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METHODS FOR REGULATING EJECTOR SYSTEMS WITHIN INTERDISCIPLINARY RESEARCH USING COMPUTER MODELING

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Abstract- This paper aims to discuss an interdisciplinary approach to solving innovative thrust vector control problems using ejection processes when changing the direction of the thrust vector and its modulus in a controlled manner. This study showed examples in which the range of thrust control in modulus is from 0.1 to 1.0 of the maximum value, considered some methodological issues to solve inventive problems within the training of modern designers, developed and patented jet systems designed for thrust vector control within a complete geometric sphere with thrust turning angle from +180° to –180° degrees. The research results mainly focus on creating new energy-saving equipment and technology in energy, hydrocarbon recovery and refining. However, certain results of these studies are applicable in robotics and unmanned vehicles for various purposes. Training materials and proposals for developing fluidics design methodology have been prepared.

Keywords: Interdisciplinary Research, Ejector, Nozzle Apparatus, Thrust Vector, Computer Simulation.

1. INTRODUCTION

The most pressing problem is the reduction of energy costs in all production processes, including the extraction and refining of hydrocarbons. Scientists from the Gubkin Russian State University of Oil and Gas conduct scientific research to create promising jet devices and ejector systems for various purposes [1-4], including special ejectors in the flow path of turbomachines. For the first time, the extreme conditions of liquid and gas flow through a nozzle equipped with the velocity vector (thrust vector) control system were considered in the control range for the velocity vector (thrust vector) angle from +180° to –180° within the complete geometric sphere [1].

In parallel, the issues of special training of designers for developing advanced equipment, including dynamic positioning systems for exploring and developing marine hydrocarbon fields, are being considered.

Oil and gas industry actively uses all advanced scientific developments, including aviation technologies, considering the issues of energy saving and optimal regulation of ejector systems from the common standpoints of mechanical engineering, including the use of cross-disciplinary and transdisciplinary approaches to conduct study. Generally, the dynamics of gas and hydro flows consider the interaction of a fluid medium with a solid wall during fundamental scientific research and, in particular cases, consider separate ejector systems during applied scientific research.

Recently, various transformable and hybrid technical systems, which make it possible to extend the range of regulation for operating parameters, have been considered with particular interest. From the same positions, researchers propose considering algorithms (including hybrid algorithms for solving inventive problems to shape science and technology for the near future. Creating more efficient but, at the same time, more complex technical systems has become possible due to the emergence of computer technologies, including computational fluid dynamics (CFD) and additive technologies. With the application of these new tools, it is advisable and necessary to revisit the accumulated scientific and technical information. A deeper analysis of workflows, considering multivariate transformations of geometric shapes, opens up limitless possibilities for developing the theory of inventive problem solving and creating highly efficient hybrid technical systems of various complexities. Today, interdisciplinary and transdisciplinary approaches for organizing research are becoming increasingly available, with good prospects for more active use of artificial intelligence (AI) [5].

For AI, there should be no boundaries between scientific fields and disciplines; ideally, AI should collect and analyze all available scientific information, regardless of the history of its origin. Too much such scientific information is not an insurmountable obstacle for AI, but for a single person or a large group of specialists, such a large amount of information is a problem that will complicate or even stop studies.

Modern high-tech processes widely use many moving technical devices, including many robots or drones, for various purposes. In a complex system, moving objects can number in the thousands. With the development of modern technologies, their speed is steadily increasing. Coordinated action for a swarm of drones is a hot topic in academic research in all countries worldwide, and dynamic maneuvering decision-making is one of the most essential research areas [6]. There are some unsolved problems [6]: computer modeling does not consider the flight characteristics of the drone itself, dynamic changes in the number of drones (scalability), and weather complicated effects in complete volume. Thus, there is still a large gap between the actual environment and the virtual computer environment, so further studies are necessary. In particular, to solve the problem of excessive computational complexity in solving flight conflicts in 3D space, Pan et al. [7] proposed an improved method to achieve a faster solution by simplifying a complex 3D problem to a 2D problem.

