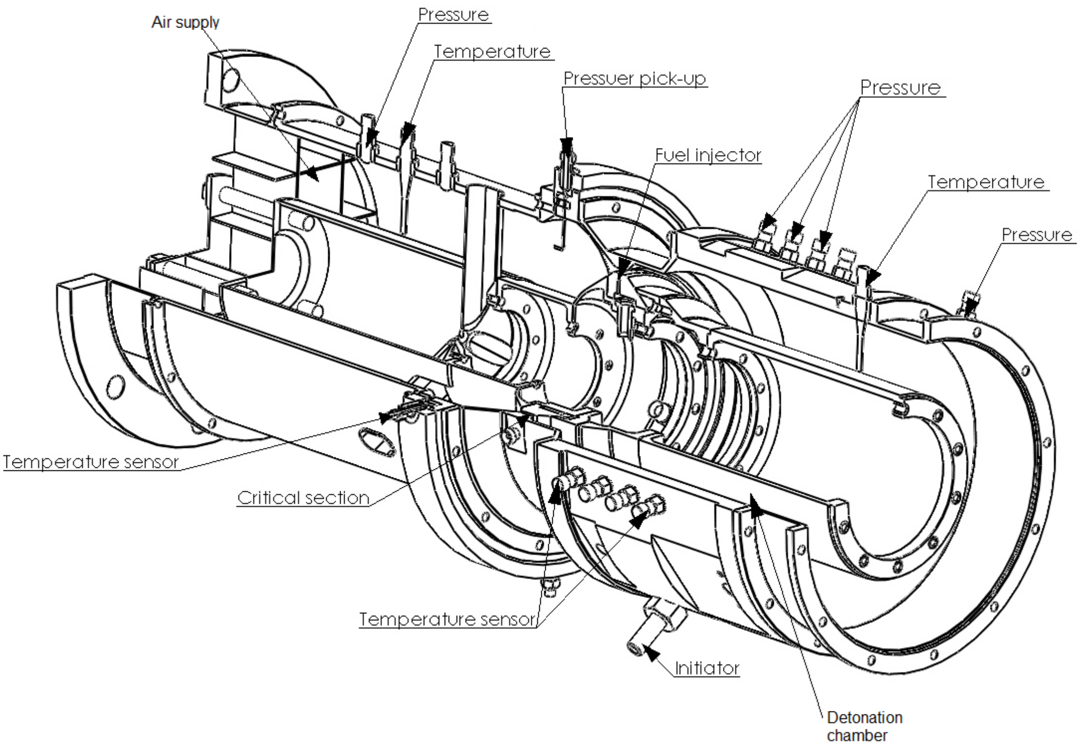

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Fig.3. Schematic diagrams of two different continuous rotating detonation test chambers used in experiments: a) with variable cylindrical geometry, b) with constant cylindrical geometry.

