Introduction

In order to use oblique or propagating detonations for propulsion and realize the corresponding thermodynamic advantages, a number of challenging fundamental and engineering problems has yet to be solved. These problems deal basically with low-cost achievement and control of detonations in a propulsion device. To ensure rapid development of a detonation wave, one needs to apply:

(1) efficient liquid fuel injection and air supply systems to provide fast and nearly homogeneous mixing of the components in the detonation chamber;

(2) low-energy source for detonation initiation to provide fast and reliable detonation onset;

(3) cooling technique for rapid, preferably recuperative, heat removal from the walls of detonation chamber to ensure stable operation and avoid premature ignition of fuel–air mixture leading to detonation failure;

(4) geometry of the combustion chamber to promote detonation initiation and survival at lowest possible pressure loss; and

(5) control methodology that allows for adaptive, active control of the operation process to ensure optimal performance at variable flight conditions, while maintaining margin of stability.

In addition to the fundamental issues dealing with the processes in the detonation chamber, there are other issues such as, for example, efficient integration of the chamber with inlets and nozzles to provide high performance. Among the most challenging engineering issues, is the problem of durability of the propulsion system. As the structural components of a pulse detonation engine (PDE) are subject to repeated high-frequency shock loading and thermal deformations, a considerable wear and tear can be expected within a relatively short period of operation. The other problems relevant to PDEs are noise and vibration.

Some of the advances made in solving these issues have been discussed and disseminated at the present Colloquium. The papers presented at the Colloquium are organized in this book in such a way that the reader first gets acquainted with the material on fundamental issues of gaseous (Section 1) and heterogeneous (Section 2) deflagrations and detonations, providing the current understanding of gas and spray detonation properties and dynamics. Then, various aspects of propulsion on continuous detonations are discussed in Section 3. Current accomplishments and the problems encountered in the utilization of PDE for propulsion are discussed in Section 4. The articles included in each section are briefly outlined below.

Section 1: Fundamentals of Gaseous Deflagrations and Detonations

Vasil'ev discusses some of the not-so-well understood problems in gaseous detonation, namely, the detonation of free (without confining walls) charges, detonation diffraction, spontaneous onset of a detonation in an expanding rarefaction wave, detonation initiation, deflagration-to-detonation transition (DDT) enhancement, and the effect of various additives on gaseous detonation.

Pintgen & Shepherd report their quantitative experimental studies of the reaction front geometry complexity obtained by the planar laser induced fluorescence images. The front geometry is characterized by examining two characteristics: the rectified length and the effective dimension. The geometric and stability characteristics of the mixtures are correlated using as a figure of merit the reduced effective activation energy as computed from detailed chemical reaction mechanisms. The mixtures studied vary in the degree of cellular regularity from "regular" to "highly irregular," corresponding to effective reduced activation energies between 5.2 and 12.4.

Aslanov & Volkov study theoretically the stability and structure of the self-sustaining detonation wave propagating in a cylindrical tube considered as a model combustor. The method used for the analysis of perturbation development in the detonation wave provides a satisfactory prediction for the detonation structure. According to the analysis, an integer number of nonuniformities is packed in the tube cross-section.

This number can be found precisely. Thus, the solutions of single-, double-, and multihead detonations can be obtained.

Tsuboi et al. present the results of their extensive numerical studies of three-dimensional detonation in rectangular tubes of various cross-sections and show the interaction between two orthogonal detonation modes.

Ishii & Kojima focus their experimental study on detonation propagation in mixtures with the composition changing continuously in the direction normal to the propagation direction. The detonation chamber used is a rectangular 40×20 mm cross-section channel of total length of 500 mm. The detonation chamber is filled with the stoichiometric hydrogen–oxygen mixture. Concentration measurements were made by the infrared absorption method using ethane as an alternate to oxygen. Smoked foil records show that variation of cell size and behavior of triple point trajectories correlate with concentration gradients.

