Development of Dual-Fuel Rotating Detonation Chamber

Piotr Wolanski[1,2], Wlodzimierz Balicki[1], Piotr Kalina[1], Jan Kindracki[1,2], Borys Lukasik[1], Witold Perkowski[1] and Artur Rowinski[1]

Institute of Aviation[1], and Warsaw University of Technology[2],
Warsaw, Poland

Key words: detonation, dual fuel, RDE, Gas-turbine;

1. Abstract

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]. Later many research on rotating detonation were conducted for air mixtures with different gaseous fuels [3-7], but no conclusive results were reported for liquid fuels-air mixtures. Only recently research on establishment of the continuously rotating detonation for the mixture kerosene-air mixtures with addition of gaseous hydrogen were conducted at the Warsaw University of Technology (WUT) and at the Institute of Aviation (IoA) in Warsaw. In the paper development of continuously rotating detonation in cylindrical chambers in WUT and in IoA are described.

2. Research Facility

The experiments were conducted at two different facilities. In both cases experiments were conducted for Jet-A fuel with addition of gaseous hydrogen with air, and the auxiliary detonation tube was used as the initiator. At WUT facility (Fig.1), due to the tank based supply system, duration of the experiment was limited to a part of the second (up to 0,6 s) while at IoA experiments were carried out using continuous flow of air and could last a few seconds. Schematic diagram of the IoA facility is presented on Fig.2. In the IoA facility air can be preheated to the temperature of about 100 ^{0}C, while the pressure was basically close to atmospheric. In both cases research was carried for the different ratio of gaseous hydrogen and Jet-A fuel.

Fig.1. Picture of the research facility at the Warsaw University of Technology.

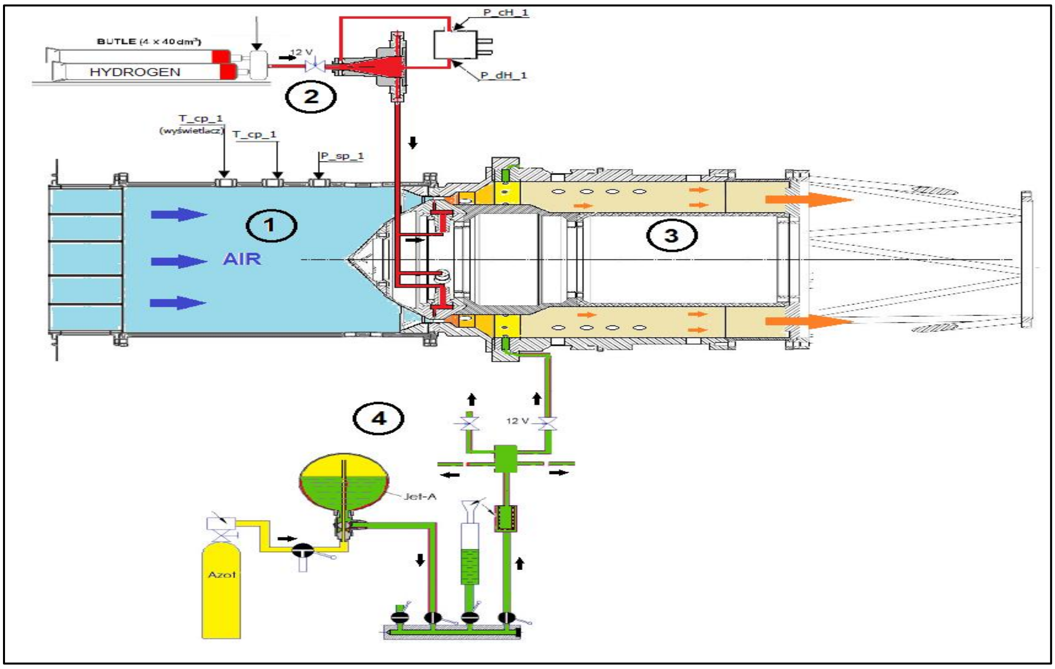

Fig.2 Schematic diagram of the test stand at the Institute of Aviation: 1.Air inlet; 2. Hydrogen supply system; 3. Combustion chamber; 4. Jet-A supply system

3. Experimental Results

The main aim of the research was to evaluate condition under which continuously rotating detonation could be established with minimum addition of gaseous hydrogen. In both cases small addition of hydrogen to nearly stoichiometric Jet-A with air mixture resulted in establishment of the continuously rotating detonation wave in both experimental chambers. Typical experimental pressure measurements of the continuously rotating detonation wave are presented on Fig.3 and on Fig.4.