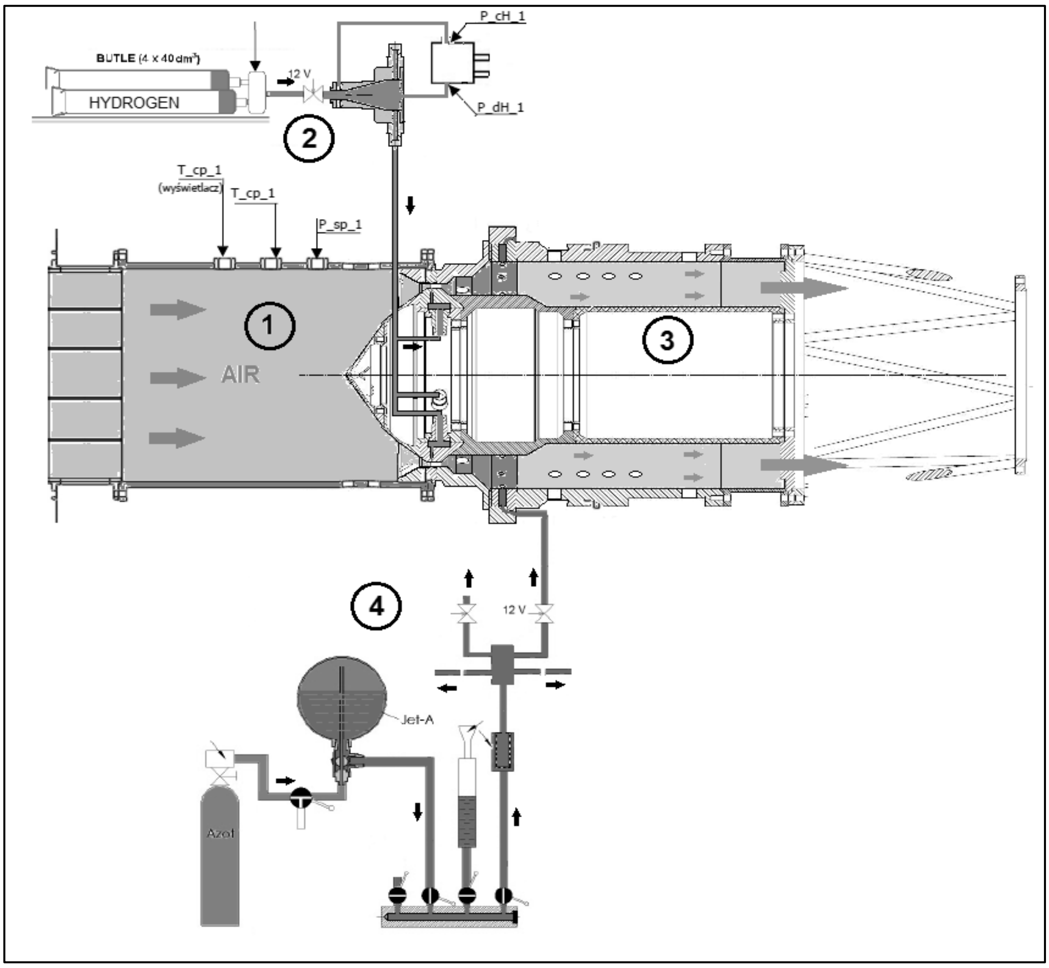


Fig. 4. Schematic diagram of the dual-fuel supply system to continuously rotating detonation chamber. 1- air supply, 2-hydrogen supply system, 3- detonation chamber, 4- Jet-A pressure fed supply system.

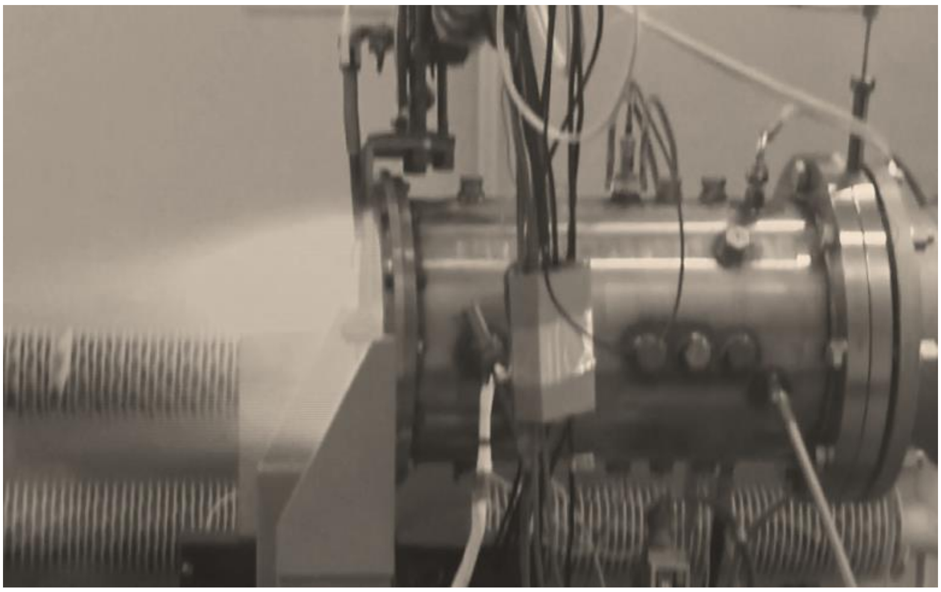
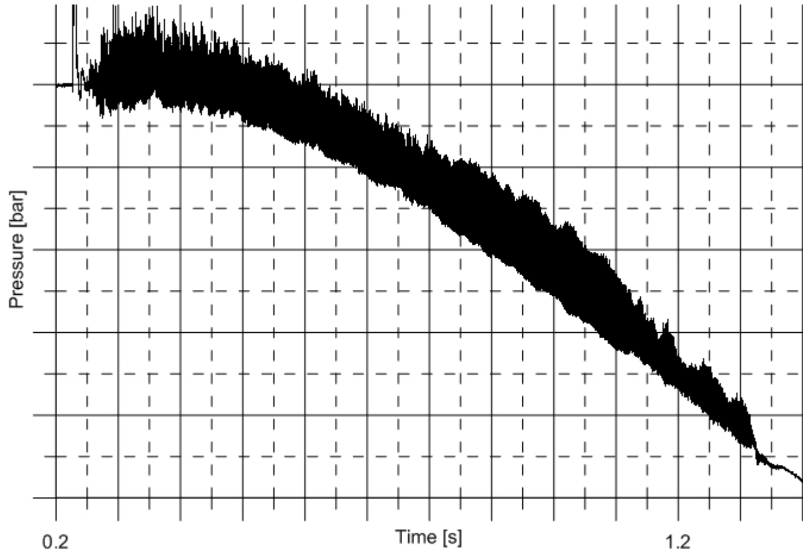