Penyazkov et al. present a systematic experimental and numerical investigation of autoignition delay times and modes of propane–air mixtures behind reflected shock waves. Experiments were performed over the temperature range of 1000–1750 K, pressure range of 2–20 atm, and equivalence ratios of 0.5, 1.0, and 2.0. Two empirical correlations for ignition delay times have been deduced from the experimental data. Autoignition modes of the mixture (strong, transient, and weak) were identified by comparing velocities of reflected shock waves at different locations from the reflecting wall. Parametric autoignition domains and reactive flow dynamics for some selected postshock conditions were investigated via computer simulation. The data obtained can be directly used for propulsion applications, validations of reaction mechanisms, and for analyses of detonability limits and explosion hazard of propane–air mixtures.

Dean et al. report their experimental investigations of autoignition phenomena at shock wave reflection from the end-walls of different geometry. Experiments were performed with the propane–air mixture in a shock tube 76 mm in diameter equipped with an optical window for ignition delay time measurements. Two-dimensional (2D) and axisymmetric end-walls of different shapes were used as the focusing elements. Autoignition domains in the stoichiometric propane–air mixture at postshock pressures of 3.2 ± 0.5 atm were determined at shock wave focusing with wedge and cone reflectors with apex angles of 90°, as well as with parabolic and paraboloid reflectors. The critical Mach numbers required for direct detonation initiation were 2.76 and 2.69 in the cone and paraboloid reflectors, respectively. For the cone reflector, the transient ignition resulting in DDT occurred at shock wave Mach number $M > 2.32$. The cone reflector with the apex angle of 90° was found to be most efficient for DDT or direct detonation initiation.

Vasil'ev derives the relationships allowing the critical initiation energies for detonation and combustion to be estimated and further used for assessing explosion hazards of various combustible mixtures.

Borisov et al. attempt to answer two questions: (1) what type of transient self-supporting or non-self-supporting fast combustion regimes can be initiated by energies lower than and close to the critical value, and (2) how mixture preheating changes the critical initiation energy. Propane is taken as an example because initiation of detonation in its mixtures with air at room temperature was thoroughly studied previously. In addition, the initiation energy was measured for a kerosene–air mixture and shock-to-detonation transition initiated by high-speed jets was studied in propane–air mixtures. It has been shown that the energy of direct initiation of detonation in propane–air mixtures gradually decreases from about 2 to about 1 MJ/m^2 as the initial mixture temperature rises from room temperature to 720 K. The critical initiation energies in regimes with strong initial shock waves (detonating energy sources) and with relatively weak shock waves and jetting of the combustion products in the mixture being initiated differ insignificantly. Detonability of homogeneous kerosene–air mixtures was found to be similar to that of propane–air mixtures.

Yu et al. report their one-dimensional (1D) and 2D numerical analyses of imploding waves by using the space–time Conservation Element and Solution Element (CESE) method. One-dimensional calculations show that a Mach 1.3 converging shock is capable to initiate the detonation in a 2:1:7 $H_2/O_2/Ar$ gas mixture, initially at 0.2 atm. Results also clearly show a two-shock implosion system, resulting from interactions between the reflected main shock and the contact discontinuity wave. Implosion of the second shock pushes pressure and temperature at the focal region to be more than 5000 times higher than its initial values.

Levin et al. report the results of their extensive numerical investigations of detonation initiation and propagation in axisymmetric and plane 2D channels of complex shape filled with the stoichiometric hydrogen–air mixture at normal conditions. Their mathematical model is based on the 2D Euler equations with detailed chemistry of hydrogen oxidation. It is shown that detonation initiation can be facilitated by using the effect of imploding blast waves. In the problem of detonation diffraction, the minimal radius of the tube required for detonation transition into the unconfined space was found to decrease with increasing tube length. The maximal cone angle for detonation transition from a tube into the unconfined space was also established.

