Three-dimensional numerical simulation of a continuously rotating detonation in the annular combustion chamber with a wide gap and separate delivery of fuel and oxidizer

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Modern power plants in aircraft are mainly represented by gas-turbine engines (GTEs) operating on the Brayton thermodynamic cycle. The same cycle is used in liquid rocket engines (LREs). For many decades, GTEs and LREs were continuously developed and further improvements of their performance require large investments. Alternative solution to significantly improve the thermodynamic efficiency of modern GTEs and LREs is the use of the combustion chambers with total pressure gain. The total pressure gain in the combustion chamber can be provided by means of increasing the burning rate of fuel and oxidizer, and/or changing the combustion mode. In view of it, the most attractive in terms of thermodynamic efficiency is the detonation mode. In the detonation wave, the chemical energy stored in the fuel is released for a very short time in a very thin layer of shock-compressed mixture. Two basic schemes of detonation-driven propulsion are currently studied worldwide, namely, one with periodic detonation waves traveling along the combustion chamber (a pulse detonation chamber), and another with detonation waves, continuously rotating above the injector head in the annular or disc-shaped combustion chamber (a continuous detonation chamber, CDC). Both schemes are considered promising for air-breathing and for rocket propulsion.

This study is the continuation of our previous computational studies [1]. The objective of this work is to demonstrate the possibility of integrating CDC in GTE, i.e. to prove computationally the feasibility of the operation process in the annular combustion chamber with a wide gap (comparable to the blade height of the last compressor stage in GTE) with separate feeding of fuel (hydrogen) and oxidizer (air). The other issue addressed in this work is the design of the input insulator which provides damping of pressure fluctuations, which are generated by continuously rotating detonations in CDC, behind the last stage of the compressor. The mathematical formulation of the problem, the calculation method and procedure of detonation initiation were the same as described in detail in [1].

The most important result of this work is the proof of feasibility to integrate CDC in GTE together with the input insulator of specific design, installed upstream of the CDC, which provides almost complete damping of pressure fluctuations for the last stage of GTE compressor. This input insulator does not deteriorate the CDC performance, as the gain in the total pressure in the CDC is still 14%-15% as compared with the same combustion chamber operating in the deflagration mode. As a matter of fact, Fig. 1 compares the average total pressure distribution along the input insulator and CDC in the both operation modes: detonation (solid curve) and deflagration (dashed curve), other conditions being equal.

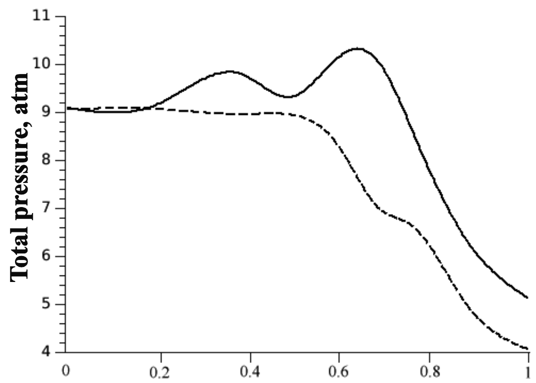

Fig. 1: Estimated distribution of the total pressure averaged over the cross section in the annular combustion chamber with detonation (solid curve) and deflagration (dashed curve)

References

1. Frolov S.M., Dubrovskii A.V., and Ivanov V. S. Three-dimensional numerical simulation of operation process in rotating detonation engine. Progress in propulsion physics / Eds. L. DeLuca, C. Bonnal, O. Haidn, and S. Frolov. EUCASS Advances in Aerospace Sciences Book Ser. EDP Sciences, TORUS PRESS, 2012, Vol. 4, pp. 467-488.