Fig. 5. Picture of chamber operating under conditions of continuously rotating detonation for hydrogen-air mixture.



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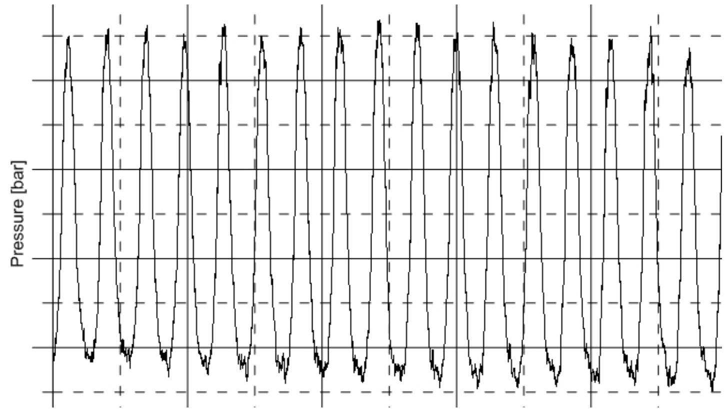

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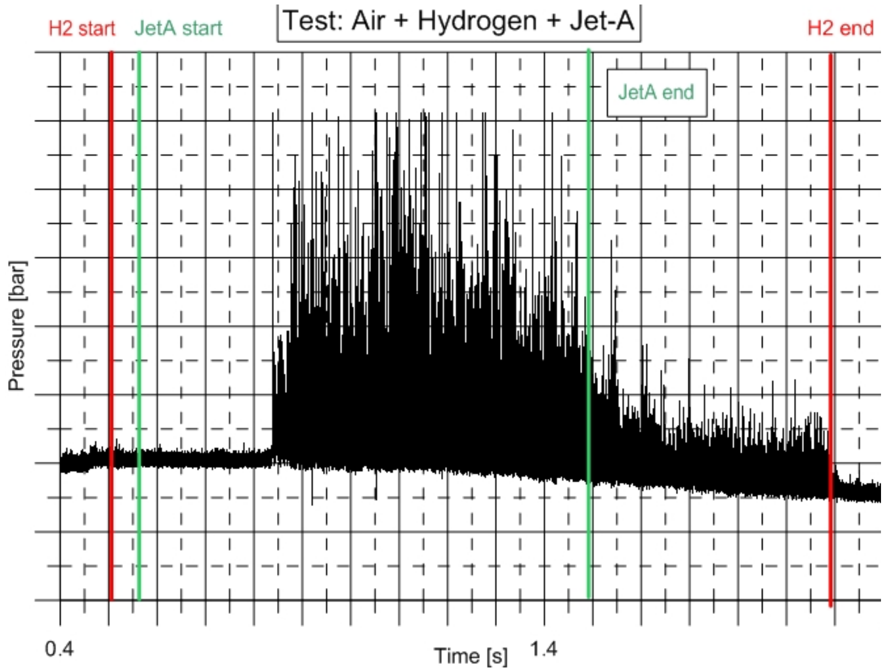
Fig. 6. Typical pressure records for hydrogen-air mixture. a) whole test record; b) enlargement of selected interval. Air supply rate – 1kg/s, H_2 – 0,017 kg/s.