Additive technologies have opened up opportunities for the application of mesh structures. The mesh structure of solid walls allows us to solve significant technical problems, including creating new structural materials [8]. Study the gas-dynamic processes when creating aircraft with the mechanized wing adapted to the controllable change of its geometric shape. The transformable wing design covers most of the changes in flight conditions and can respond accordingly. Also study the control strategy for the dynamic conversion procedure of a convertiplane with the transition from helicopter to airplane mode, building a model for the optimal control of this conversion to consider factors such as conversion corridor constraints, pilot control, flight attitude, engine power rating, and wing stalling effects.

There are known transformable jet devices with nozzles in a fixed [9] or rotating disk support [10]. Study the relationship between dimensional design and working body state parameters with ejector performance [11]. Investigate supersonic ejectors and nozzles for various applications [12]. Reviewed recent numerical and experimental studies of the ejector and its applications [13]. Consider measures for modernization of ejectors for various purposes [13, 14], high-speed flows in fundamental scientific problems of internal and external gas dynamics [15]. Such high-velocity gas flows occur during the motion of aircraft (airplanes, rockets, and landers) and in many other technical devices, including detonation engines [16]. Of primary importance is the study of innovative technologies to improve the gas turbine cycle in propulsion plants [17].

The gas turbine engine uses a detonation combustion chamber and a hybrid electric propulsion plant. An in-depth study and understanding of these technologies are critical to developing more sustainable and efficient propulsion plants. In this case, maintaining a predetermined operating condition is challenging due to the ever-changing propulsion plant operating conditions and environments, which vary depending on the aircraft's flight phase and required power. Such a hybrid plant may also have potential disadvantages that need consideration regarding safety, cost, and maintenance [17]. Hybrid rocket engines typically use solid fuel placed in the combustion chamber to generate high-velocity gas flows, while the oxidizer, which can be liquid or gaseous, is stored in an external tank. This fuel separation makes handling and operation safer than solid rocket engines.

Non-mechanical control of high-speed flows is currently a widely studied research topic [15]. Injection of secondary airflow near the nozzle exit creates lateral loads on the nozzle, which are also lateral components of the thrust vector. Uses a hybrid complex of two methods to modify the thrust vector, including the differential throttling application and injection of secondary flow from the slot (hydrodynamic or gas-dynamic thrust vector control). There are known variants of transforming mesh nozzles for ejectors [18]. Relatively poorly studied are ejector variants with curved mixing chambers [19]. Presented the adjustable nozzle as a diaphragm [20]. The maximum flow deflection angle at the nozzle outlet can range from +20 to -20 degrees for the majority of known thrust vector control systems. The central body of the adjustable transformable nozzle can be conical and move axially or radially. Deflectors of all shapes, including variations with a cross-shaped nozzle outlet channel [22], have been used in studies [21]. Hybrid systems and aircraft jet systems for thrust enhancement are under consideration. Cican et al. [23] revealed a reduction in acoustic noise when using an ejector [23]. Investigates various methods to predict aircraft noise, primarily from airfoils, air intakes, and tail nozzle jets [24]. Radio-locating technologies for drone detection and their identification using radar are being improved, which can also recognize the types of airscrews. Performs a numerical study of controlling noise due to the airfoil profile with wavy edges. An integrated ejector acts as an infrared suppressor capable of reducing the infrared signal with radar-acoustic stealth.

When studying an ejector with a curved mixing chamber, it is necessary to consider the study results of S-shaped ducts [25]. Many significant interdisciplinary technological advances are now visible in aerospace and energy engineering [26]. These encompass the increased use of computers at every stage of product design, breakthroughs in materials science, including high precision and additive manufacturing methods, and options for electrification of turbomachines using unconventional fuels. Study various methods for flow control to improve efficiency, aerodynamic quality, and boundary layer stabilization, including aircraft passive and active control in low and high-velocity flows [26].

Notes that increasing pressure drop and jet velocity enhances the control performance in high subsonic approach flow conditions; however, due to excessive pressure drop, the jet comes off prematurely at the Coanda surface, resulting in control failure.

Experts note that AI methods should deeply immerse in interpretability with detailed explanations of cause-and-effect relationships, and the potential impact of AI will be high only if the output obeys physical laws. Presented a thorough analysis of unmanned aerial vehicles (UAVs or drones) with fixed wings, analyzing the critical parameters of such aircraft designs [27]. Deploying a swarm of intelligent robots that can collectively perform tasks is a massive research challenge [6, 7]. Review publications illustrate the fundamentals of swarm systems and make some predictions for the future.