Smirnov et al. present the results of their numerical study of DDT processes in gaseous hydrocarbon–air mixtures in combustors of complex shape. The combustors considered are comprised of a tube and a number of chambers of a wider cross-section incorporated in different places in the tube. The number of chambers was varied from one to twenty. Simulations were performed for the configurations with two chambers attached to the ignition section, with two chambers attached to the tube end opposite to ignition location, and with twenty chambers equally distributed along the tube. It has been found that depending on the combustor configuration and mixture composition, different combustion regimes can be established, namely, low-speed combustion, high-speed galloping combustion, low-speed detonation, Chapman–Jouguet (CJ) detonation, and overdriven detonation modes.

Baklanov et al. present numerical simulations of DDT in transient turbulent reactive flows relevant to conditions in an actual laboratory-scale PDE. The calculations are made based on the Favre-averaged quasi-2D Navier–Stokes equations, supplemented with the models of turbulence and turbulent combustion. The combustion chemistry is simulated based on the two-step Korobeinikov–Levin model. The numerical results on the DDT distance and time are validated against the experimental data obtained in the PDE.

Anil Kumar et al. present the results of the numerical simulations of deflagrations and detonations of the mixtures of hydrogen with oxygen inside a fully confined volume. The predicted temporal evolution of the pressure at the selected points inside the volume is compared with the experimental measurements. A typical fluid-structure interaction problem is studied using the complete model including the transient analysis of the structural response to the pressure waves.

Section 2: Fundamentals of Heterogeneous Detonations

Borisov et al. analyze various interactions of liquid fuel drops with the gas flow, in particular those that are directly relevant to PDEs. Among them are enhancement of fuel–air mixing on the molecular level at the stage of preparation of the fuel–air mixture and in the reaction zone of detonation waves spreading in sprays. Also, other interactions between liquid drops and gas flow such as vaporization, ignition, and combustion are discussed. Analysis of these interactions indicates that the encountered phenomena are very complex and interrelated. It is shown that the phenomena of drop breakup combined with the formation of a mixing layer of micromist droplets with air, micromist vaporization, ignition, and combustion exhibit many features that are not studied yet. The essential role is played by various local rather than averaged processes implying that a multidimensional treatment of the problem is inevitably required.

Frolov et al. estimate the limiting drop diameter for spray detonation. Evaporation and combustion of fuel drops were studied within the frame of a mathematical model providing surface regression rates and evolution of flame diameter consistent with available experimental data. Their results demonstrate that there exist definite requirements to the maximum drop size and the minimum prevaporization degree that have to be met to ensure detonation propagation in fuel sprays. This result correlates with available experimental findings for spray detonation initiation.

Khmel & Fedorov report their 2D computational studies of confined heterogeneous detonations in the aluminum particle – oxygen suspensions. The results of numerical simulations of cellular detonations in a mixture with particles of a fixed size were found to depend on the channel width. Depending on the channel width, the structures may be regular or irregular. Regular uniform structures form in sufficiently wide channels when the channel width is divisible by one-half of the transverse cell size of a detonation. Irregular structures exhibiting cell subdivisions or junctions form if the channel width is close to the point of bifurcation. Analysis of the computational results indicates that the cell size is not determined unambiguously by other length scales of the problem.

Emelyanov & Volkov study the laser ignition and detonation of a reactive gas-dispersed mixture with suspended aluminum particles. A system of equations is formulated to describe the processes of radiation propagation in the mixture and its interaction with individual particles of a nonspherical shape. The space–time distributions of parameters are obtained on the basis of the numerical solution of the formulated system of equations. The density of laser pulse required for optical breakdown depending on the size of particles and radius of laser spot is computed. Comparison of some numerical results with experimental data is made.