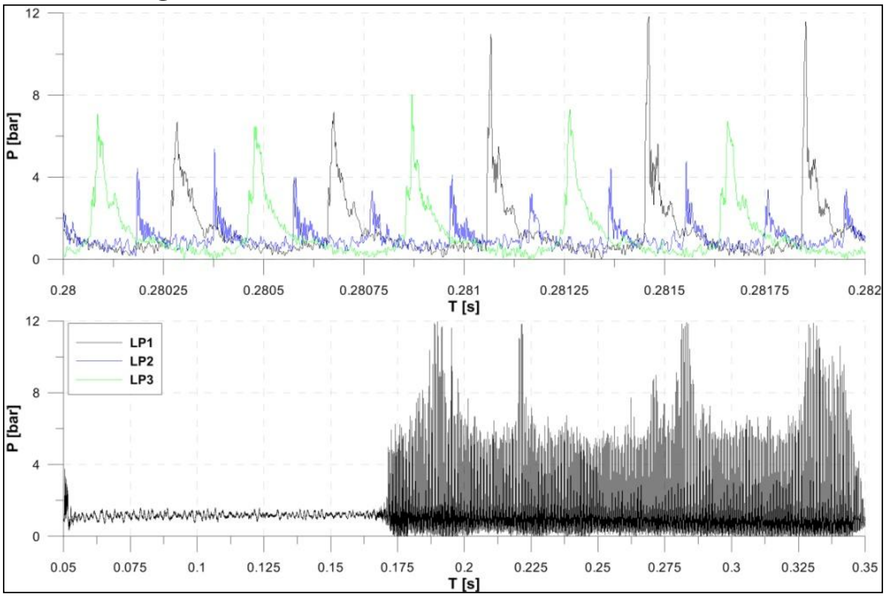

Fig.3. Variation of pressure as a function of time at WUT test chamber. Top pressure record is the enlargement of the segment of the part of bottom record when both hydrogen and Jet-A liquid fuel (from 0.17 to 0.35s) were supplied.

