INTRODUCTION

Jet propulsion engines and technological burners of new generation operating on controlled continuous and pulsed detonations are becoming a subject of pragmatical interest worldwide. The concept of a detonation engine or burner implies that chemical energy of liquid or gaseous fuel is released in a detonative rather than deflagrative combustion mode. In the detonative mode, energy release rates approach 10^{10} W/m^2, i. e., 3 to 4 orders of magnitude higher than in the deflagrative mode. In detonation-driven jet propulsion engines, propagating or rotating detonation waves are utilized to produce the thrust due to rapid burning of fuel in a combustion chamber resulting in a nearly constant-volume heat addition process accompanied with the high kinetic energy of emanating jets. The detonation-based technological burners are designed to utilize a combination of the destructive mechanical potential of periodic shock waves generated by the burner and high-temperature high-speed jets of combustion products for fragmentation and gasification of various materials, waist, etc. The concept of controlled detonative combustion is attractive, first of all, for reduced fuel consumption, simplicity, and easy scaling. Also, it is attractive for the reduced pollutants emissions due to volumetric-type combustion and significantly shorter residence times in a combustor.

From 1998 to 2008, the U.S. Office of Naval Research (ONR) and the Russian Foundation for Basic Research (RFBR) have jointly sponsored six international colloquia on detonations, in particular, those aspects of detonations that are directly relevant to the development of pulse detonation engines (PDE). In 1998, the International Colloquium on Advances in Experimentation and Computation of Detonations was held in St. Petersburg with the participation of more than 60 experts. In 2000, the International Colloquium on Control of Detonation Processes was organized in Moscow with more than 100 participants. In 2002, the International Colloquium on Advances in Confined Detonations was held in Moscow with more than 120 participants. In 2004, the International Colloquium on Application of Detonation to Propulsion was again organized in St. Petersburg with more than 120 participants from 12 countries. Since 2006, further colloquia were referred to as International Colloquia on Pulse and Continuous Detonations (ICPCD) and given a serial number. Thus, the 5th ICPCD was held in 2006 in Moscow with more than 100 participants from 11 countries. Finally, the 6th ICPCD was held in 2008, also in Moscow, with 80 participants.

These meetings resulted in a number of books of condensed papers of all presentations [1–5] and full manuscripts of selected papers presented at the colloquia [6–9]. This volume is the continuation of the series of books of selected papers presented at the 5th and 6th ICPCD meetings.

The book is organized with five Parts: Fundamentals of Combustion (Part 1), Fundamentals of Deflagration-to-Detonation Transition (Part 2), Fundamentals of Detonation (Part 3), Pulse Detonation Engines (Part 4), and Continuous Detonation Engines (Part 5). The contents of the articles included in each section are briefly outlined below.

Part 1: Fundamentals of Combustion

Polikhov and Segal applied Planar Laser Induced Exciplex Fluorescence for investigating subcritical, near-critical, and supercritical coaxial liquid-to-gas mixing and found that due to changes in the dominating mixing mechanisms, the mixing regimes under these conditions differ significantly.

Starik et al. presented an updated detailed kinetic mechanism of hydrogen combustion in oxygen (or air) involving small additives of singlet oxygen $O_2(a^1\Delta_g)$ and $O_2(b^1\Sigma_g^+)$ molecules capable of noticeably decreasing the mixture induction time and ignition temperature even at atmospheric pressure. The updated mechanism was validated against a wide range of experimental conditions found in shock tubes, laminar premixed flames, and flow reactors including experiments with adding singlet delta oxygen produced in electrical discharges.

Azatyan et al. studied experimentally and theoretically the influence of inhibitors of various chemical nature on flammability limits in H_2 + oxidizer (O_2 + N_2) + diluent (C_2F_5H; CF_3H; olefins) mixtures and arrived at a conclusion on the important role of spontaneous inhibitor regeneration in its efficiency.