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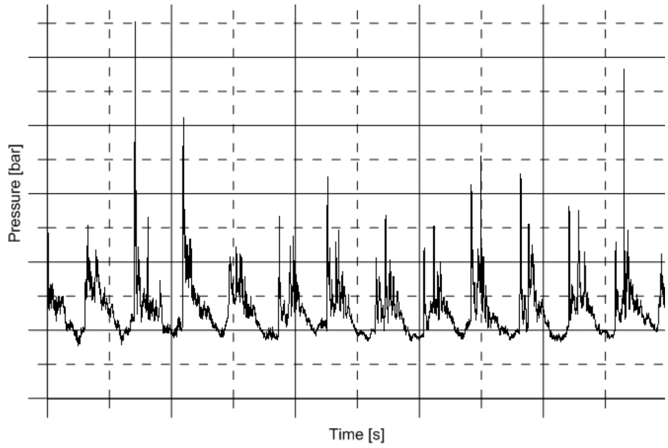
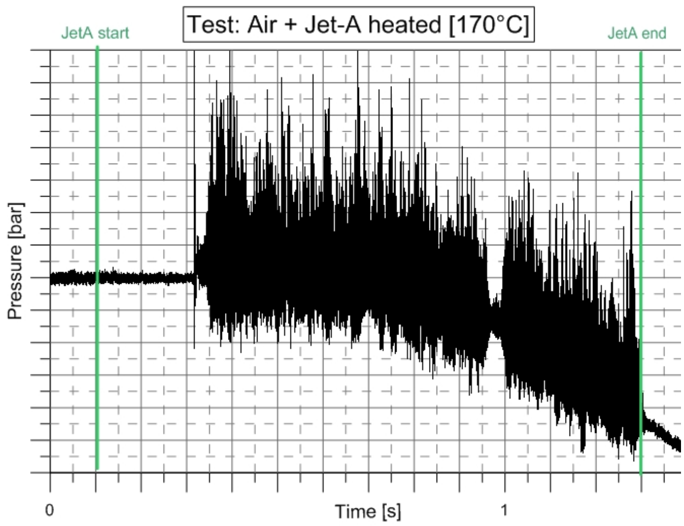


Fig. 7. Typical pressure record for dual fuel (hydrogen and kerosene): a) whole test record; b) enlargement of selected interval. Air supply rate – 2kg/s, H_2 – 0,022 kg/s, Jet-A – 0,021 kg/s.



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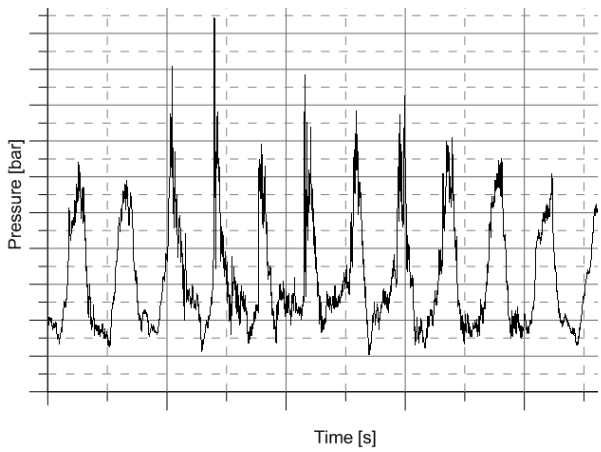
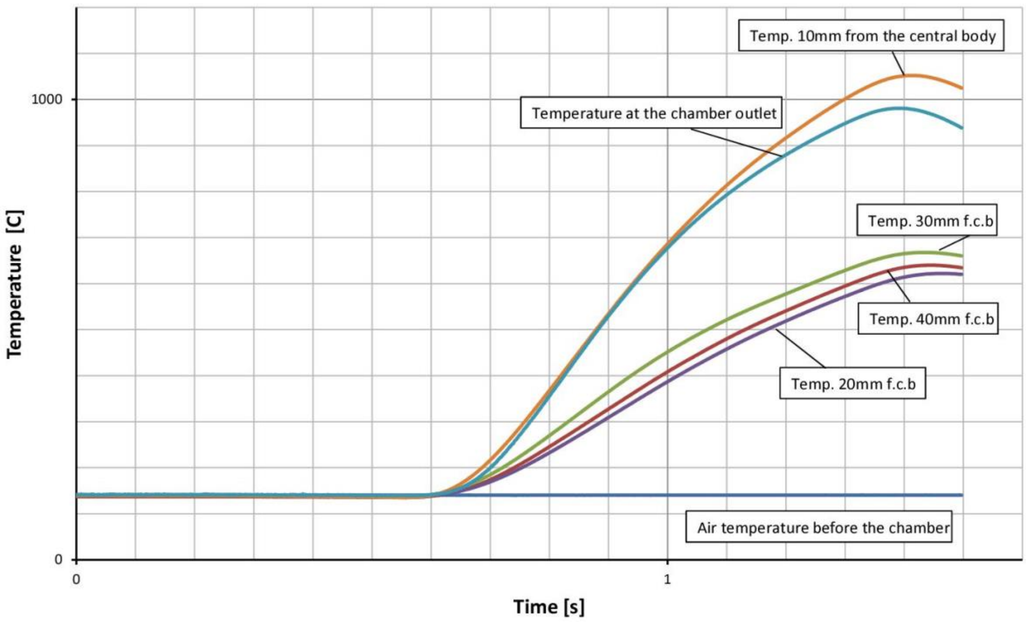


b)

Fig.8. Typical pressure records of rotating detonation in cylindrical chamber for liquid kerosene: a) whole test record; b) enlargement of selected interval. Air supply rate – 0,7kg/s (100^{o}C), Jet-A – 0,032 kg/s (170^{o}C).



