Section 3

COMPUTER MODELING OF COMPLEX PROCESSES USING A ONE-DIMENSIONAL APPROACH

Dymertsov D.O.

Simon Kuznets Kharkiv National University of Economics
Kharkiv, Ukraine

The relevance of the study is determined by the need to develop efficient information technologies and software tools for modeling gas-dynamic processes in technical systems. Full-scale multidimensional models are limited by high computational costs and implementation complexity, which reduces their practical applicability. In this context, one-dimensional models provide an optimal balance between accuracy, computational efficiency, and algorithmic simplicity, and also support the development of integrated information and analytical systems with databases for storing and updating operational parameters.

The aim of the study is to develop, implement, and verify a one-dimensional mathematical and computational model for thermogas-dynamic processes in flow elements of technical systems using modern numerical methods. The research focuses on constructing efficient and stable algorithms that account for key physical phenomena such as gas flow, heat and mass transfer, energy transformations, turbulence, and hydraulic losses. The object of the study is numerical modeling of gas-dynamic processes in technical systems, while the subject is methods based on a generalized one-dimensional mathematical model for their calculation and analysis.

A relevant direction in Computer Science is the development of algorithmically efficient software tools for modeling gas-dynamic processes. Modern numerical methods and computational approaches enable the creation of software systems capable of accurately reproducing complex unsteady phenomena in technical systems. Mathematical modeling plays a fundamental role in Computer Science, as it formalizes physical processes into computational models suitable for software implementation. Under current conditions, the development of efficient numerical methods and algorithms for technical and energy systems is especially important [1], since it requires high accuracy under limited computational resources. This leads to the need for optimized, scalable, and performance-oriented computational models integrated into applied software systems.

In this work, within the framework of developing a software complex for calculating gas-dynamic processes in gas-jet acoustic generators, a unified computational model is proposed, focused on filling and emptying processes in closed technical volumes. The model development emphasizes algorithmic formulation, selection of discretization methods, and implementation of efficient numerical procedures. The proposed model was verified by comparison with experimental and reference computational data, confirming its correctness and suitability for engineering applications. The results demonstrate the potential of the approach for building intelligent decision-support systems, optimizing parameters, and automating the analysis of complex energy processes. The aim of the study is to develop a generalized mathematical and computational model of thermogas-dynamic processes in gas-jet cooling-heating acoustic generators with further software implementation, focusing on an efficient numerical algorithm that describes the interaction of wave, thermal, and hydrodynamic phenomena. The final goal is the creation of a software-oriented system for numerical experiments, analysis of operating modes, and optimization of gas-jet acoustic generator parameters, which improves energy efficiency, enables adaptive control of operating regimes, and expands practical applications in modern information-controlled systems. The developed software complex also allows the formation of a database of operational characteristics and simulation results for further analysis and systematization.

In modern Computer Science research, mathematical modeling is a key tool for analyzing complex dynamic systems, particularly physical and gas-dynamic processes, as it enables the representation of governing equations as computational algorithms implemented in software systems [2]. Numerical models are based on methods for solving nonlinear differential equations, including the finite difference method, finite volume method, and other approximation schemes [3, 4]. Multidimensional (2D and 3D) models provide detailed spatial-temporal resolution of processes but are computationally expensive and require significant optimization of implementation algorithms [5]. In contrast, one-dimensional models reduce complexity, simplify algorithmic structure, and improve computational efficiency while maintaining acceptable accuracy for engineering analysis and system behavior evaluation [6].

Modern computational approaches increasingly include hybrid and adaptive models that combine different numerical methods to improve stability and efficiency. These methods allow dynamic adaptation of discretization depending on the complexity of the simulated process, which is particularly important for nonlinear and unsteady physical systems [4, 5]. A crucial role in these approaches is played by algorithm design, numerical method selection, and optimization of computational procedures. Implementation typically involves methods such as finite differences and finite volumes, solvers for hyperbolic systems, and integration into programming environments using languages and tools like Python, C++, and Lazarus. As a result, flexible software systems are developed that support simulation, visualization, and analysis of complex dynamic processes.

The analysis of modern scientific literature shows that computational modeling methods are a core component of information technologies in engineering and scientific applications, as they combine accuracy, algorithmic efficiency, and automation capabilities. These approaches enable the construction of formalized mathematical and computational models of complex physical processes, forming a foundation for the development of effective simulation and optimization software systems.

The developed unified one-dimensional computational model was implemented using the Lazarus and Free Pascal as a software complex for numerical calculation of operating parameters of gas-jet acoustic generators. The selected programming environment provides high computational performance, flexibility in implementing numerical algorithms, and the ability to create an intuitive graphical user interface. The developed software enables numerical simulation of thermogas-dynamic processes occurring in the working elements of the system. In particular, it allows the study of wave phenomena associated with the propagation of shock and expansion waves, as well as thermal processes involving heat exchange between the working medium and the walls of the receiving tube. This approach makes it possible to integrate the computational model into software systems for analysis, optimization, and verification of gas-jet acoustic generator operation.

As a result of the study, a unified one-dimensional computational model of gas-dynamic processes was developed. It accounts for key physical mechanisms, including gas flow, energy conversion, heat and mass transfer, turbulence effects, and local hydraulic losses, and enables software implementation of numerical algorithms for engineering simulations. The model is based on fundamental conservation laws of mass, momentum, and energy, ensuring its physical validity and applicability to a wide range of gas-dynamic problems. During development, the model structure, initial and boundary conditions, and discretization approach were defined, ensuring numerical stability, convergence, and computational efficiency.

The proposed model was implemented as a software system for engineering calculations, operating режим analysis, and parameter optimization of gas-dynamic systems. Validation against experimental and literature data confirmed good agreement (error within 5%), demonstrating the correctness of assumptions and practical applicability of the approach. The model can also be integrated into information systems supporting the life cycle of technical objects, enabling data storage, processing, and updating through databases or data warehouses. Such integration allows recalculation of operational parameters based on updated input data, supporting prediction of equipment condition, degradation analysis, and maintenance planning.

The obtained results confirm the feasibility of using one-dimensional models as part of modern information technologies for engineering analysis and lifecycle management of technical systems. The proposed approach can be used to develop integrated software-information systems for decision support and optimization of gas-dynamic installations.

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Димерцов Дмитро Олександрович, старший викладач каф. ЗСЖТіБЖД ХНЕУ ім. С. Кузнеця ., ORCID: 0009-0000-4894-3495, dmytro.dymertsov@hneu.net