Starik developed thermally equilibrium and nonequilibrium kinetic mechanisms for modeling ignition and combustion of light (methane) and heavy (n-decane) hydrocarbons in air with a particular attention paid to nonequilibrium effects associated with a delayed excitation of vibrational degrees of freedom of molecules behind incident and reflected shock waves. Conventional thermally equilibrium models for hydrocarbon–air mixtures were shown to underestimate significantly (by a factor of 2 to 3) the ignition delay length and overestimate the pressure (by 20%–30%) of combustion products as compared to the predictions of thermally nonequilibrium kinetic models.

Lipatnikov tested various models of premixed turbulent combustion against two well-documented features of developing turbulent flames, namely, (*i*) self-similarity of the mean flame structure and (*ii*) faster growth of the turbulent burning velocity as compared with the mean flame thickness. The majority of available models were shown to fail in complying with these features, whereas the "gradient" models were proven to reflect them properly.

Korytchenko et al. addressed a problem of increasing the volume of thermal ignition source by affecting gas discharge in such a way that most of discharge energy input is concentrated in a gas-discharge gap and plasma parameters approach thermally equilibrium values in the course of discharge.

Part 2: Fundamentals of Deflagration-to-Detonation Transition

Gostintsev and Shatskikh examined theoretically the scenario of self-turbulization and the limiting (experimentally recorded) laws of the accelerated expansion of a free turbulent spherical flame in premixed combustible gas and showed that the limiting self-similar law of completely turbulized spherical front propagation corresponds to the generalized Kolmogorov–Obukhov law for a locally-isotropic velocity field in the turbulent environment with the quiescent gravity center at a constant mean rate of heat release.

Molkov et al. further developed the Very Large Eddy Simulation model for large-scale hydrogen–air deflagrations by including transitional effects of turbulence generated by flame front and performed numerical simulations of large-scale experiments with hydrogen–air mixtures in closed vessels, open atmosphere, and vented vessels.

Frolov and Ivanov developed a computationally efficient algorithm for multi-dimensional numerical simulation of deflagration-to-detonation transition (DDT) in a gas-fueled air-breathing PDE and applied it to the two-dimensional (2D) numerical simulation of DDT in a PDE channel 3 m long with flame accelerating obstacles and shock-wave focusing nozzle filled with the stoichiometric propane–air mixture at normal initial conditions.

Kagan et al. performed a numerical study of the effect of hydraulic resistance and heat loss on the DDT in a thin semiinfinite channel filled with a premixed reactive gas and demonstrated that DDT is sensitive to the wall temperature and reaction order.

Kilchyk et al. studied theoretically the interaction between laminar premixed flames and shock or expansion waves and predicted the appearance of hot spots ahead of the flame at shock–flame irregular refractions which can trigger the onset of detonation or DDT.

Smirnov et al. presented the results of numerical simulations of DDT in heterogeneous polydispersed mixtures taking into account the effects of fuel droplet atomization, vaporization, and combustion as well as nonequilibrium effects in droplet atomization and phase transition.

Part 3: Fundamentals of Detonation

Frolov and Medvedev applied a one-dimensional theory of detonability limits for mathematical modeling of chemical inhibiting of hydrogen–air detonations and showed that the theory is capable of predicting the main specific features of the effect of chemical inhibitors on the concentration limits of hydrogen–air detonations in straight round tubes of different diameters at different initial pressures and temperatures.

Levin et al. investigated numerically the propagation of cellular hydrogen–air detonation waves in plane channels with transversal rigid barriers and abrupt widening of cross section and determined the critical parameters for detonation propagation, survival, and decay.

Davidenko and Mevel performed a 2D numerical simulation of cellular detonation structure in hydrogen – nitrous oxide – argon (H_2–N_2O–Ar) mixtures with a systematically reduced reaction mechanism and showed that the predicted results correspond well with available experimental data.

Tsuboi et al. performed unsteady three-dimensional numerical simulation of hydrogen–air single-spin and two-headed detonations in circular and coaxial tubes and showed that the single-spin mode maintains complex Mach reflections whereas the two-headed mode develops periodically from the single Mach reflection to the complex one.

Zhukov et al. studied experimentally ignition and detonation initiation in various stoichiometric hydrocarbon – oxygen – diluent mixtures by a nonequilibrium high-voltage nanosecond gas discharge and detected three modes of flame front propagation: deflagration, transient detonation, and Chapman–Jouguet detonation.