The authors consider the listed publications, research, and design developments within collecting, analyzing, and summarizing information for its use in the educational process to train modern designers, in particular leveraging the inventive problem-solving theory when it is essential to know in detail the level of development of modern technology. The main objectives of this research are to identify perspective scientific directions, technology, and engineering development using jet apparatus and complex jet systems as well as new options for improving the methodology for their design within training modern design inventors.

2. METHODOLOGY

Figure 1 demonstrates a flow chart that describes the research methodology. The methodology involves developing a working hypothesis about the ejection process when using a controlled nozzle to deflect the thrust vector (velocity vector) in any direction within a complete geometric sphere, according to the flowchart (Figure 1). The primary concept relates to studying gas-dynamic and hydrodynamic processes in the nozzle and jet system channels. Developing the working hypothesis involves reviewing scientific and technical information and analyzing individual facts, performing their synthesis and generalization within Euler's ideas development. Further, the working hypothesis suggests the possibility of creating a new jet system and includes developing a new schematic diagram, 3D models, and computer simulation. After analyzing its results (analyzing and storing all results, regardless of positive or negative), the work, if necessary, returns to developing the schematic diagram to improve it. In case of obtaining positive results, the work proceeds to create a series of 3D models. The following steps are patenting new technical solutions and developing plans for applied research and R&D.

When performing research and design works [1-4], the authors prepared a scientific groundwork and decided to use the widely known methodology [28] with a cross-disciplinary approach, which addresses issues of the philosophy of technology and the theory of inventive problem solving. The selected methodology [28] also aims at holistic forecasting [29, 30].

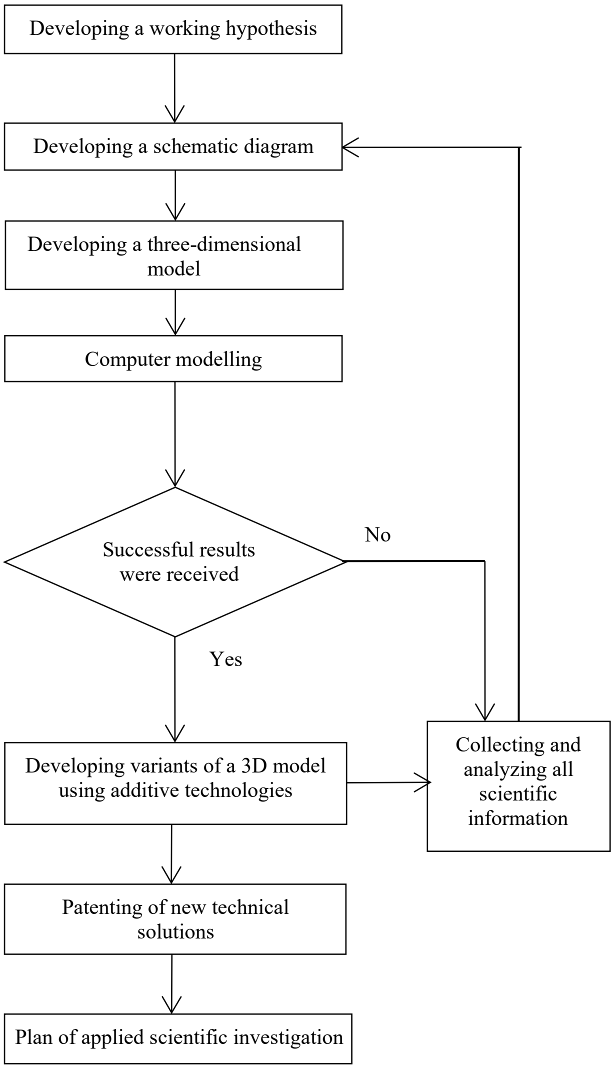


Figure 1. Flowchart demonstrating the research methodology

The presented paper aims to discuss the issues on the variants of fluidics development, in particular within developing Euler's ideas [31]. Euler himself, as follows from his works, had already used a transdisciplinary approach and, in particular, successfully predicted developing hydraulic machines for tens and hundreds of years, if to speak about foresight research [30]. The authors plan to use their scientific groundwork [1-4] to achieve this goal.