Krivosheyev et al. present the results of experimental studies of quasi-detonations in inert porous beds. The studies were focused on the relative influence of normal shock wave reflections on ignition and propagation of quasi-detonations near the detonability limit. Experiments were made with a stoichiometric oxyacetylene mixture with different degrees of nitrogen dilution at initial pressures varying from 0.02 to 0.3 MPa. It has been proved that the normal shock reflection mechanism cannot produce the successive autoignition of the mixture at realistic length scales in a porous bed and therefore cannot ensure the self-sustained propagation of quasi-detonation near the detonability limits.

Voronin studies computationally the propagation of self-supported waves in a liquid with bubbles of chemically active gas. He considers the dynamics of a single chemically active bubble behind an acoustic wave and determines the fields of the basic thermodynamic parameters both inside and outside the bubble to better understand the interaction between the exploding bubble and the neighboring bubbles in the medium. Bubble deformation and liquid jet penetration phenomena are taken into account. The critical values of flow parameters (initial bubble size and distance between bubbles) at which a self-supported propagation of a detonation wave occurs along a bubble array are determined.

Rybakov et al. evaluate the performance of a heterogeneous suspension explosive based on powdered octogen and liquid natol relative to the standard solid high explosive. It has been shown that for attaining a similar performance in terms of detonation energy, impulse, and pressure, the dimensions and mass of the suspension explosive should be properly varied.

Section 3: Continuous Detonation Propulsion

Starik et al. analyze the extended kinetic mechanisms of autoignition of H_2–O_2 and CH_4–O_2 mixtures for the case of simultaneous excitation of molecular vibrations and electronic states of O_2 molecule by resonant laser radiation. They have shown computationally that laser-induced excitation of vibrational and singlet electronic states of O_2 molecule may be an efficient approach to initiate combustion in a reactive supersonic flow. The efficiency of this approach appeared to be considerably higher as compared to the approach based on the excitation of oxygen molecules to purely electronic states. This is caused by production of additional formation channels of highly reactive atoms and radicals due to an abundance of vibrationally excited O_2 molecules in the reacting mixture.

Bezgin et al. report the results of 2D computational studies of oblique detonation wave formation in a supersonic flow of premixed hydrogen–air mixture over a compression wedge. Their particular interest is to explore the possibility to promote detonation formation by electronic excitation of molecular oxygen in an electric discharge. This has been shown computationally that such an excitation can develop detonation at relatively short distances of an order of 1 to 2 m from the wedge apex. This effect was attained at relatively small values of the specific energy delivered to molecular oxygen in the electric discharge and at low initial temperature and pressure of 600 K and 5 kPa. In the absence of O_2 molecule activation, this distance is as large as 8.3 m. The reduction in the induction and transition zone lengths under activation of molecular oxygen is caused primarily by the production of electronically excited O_2 molecules in an electric discharge that enhance the chain mechanism of combustion. For detonation initiation, it is sufficient to activate molecular oxygen in a narrow near-axis region, i.e., in a thin layer adjacent to the wedge apex.

Trotsyuk et al. investigate numerically the feasibility of "stationary" detonation at the Mach reflection of an oblique shock wave generated by a double-wedge model in a supersonic stream of hydrogen–oxygen mixture. Numerical investigations of regular and Mach reflections have been performed by a high-order MUSCL TVD scheme. In the case of Mach reflection, the Mach stem was shown to be a section of an overdriven detonation front. It has been shown that at certain flow parameters, there may exist a standing Mach stem with a smooth front or with a system of unsteady transverse waves on its front. For a lean hydrogen–air mixture, an extremely interesting regime of Mach reflection with a strongly oscillating Mach stem was obtained for the first time.

Bykovskii et al. report the results of their experimental studies of continuous spin detonation in a scramjet-type combustor with a varied flow rate of the oxidizer through the annular slot. The experiments were performed in chambers of two types: with expanding and constant cross-sections of the annular duct. The reactive mixture components, acetylene and oxygen, were supplied separately. Under certain conditions, stable regimes of mixture combustion in spin transverse detonation waves were obtained.