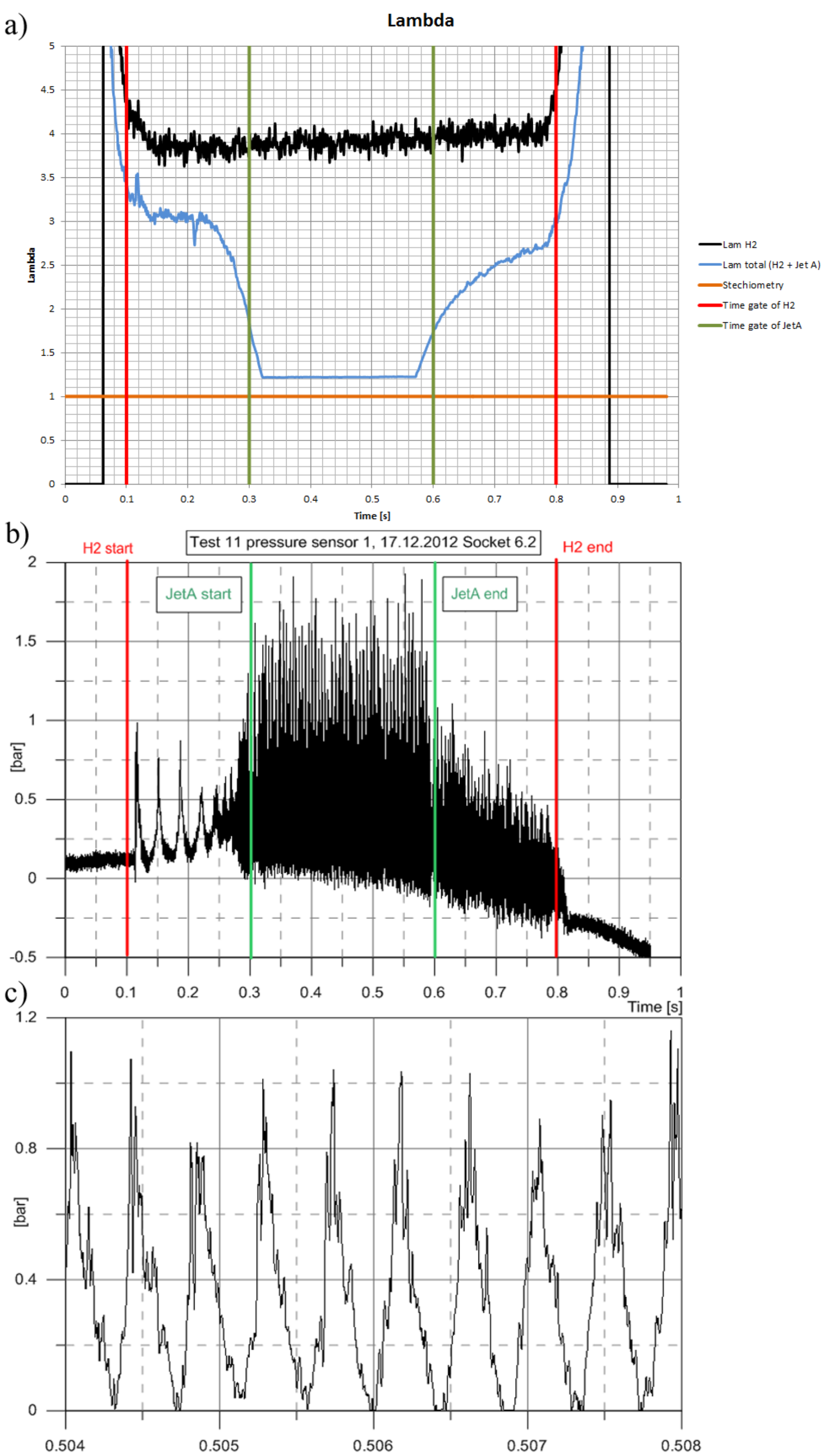

Fig.4.Variation of lambda and pressure at IoA test chamber: a) Variation of lambda against the time for hydrogen only (black line) and for total fuel added (hydrogen and Jet-A) – blue line. Please note reference line for the stoichiometric composition and the time gate for hydrogen valve opening; b) Variation of pressure against the time at IoA test chamber. Please note indication of beginning and end of injection of hydrogen and Jet-A; c) Enlarged part of the pressure record from (b) chart when both hydrogen and Jet-A liquid fuel was supplied.

For all tested mixture combinations stable rotating detonation was possible when hydrogen equivalence ratio was close to 0,25 (Lambda about 4) and overall equivalence ratio close to unity. Variation of lambda as a function of time for hydrogen and total fuel (hydrogen and Jet-A) is shown on the Fig.4a. For this case lambda is slightly higher than one, so its means that mixture composition is close to the stoichiometric concentration, but slightly on the lean site.

4. Summary and Conclusions

Research of the process of initiation of continuously rotating detonation in the cylindrical chamber were conducted at the two different test stands. For both cases continuous rotating detonation was achieved with relatively small addition of gaseous hydrogen to Jet-A liquid fuel mixed with air. In all cases rotating detonation was stable, however for lean hydrogen-air no detonation or "galloping rotating detonation" was only observed. Its seems that in larger chamber (research test stand of the IoA – is 252 mm in diameter) less hydrogen will be needed when initial pressure of the mixture will be increased to 2-4 bar. To demonstrate this further research are necessary.

5. Acknowledgements

This work was conducted in frame of project UDA-POIG.01.03.01-14-071 "Turbine engine with a detonation combustion chamber" supported by EU and Ministry of Regional Development, Poland, and also work was supported by the National Science Center, Republic of Poland, project no. 838/B/T02/2009/37.

6. 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).
2. Bykowski, F.A., Mitrofanov, V.V., and Vedernikov, E.F., "Continuous Detonation Combustion of Fuel-Air Mixtures," *Combustion, Explosion and Shock Waves*, Vol.33, 1997, pp.344–353.
3. Kindracki J, Fujiwara T. Wolanski P.,(2006). An experimental study of small rotating detonation engine, in: Pulsed and continuous detonation. Torus Press. 2006, pp.332-338
4. Bykovskii F.A., Zhdan S.A., and Vedernikov E.F. Continuous Spin Detonations , *Journal of Propulsion and Power.* 2006, V. 22, No. 6, P. 1204 – 1216.
5. Tobita A., Fujiwara T., and Wolanski P.,: "Detonation engine and flying object provided therewith"; Publication data: 2005-12-29; Japanese Patent, No. 2004-191793 (granted 2009) Patent US 2005_0904A/AND/01983 (granted 2010)
6. Wolanski P.,: "Development of the continuous rotating detonation engines", in "Progress in Pulsed and Continuous Detonations», edited by G.D. Roy and S.M. Frolov, Moscow, Torus Press, 2010, pp.395-406.
7. Wolanski Piotr,: "Detonative propulsion". Proceedings of the Combustion Institute 34 (2013) 125–158