Penyazkov and Sevryuk investigated experimentally the structure of spinning, two-cell marginal, and three-cell normal detonations in a stoichiometric acetylene–air and fuel-lean acetylene–oxygen–argon mixtures in a circular tube and showed that the detonation cells are reinitiated when a local flame velocity decays to a certain critical value very close to the isobaric sound speed in the burnt gas.

Khmel and Fedorov studied numerically the initiation and propagation of planar and cellular detonations in suspensions of small aluminum particles with bimodal size distribution in gaseous oxygen and revealed the dependence of the detonation cell size and initiation energy on the relative concentration of each particle fraction.

Veyssiere et al. performed a numerical study of direct detonation initiation in suspensions of aluminum particles in gaseous oxygen in plane and spherical geometry and estimated detonation run-up distances depending on particle size and initiation energy.

Part 4: Pulse Detonation Engines

Remeev et al. investigated experimentally and computationally detonation initiation in a model PDE operating on hydrogen–air mixture. Various types of initiators were considered such as small detonation tube, counterflow initiator with a bursting diaphragm and valve, and circular initiator.

In another contribution, *Remeev et al.* presented the results of experimental and numerical studies of the PDE operation process with the particular emphasis to detonation/shock wave damping in a PDE isolator with perforated side walls.

Asato et al. examined experimentally the effects of flame propagation velocity and rotation speed in the vortex flow for controlling the DDT run-up distance in a PDE and succeeded to shorten the run-up distance by 15% to 56% as compared to the case with a regular counterflow injector.

Kojima et al. estimated analytically the thrust performance of air-breathing PDE implying its application to supersonic flight. Since the thrust density was shown to decrease with the flight speed due to low density of atmospheric air at high altitude, a new concept of air-breathing PDE with exit valve was proposed and tested experimentally.

Kitano et al. measured the performance of micro-PDE for a small-scale thruster operating on gaseous hydrogen–oxygen mixture. The measurements indicated that the key issues deteriorating the micro-PDE performance were thermal loss and friction.

Semin and Golub presented a review of several concepts of PDE design with a particular emphasis to the problems of air intake and vibrations.

Part 5: Continuous Detonation Engines

Wolanski presented a comparative analysis of several concepts of propulsion units operating on detonative combustion, namely, PDEs, engines utilizing standing detonation waves, and Rotating Detonation Engines (RDEs) and considered applications of RDEs in turbojet, ramjet, and rocket propulsion.

Davidenko et al. conducted a 2D numerical study of detonation propagation in the RDE combustion chamber operating on a stoichiometric hydrogen–oxygen mixture to determine the influence of engine geometry and mixture injection parameters on the flow pattern.

Bykovskii et al. studied experimentally the controlled continuous spin detonation of acetylene–air and hydrogen–air mixtures in a ramjet-type cylindrical chamber simulating RDE to obtain the flow structure, conditions, properties, and regions of existence of continuous detonation.

In another contribution, *Bykovskii et al.* studied experimentally the effect of air addition to the products of continuous spin hydrogen–air detonation and to the mixing region in a ramjet-type annular cylindrical RDE combustor on parameters of detonation waves, combustor pressure, and specific impulse.

Daniau et al. presented a preliminary design of an operational RDE which takes into account engine – airframe integration issues to optimize the benefits of detonative combustion. The design is based on theoretical and experimental works, performed by MBDA in cooperation with the Lavrentyev Institute of Hydrodynamics. Compared to PDEs, this design allows an easier operation in reduced-pressure environment and an increase in engine mass flow rate and thrust-to-weight ratio.

Shatalov et al. studied computationally a possibility of stabilizing the detonation in the supersonic flow of hydrogen–air mixture in an axisymmetric Laval nozzle and calculated the dependence of thrust on governing parameters with due regard for a drag force acting on a conical capsule around the nozzle.

We outlined the contents of the articles included in the book to enable easy selection of the subject of choice by the reader. A quick glance at the book contents indicates that there has been a considerable progress in the detonation research during last years.

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