Yanovskiy & Baykov study experimentally the reactivity of the gaseous decomposition products of endothermic hydrocarbon fuels. Such fuels, when heated in the cooling system of an engine, decompose to hydrogen and low hydrocarbon compounds with energy absorption. It has been shown that the decomposition products of such fuels exhibit higher reactivity in terms of the stability of a lifted diffusion flame than the prevaporized endothermic fuels, methane, and surrogate gaseous fuels containing methane and hydrogen. This effect is attributed to the presence of active radicals in the decomposition products. It is claimed that the use of the decomposition products of endothermic hydrocarbon fuels in PDEs can result in reduction of the predetonation distance.

Galligan et al. study catalytic heterogeneous decomposition of JP-10 — a liquid endothermic hydrocarbon fuel specifically targeted for supersonic and hypersonic air-breathing propulsion applications and, in particular, for PDEs. The thermal stability of JP-10 is only comparable to the conventional rocket fuel, RP-1. However, contrary to RP-1, JP-10 is a single molecule $C_{10}H_{16}$ rather than a mixture of paraffins and cycloparaffins. To improve ignition properties of JP-10, it is suggested to catalytically decompose it to hydrogen and light hydrocarbons. Three zeolites and two sulphur-aluminum phosphate catalysts have been studied in the paper. Catalytic reactions were carried out at temperatures between 250 and 650 °C at 25 PSI of pressure. Analysis was done using a gas chromatograph/mass spectrometer and a gas chromatograph using a capillary column with a flame ionization detector and a thermal conductivity detector. The major products of JP-10 decomposition for the various catalysts were identified.

The study of *Walton et al.* is closely connected with the possibility to use the decomposition products of a solid propellant as a fuel for detonation-based propulsion. Solid propellant presents the advantage of being easily loaded and transported safely. Its controlled combustion provides gaseous products containing several reactive species which can be used as a combustible and, when mixed with an oxidizer (e.g., air), can form the detonable mixture running the PDE. However, a considerable amount of solid carbon particles can be produced in the process of solid propellant decomposition. Since those particles may represent a very important fraction of the total mass (eventually up to 50%), they can strongly influence the impulse yielded on the thrust wall and, to a greater extent, the engine specific impulse. In fact, it has been demonstrated computationally that solid carbon particles added in suspension to a fuel-lean hydrogen–air mixture are able to augment up to 15% the pressure impulse on the thrust wall of a PDE during one cycle, provided that the particles are sufficiently small ($< 10\ \mu$m).

Section 4: Intermittent Detonation Propulsion

Hayashi et al. study the mechanism of flame jet ignition in the PDE by visualizing the encountered phenomena with a Schlieren system. The experiments were performed in a PDE 40×40 mm in cross-section and 1 m long with separate delivery of fuel (hydrogen) and air. To promote DDT, a Shchelkin spiral 500 mm long, 3.5 mm in diameter, and 15-millimeter pitch was attached to the tube end. Both single- and multipulse 16-hertz PDE operation was tested. Schlieren movies were taken to visualize injection, ignition, and flame propagation mechanisms. It has been demonstrated that the DDT time can be shortened using flame jet ignition instead of a conventional automobile spark ignition.

Brophy et al. demonstrate the results of application of a transient plasma ignition system in the setup reproducing the flow conditions relevant to a PDE. The plasma ignition system was shown to substantially reduce the ignition delay and DDT time for ethylene–air and propane–air mixtures under dynamic fill conditions. The equivalence ratio range evaluated was from 1.0 to 1.5, and a temperature and pressure range of 280 to 480 K and 1 to 6 atm, respectively, were used to simulate the expected in-flight stagnation temperatures and pressures. Ignition delays were reduced by up to a factor of 5 and the corresponding DDT time scales were observed to decrease accordingly when compared to conventional capacitive discharge systems. Although direct initiation of a detonation wave was not obtained, the sequential use of various turbulence generating devices was able to rapidly and reliably accelerate the combustion-driven shock waves to detonations within practical distances.