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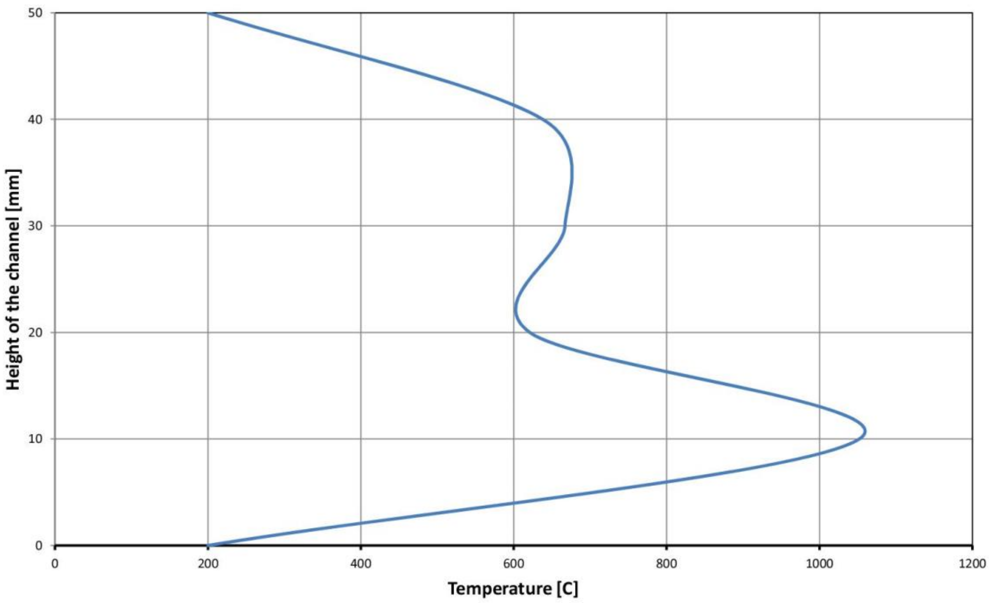

b)

Fig.9. Temperature record at the end of detonation chamber for kerosene-air mixture: a) variation of temperature in time, b) temperature profile at detonation chamber exit at the end of test. Air supply rate – 0,7kg/s (100^{o}C), Jet-A – 0,032 kg/s (170^{o}C).

As it can be seen from figures 6-8 continuously rotating detonation can be initiated and sustained for different fuels as well as for different chamber geometry. However, to obtain stable rotating detonation several conditions have to be fulfilled, such as:

1) good mixing of combustible mixture components,
2) Respectively high rate of flow of combustible mixture in the cylinder-shape channel,
3) the appropriate height of the flow channel, associated with detonation cell size for the combustible mixture,

4) use of a source of initiation of detonation of a correspondingly high energy and power for a given combustible mixture.

If this conditions are not fulfilled initiation of continuously rotating detonation is not possible, and only deflagration, with slow combustion and very long flame can be initiated. Also, very important is the temperature distribution at the exit from detonation chamber. In our experiments relatively large thermocouples were used for temperature measurements, so time constant of it was also relatively large, so for short duration of test only temperature measured at the end of test should be considered as representative for such measurements. Typical results of such measurement are presents on Fig. 9. Fig 9a shows variation of temperature measured at different locations in the chamber, while on Fig. 9b instantaneous temperature profile at the end of the chamber is presented. It is evident that for this test mixture composition inside the chamber was different in different section of the chamber, so it is necessary to correct injection system to obtain desirable temperature profile.

Summary and conclusions

Extensive research were conducted at the Institute of Aviation in Warsaw on possibility of application of the continuously rotating detonation to gas turbine. At this stage different configurations of detonation chamber and different fuels were tested. It was shown that continuously rotating detonation can be obtained and sustained for relatively long time. However, to apply such system to gas turbine, still further research are necessary. At this point we are prepared to integrate selected chamber with the GTD-350 engine and perform test of the whole system in the near future.

Acknowledgement

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