3. RESULTS

3.1. Development of a Principal Diagram for a Perspective Jet Unit in the Process of Patenting a Technical Solution

The developed technical solution [3] refers to fluidics, including jet pumps and compressors, jet control systems, and jet reactive propulsion units for dynamic positioning systems. In particular, this technical solution and its modifications are applicable in the oil and gas industry to improve the efficiency of technologies in extracting and processing hydrocarbons, including developing offshore fields.

The disadvantage of the known jet units is a relatively narrow range of regulation of the flow operating parameters at the working chamber outlet, which limits the field of application of fluidics in general. The technical problem that the proposed invention aims to solve is to outspread the variety of the flow operating parameters at the working chamber outlet.

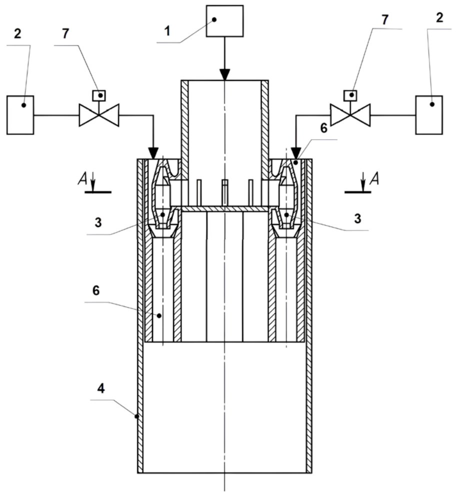


Figure 2. Diagram of the jet pump unit (patent for invention of the Russia No. 2781455) [3]

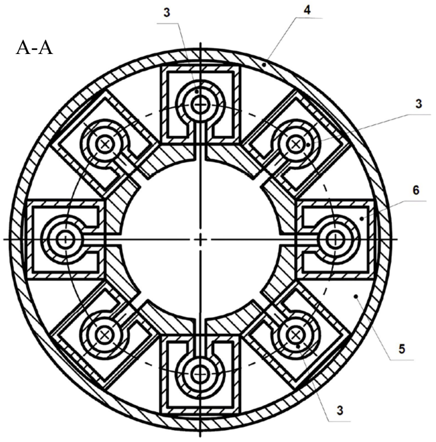


Figure 3. Diagram of the jet pump unit, A-A cross-section (patent for invention of the Russia No. 2781455) [3]

The achieved technical result provides a controlled redistribution of flow energy over the outlet channel area in the working chamber to regulate the flow momentum and velocity diagram parameters in the cross-section at the working chamber outlet. Under the momentum parameter, it is customary to understand the product of mass flow rate by the flow velocity of the fluid medium. If flow velocity over the channel cross-section is uneven, it is necessary to consider the value of the Boussinesq coefficient. Figures 2 and 3 explain the essence of the described jet unit: Figure 2 shows the diagram of the jet pump unit with a cylindrical working chamber, and Figure 3 shows its A-A cross-section. The proposed jet pump unit contains source 1 of the working medium, sources of pumped medium 2, a jet pump (ejector) equipped with a system of nozzles 3, hydraulically connected in a parallel scheme and placed at the inlet of working chamber 4 with forming annular channel 5 at the inlet of working chamber 4. Source 1 of the working medium and nozzle 3 inlets are hydraulically connected.

Annular channel 5 has U-shaped pockets 6 with forming therein isolated from each other supply channels 7, each of which has one of nozzles 3; supply channels 7 hydraulically connect working chamber 4 with sources 2 of the pumped medium through shut-off regulating devices 8. Supply channel 7 acts as a mixing chamber, while nozzle 3 and mixing chamber 7 form an ejector. Each source 2 of the pumped medium has a hydraulic connection with annular channel 5. Working chamber 4 may have various geometric shapes. In particular, it may be cylindrical or circular; in cross-section, it and nozzle 3 may have a rectangular or triangular shape or other unconventional shapes. The flow channels in nozzle 3 and supply channel 7 groups may form a mesh structure or mesh. In the traditional sense, a mesh is a large geometric area with smaller discrete cells. For instance, a package small nozzle interconnected to form flow channels of a mesh structure replaces larger nozzles.