Baklanov et al. study experimentally the effect of mass-flow variation in the valveless PDE on the detonation formation and parameters. The detonation chamber is a tube 83 mm in diameter and 660 mm long fed separately with hydrogen and oxygen via injectors mounted at the tube end and equipped with supersonic nozzles and nozzles with resonators. A spark plug located at a distance of 150 mm from the tube end was used to ignite the mixture. The unsteady processes of tube filling with mixture components were found to affect the detonation formation. The optimal ignition delay times leading to DDT were determined. It has been shown that detonation in the chamber may fail if the ignition delay time is beyond a certain optimal range.

In their other contribution, *Baklanov et al.* study both experimentally and numerically the effect of turbulence and ignition location on detonation formation in the flow of nonpremixed fuel components in a PDE. The experiments were performed in the same detonation chamber as described above. Numerical simulation was used for better understanding of the processes of tube filling with fuel components and determining the pressure field prior to ignition. As a result of the study, the minimal time of tube filling with fuel components was determined by means of numerical simulation. The influence of mixture turbulence and igniter location on the DDT was investigated experimentally. It has been shown that the turbulence in the flow of nonpremixed components and ignition location affect considerably the detonation formation. On the basis of the experimental data, the thrust, mass flow rate, and specific impulse of the PDE were estimated.

Conrad et al. study the performance of an air-breathing PDE with a predetonator. The PDE is composed of three sections. Either a 2.020

or a 1.718-meter-long rectangular tube, 133 mm in width and 58 mm in height, is used as the predetonator, and a 1.082-meter-long rectangular tube, 133 mm in width and 183 mm in height, is used as the thrust tube. A transition section with a 15-degree divergence angle joins the two tubes. A series of plate obstacles is used in the predetonator to accelerate the flame and produce a detonation wave at the entrance of the transition section. Ethane–oxygen–nitrogen mixtures, with a fixed equivalence ratio of 1.0 and a nitrogen-to-oxygen molar ratio of 3.76, are injected at the head end of the predetonator through an impinging jet injector which assures *in situ* rapid and uniform mixing of the reactants. The proposed design strategy implies that the region containing the predetonator obstacles should be long enough to accelerate the deflagration wave up to the CJ detonation velocity and should terminate at this point. In addition, the distance between the last obstacle and the entrance to the transition section should be chosen so that an overdriven detonation wave enters the transition section. The results obtained support the proposed design strategy, although some intermittency in successful detonation transitioning was noticed when a short predetonator was employed. The results also showed that generating an overdriven detonation wave in the predetonator is a key parameter for obtaining a thrust tube detonation transition.

Frolov et al. provide experimental evaluation of the feasibility of the shock-booster PDE concept. This concept implies that the propagating primary shock wave is accelerated by in-phase ignition of the reactive mixture stimulated by distributed external ignition sources. A powerful electric discharge utilized previously for generating a primary shock wave was replaced by a primary shock wave generator comprising a low-energy (50–60 J) electric discharge, Shchelkin spiral, and tube coil. A second discharge was mounted at the exit of the tube coil and was activated in phase with the primary shock wave arrival at its position. Due to interactions between various wave systems in the tube coil formed at expansive and compressive surfaces, the total critical energy of n-hexane spray – air detonation initiation with two successively triggered discharges was decreased to about 100 J, i.e., by an order of magnitude as compared with the energy ($\sim$ 1 kJ) required for the direct initiation of the n-hexane spray detonation in the straight 28-millimeter diameter smooth-walled tube by a single electric discharge. Multipulse 2-hertz operation of the setup in the detonation mode was successfully demonstrated with the energy requirements of about 130 J per pulse. It has been shown that a second discharge triggered at a properly chosen time can serve as an efficient means for detonation initiation control.

