On Modeling of Electrochemical Detonation Pulsejet

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Abstract

Incentives for employing electrochemical effect to produce detonation in pulsejets are considered and it is shown that such a measure enables full automatization of operation of the system without use of air moving parts in the design. Two mathematical models were built to simulate two modes of achieving detonation in the operational cycle of the engine owing to electric discharges: one by explosion and the second, by considerably more effective process-implosion.

Introduction

Standard pulsejet with its all beneficial qualities (simplicity, self-reignition and self-aspiration) is crippled by two shortcomings:

- very low thermal efficiency, and
- ear-splitting noise (~140 dB)

The low thermal efficiency of its thermodynamic cycle results from practically negligible compression ratio. Luckily, there are some effective methods that can dramatically improve the efficiency, namely, "thrust augmentation" and modification of the combustion process by inclusion detonation. The thrust augmentation can be obtained by employment of flow ejectors that increase the mass flow rate through the system. It turns out however that as the velocity of the secondary flow approaching an ejector increases, as for example, when ejector thrust augmenters are used to reinforce the thrust of moving vehicles such as aircraft, the thrust augmentation obtainable falls off.

The second method of improving mechanical efficiency consists in application of detonation to increase the compression ratio by generating shock waves in the combustion chamber followed by combustion. Usually in pulsejets detonation is accomplished with the aid of explosion caused by a stream of very hot combustion products generated by igniter. The igniter is equipped with valves that regulate the flow of oxygen and fuel and a conventional spark plug, both electronically controlled. In some solutions, the igniter has been substituted by a powerful laser. There are several measures to alleviate the second shortcoming of standard pulsejets – the unbearable noise. The most effective technique is combining two units and operating them in the out-of-phase mode. This should be done automatically and without any obstruction of flow or negative influence on combustion

The Concept of Electrochemical Detonation Pulsejet

Operation of the electrochemical detonation pulsejet (Figure 2) is based on an electrochemical effect (Figure 1) that consists in transforming the combustion process into detonation by adding an adequate amount of external energy through an electric discharge, produced at the appropriate time and locations inside the combustion chamber. The discharge that occurs automatically at the moment of re-ignition generates a pressure wave, which is followed by combustion. Thus combustion takes place at an elevated pressure and both the amplitude of pulsation (Figure 4) and the thermal efficiency of the engine are increased.

Generally electrochemical pulsejet resembles the hybrid drive system for automobiles that comprises both electric motor and piston engine. In the electrochemical pulsejet case however, the idea of coupling the electric energy with thermal energy is achieved in a different but simpler manner, namely by putting these two sources of energy into one process. As a whole, the engine is characterized by lack of moving parts, automatic cyclic operation in stationary conditions, self-regulation based on strong feedback (Figure 3) and utilization of diverse physical processes which interact dynamically to build a smoothly functioning whole.

Mathematical Modeling

Euler and Navier-Stokes equations are used to describe the flow processes. Twostep averaged chemical reactions are included in the model. Energy input from the electric discharges is also taken into account. The Godunov's finite difference method and the method of large particles are being used for the numerical simulation. Quasi-onedimensional and two-dimensional unsteady approaches to the combustible mixture flow are employed. Quasi-one-dimensional model was applied to simulate the generation of strong pressure waves by one-point explosion (Figure 2 & 6a). The modeling (Figure 5) shows good agreement with the experiment (Figure 4). Implosion caused by electrical discharges in annular system of electrodes (Figure 6b) was simulated by two-dimensional model (Figure 7)

Suppressing Noise

A method of noise suppression in pulsejets was developed as part of a project related to what is called "precision farming". Precision farming is the computerized and by satellite controlled management of crops to suit variations in land characteristics. This procedure can reduce costs, increase yields and decrease environmental impact. One of the environmental problems is frost protection of orchards, vineyards and nurseries. It seems that the best protection system would be that, which is based on utilization of pulsejets, but with considerably reduced noise. Figure 8 shows twin, U-shaped pulsejets that satisfy this condition. The noise is reduced (from 135dB to 75dB) by silencers that force the pulsejets to out of phase operation, without obstructing the flow. This is done by standing waves generated inside the silencers that control both the recharges and the exhausts of the individual pulsejets.

Conclusions

The electrochemical detonation pulsejet is a hybrid propulsion system that utilizes both electric and thermal energy. Electric energy however constitutes only a small percentage of the whole energy input. Of the two-modeled methods of generation of detonation by electric discharges namely explosion and implosion the last one is of course more effective. This results from wave amplification during the process, obtained by area construction. It is believed that electrochemical detonation pulsejet, because of its simplicity and competitive efficiency, can, in some circumstances, find application in propulsion of airplanes, missiles and small submarines. The very idea of producing strong pressure waves by electric discharges may also be probably exploited in RAM accelerators.

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References

1. Wojcicki, S., "Influence of Electric Discharge on Flame Propagation", Astronautica Acta Vol. 17, pp, 827-832. (1972)

2. Korobeinikov, V.P., "Numerical method for unsteady two-phase flows", Proc. of 5th Int. Symp. on Computational Fluid Dynamics, Sendai, Japan, V.1. 1993, pp. 76-83.

3. Korobeinikov, V.P., Wojcicki, S., "Theoretical Modeling of Detonation Pulse Engine with Application to Ram Accelerator", Proc. of 2nd Int. Workshop on Ram Accelerators. RAMACII. Univ. of Washington 1995.



Figure 1. Electrochemical effect: flame is a conductor, therefore when it bridges the electrodes an electric discharge occurs and the flame is accelerated.



Figure 2. Schematic of an experimental pulsejet used for test and calculations; dimensions are in mm.



Figure 3. A control system model for electrochemical pulsejet operation



Figure 4. Pressure variation in combustion chamber of electrochemical pulsejet (correlated with electric discharges) during the transition from standard operation to operation with discharges.



Figure 5. Quasi one-dimensional model of pulsejet operation



Figure 6. Two modes of strong pressure waves generation by electric discharges: a) explosion, b) implosion



Figure 7. Two-dimensional modeling of the implosion. t_d is the discharge time; x,r are cylindrical coordinates.



Figure 8. Twin pulsejets with reduced noise by their out of phase operation.



Figure 9. Out of phase operation of twin pulsejets.