3.2. Description of Operating Principle of the Jet Unit

The jet pump unit operates as follows. Nozzles 3 are located at the entrance to the working chamber 4, and Source 1 provides the actuating medium to them. The handled medium from sources of pumped medium 2 goes to annular channel 5 and further to the actuating medium jet, passing through supply channels 7 isolated from each other, which hydraulically connect working chamber 4 with sources of pumped medium 2. Mixing of the pumped and working media starts in supply channel 7 because nozzle 3 is multichannel in the form of a system of nozzles hydraulically connected in parallel, and each nozzle 3 is in separate isolated supply channel 7, communicating with pumped medium source 2 through shut-off regulating device 8. Further flows from supply channels 7 go to the outlet of working chamber 4. Depending on the solved process task, partial or complete mixing of the actuating and pumped media occurs in working chamber 4. The working and pumped media can be a liquid, gas, or liquid-gas flow with varying component ratios. The mixture of actuating and pumped media exits working chamber 4 and continues into the technological line to the customer. When using jet unit as a propulsor, the pumped medium is atmospheric air (for UAVs, for example) or seawater (for underwater UAVs and dynamic positioning systems for offshore oil and gas fields, for example).

According to the utility model, using several shut-off control devices 8 in isolated supply channels 7 can provide stationary or non-stationary flow modes, including different variants of pulse ones. The claimed technical solution makes it possible to control the flows of the working and pumped media, providing the required flow conditions at the exit of working chamber 4. The distribution of flow velocity at its outlet can be uniform or non-uniform. The flow velocity at individual points at the outlet of the working chamber 4 may be constant in time or variable depending on the specifics of the solved technological task. The shut-off regulating devices 8 can be remotely controlled and combined into a single digital control system operating according to a particular computer program, depending on the specifics of the solved technological task.

Thus, the proposed technical solution provides a controlled redistribution of flow energy on individual sections at the outlet of the working chamber and regulates the flow momentum and the velocity diagram parameters in the cross-section at the working chamber outlet. In the case of using the jet system as a propulsion system for UAV, for example, shut-off control devices 8 are only in contact with cold ambient air, which is the handled medium (the ambient temperature may be considerably lower than the working medium temperature). Here, a high-temperature working medium (e.g., hot gas from the outlet of an air jet or rocket engine) may flow into nozzle 3. We may call such an embodiment by the working name "the effect of cold control of a hot flow". There are also many examples from other industries, including hydrocarbon production, in which the properties of the working and pumped medium in an ejector system differ significantly.

3.3. Training Example with a Jet Thrust Regulator

In Figure 4 shows the calculation diagram of the jet apparatus. Working medium at pressure P_0 and mass flow rate Q_0 enters nozzle 1, having diameter d_o. A pumped medium with pressure P_1 and mass flow rate Q_1 enters receiving chamber 2. The ejection process occurs in mixing chamber 3 with diameter d_3 and length L_3. At the outlet of diffuser 4, the mixture of actuating and pumped media has pressure P_4 and mass flow rate ($Q_0 + Q_1$). To quantify the workflow in the jet device, we used the following dimensionless parameters [28]: mass ratio $q=Q_1/Q_0$, relative pressure head $h=(P_4–P_1)/(P_0–P_1)$, and geometric parameter $a=d_3^2/d_0^2$**.** The maximum value of the relative flow rate $q_{\max}$ corresponds to the operating mode when h=0.

For example, the stage of patenting a new technical solution involved the calculations using incompressible media and a well-known calculation method and educational computer program [28] based on the momentum equation (the developer of the equation is Leonard Euler). In the examples, we used water as the working and pumped medium. Similarity theory allows us to consider these tutorial examples when using dimensionless parameters. The examples (within the scope of this paper) mainly discuss jet propulsors, so the computational examples assume the condition that the inlet to receiving chamber 2 and the outlet from diffuser 4 communicate with the environment (Figure 4). This example considers a jet device immersed in water. By throttling the flow at the inlet to receiving chamber 2, we can regulate the parameter q.