Yatsufusa et al. describe experimental results obtained from the liquid-fueled air-breathing PDE of Hiroshima University. The PDE is equipped with a predetonator operating on liquid fuel (white gasoline) and oxygen gas and with a rotary mechanical valve. The main detonation chamber is a tube 100 mm in diameter and 2.25 m long. Automobile fuel injectors providing mean drop size of 18 μm at injection pressure of 10 MPa were used to inject fuel in the main tube and in the initiator. The thrust produced by the PDE was measured by the ballistic pendulum method. It has been shown that the maximum impulse produced by the PDE was attained when the overall equivalence ratio in the main chamber was 2, which is an indication of incomplete combustion. Partial fill was shown to result in a larger specific impulse. The initiator overfill with fuel–oxygen mixture was shown to play an important role in the PDE performance.

Taki & Fujiwara discuss the results of their numerical analysis on the resonant detonation phenomena occurring in a 7-centimeter-diameter hemispherical cavity and suggest the physical mechanism governing high-frequency detonation formation in a resonator PDE. In such a PDE, two-stage combustion is utilized to generate continuous resonant detonations with an extremely high frequency of 25 kHz. These computations can be used to optimize various parameters of the PDE (geometries, combustible mixtures, ambient conditions, etc.).

Endo et al. provide an overview of their analytical models for predicting the propulsive performance of fully-fueled and partially-fueled simplified PDEs and optimizing the PDE systems. The results obtained by using these models are compared with available experimental data. It is shown that system optimization can provide specific impulse approximately 20% higher than that for a single-straight-tube PDE.

Ma & Yang focus on modeling and simulation of the internal flowfield in a valveless air-breathing PDE, which is currently under experimental development at the U.S. Naval Postgraduate School. The PDE utilizes a predetonator to initiate detonation in the main combustor and involves no valves in the air-flow path. The isolation between the inlet and combustor is achieved through the gas dynamics in a special isolator. The analysis accommodates the full conservation equations in axisymmetric coordinates, along with a calibrated one-progress-variable chemical reaction scheme for both stoichiometric ethylene–air and ethylene–oxygen mixtures. The governing equations and their associated boundary conditions are numerically solved by means of a space–time CESE method. The transmission of detonation from the initiator to the main chamber, combustion and flow dynamics in both single- and multipulse operations, as well as propulsive performance of the PDE has been calculated and analyzed.

Remeev et al. focus on the computational study of the PDE operating process and the analysis of the thrust-efficiency performance of a single-chamber supersonic (Mach 3) ramjet PDE. The engine consists of a supersonic air inlet, the entrance perforated compartment, the combustion chamber equipped with igniter, and the exhaust nozzle. The results of numerical simulations show the possibility to implement a PDE operation process with a stationary gas flow in the air inlet. First estimations of the thrust-efficiency characteristics have not revealed any essential advantages of the PDE as compared to the conventional ramjets. The authors claim further need of performance optimization studies for the chosen PDE design.

Alexandrov et al. study the alternative design of the PDE referred to as the supersonic pulsed detonation ramjet engine. The main characteristic features, which distinguish this engine from other PDE designs are: (*i*) supersonic flow of air and reactive mixture all throughout the engine duct; (*ii*) detonation wave propagates always upstream in both fuel-rich (stoichiometric) and fuel-lean mixtures, controlled by a fuel supply system; (*iii*) the pulse process is organized due to propagation of the detonation wave along the engine duct toward the inlet if the chamber is filled with a fuel-rich mixture and drift of the wave toward the nozzle when the mixture becomes fuel lean; and (*iv*) the continuity of the detonation process makes an external detonation initiation source unnecessary during engine operation (it is only needed to start the engine). The authors present their experimental results substantiating the possibility of realizing such a combustion mode in a supersonic flow.

Kasahara et al. describe the results of ground tests with an ethylene–oxygen single-tube pulse detonation rocket (PDR) engine. The tube length and inner diameter are 1.477 m and 100 mm, respectively. The total weight of the engine flight model is 28 kg and its maximum thrust is about 400 N. The PDR flight-model engine operates for several seconds at a 10-hertz frequency. Liquid ethylene (312 K, 250 g), oxygen gas (10 MPa, 240 g), and helium gas (15 MPa, 8 g) are used as the fuel, oxidizer, and purge, respectively. The supply systems are composed of fuel – oxidizer – purge gas tanks, high-power parallel solenoid valves, and check valves. The authors schedule flight experiments for 2004–2005 in Japan.

Borisov et al. study the alternative design of the PDE referred to as the pulse blasting PDE concept. In this concept, the propulsion impulse is produced by a propagating shock wave supported by a reaction of hot products of monopropellant decomposition with air. Combining rocket and air-breathing propulsion offers certain advantages, such as simplicity and compactness of the engine, possibility of operation in the valveless regime that requires no periodical powerful ignition source, and reasonably high specific impulse. As the initial experiments have revealed poor mixing between the injected products and air, the current experimental and numerical studies of the authors are focused on the ways to improve the mixing process. Multijet injection of the decomposition products proved to be an efficient way of combustion process intensification. When operating on liquid isopropyl nitrate as a monopropellant, the specific impulse of 511 s was measured by the pendulum technique.

Bogdanov presents a constant-volume combustion chamber equipped with a self-driving slide valve for applications in pulse jet power plants. He reports the results of theoretical analyses and experimental studies aimed at the improvement of chamber performance. The theoretical analyses demonstrate that the pressure loss caused by leaks in labyrinth sealing is less than 5% for the chamber volume exceeding 200 cm^3 and a maximum operation frequency of 200 Hz can be attained. Due to purging and short-time impact to high temperature, the chamber is capable of operating at a maximum gas temperature of 3000 K with a heat loss to the air-cooling system of 5% and the temperature of the thermal coating less than 1400 °C. The average speed of the exhaust gases can attain values exceeding 1200 m/s. Experiments were made with a chamber of 310 cm^3 in volume equipped with an inlet and exhaust units. The maximum operation frequency was 100 Hz. The measured data were in good agreement with the data obtained based on the theoretical analyses.

We have tried to outline 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 recent years. We also intend to publish a volume which will contain edited versions of full papers selected from the articles included in this book.

For those who are interested in recent accomplishments in basic and applied research on PDE and numerous PDE design concepts, we provide below the list of references to the books containing the materials of previous three Colloquia on Detonations.

1. Roy, G., S. Frolov, K. Kailasanath, and N. Smirnov, eds. 1998. *Advances in experimentation and computation of detonations*. Moscow, Russia: ENAS Publ. ISBN 5-89055-013-6. 144 p.

2. Roy, G., S. Frolov, K. Kailasanath, and N. Smirnov, eds. 1999. *Gaseous and heterogeneous detonations: Science to applications*. Moscow, Russia: ENAS Publ. ISBN 5-89055-016-0. 384 p., 20 tables, 200 ill.

3. Roy, G., S. Frolov, D. Netzer, and A. Borisov, eds. 2000. *Control of detonation processes*. Moscow, Russia: ELEX-KM Publ. ISBN 5-93815-001-9. 240 p., 5 tables, 67 ill.

4. Roy, G., S. Frolov, D. Netzer, and A. Borisov, eds. 2001. *High-speed deflagration and detonation: Fundamentals and control*. Moscow, Russia: ELEX-KM Publ. ISBN 5-93815-003-5. 384 p., 32 tables, 190 ill.

5. Roy, G., S. Frolov, R. Santoro, and S. Tsyganov, eds. 2002. *Advances in confined detonations*. Moscow, Russia: TORUS PRESS. ISBN 5-94588-008-6. 312 p., 16 tables, 133 ill.

6. Roy, G., S. Frolov, R. Santoro, and S. Tsyganov, eds. 2003. *Confined detonations and pulse detonation engines*. Moscow, Russia: TORUS PRESS. ISBN 5-94588-012-4. 384 p., 14 tables, 219 ill.

Editors