At the same time, the thrust of the propulsor F made based on the jet device will also change. The maximum thrust value $F_{\max}$ corresponds to the operating mode when h=0. To quantify the workflow in the jet device, we use a dimensionless parameter, the coefficient of thrust change $k_F=F/F_{\max}$. Figure 5 shows graphically the calculation results for three different jet devices: the first variant (geometric parameter a=5.1), the second variant (geometric parameter a=2.0), and the third variant (geometric parameter a=1.4).

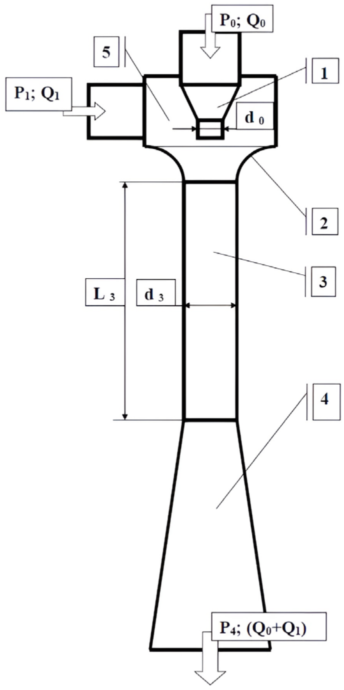


Figure 4. The calculation diagram of the jet device; 1: nozzle, 2: receiving chamber, 3: mixing chamber (working chamber), 4: diffuser [28]

In course of new technical solutions are being patented [3], calculations confirmed the ejector systems operability for thrust control as applied to incompressible media. With increasing the geometric parameter value, the thrust control range of the propulsion system F expands. For variant (a=1.4), the thrust variation coefficient is ($0.6< k_F <1.0$). For variant (a=5.1), the thrust variation coefficient is ($0.1< k_F <1.0$).

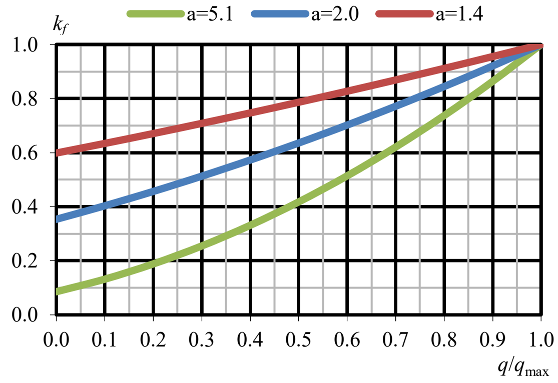


Figure 5. The calculation results for three jet devices: the first variant (a=5.1), the second variant (a=2.0), the third variant (a=1.4)

3.4. Computer Simulation of Jet Thrust Regulator

This study involved a series of calculations using CFD technologies to verify the performance of various variants of the ejector system [4] for thrust control as applied to compressible media. Figure 6 shows the basic calculation diagram of the jet device (ejector).

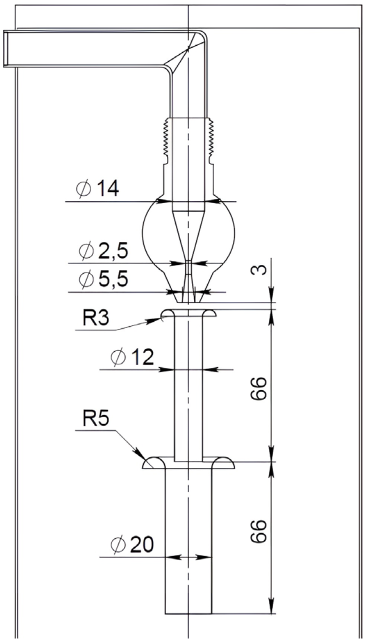


Figure 6. The basic calculation diagram of the jet device (ejector)

The presented example considers an ejector equipped with two mixing chambers installed in series, with 12 mm and 20 mm diameters, respectively. In course of new technical solutions are being patented, computer modelling aimed only to confirm the performance of the developed design and its elements. More detailed calculations and solutions of optimization problems we plan to perform later, at the stage of preliminary design. Computer modelling and computational research used the FlowSimulation (*FloEFD*) software package. 3D modeling used the CAD SolidWorks system. The turbulence parameters for the closure of the system of Navier-Stokes equations were calculated using a (k-ε) turbulent viscosity model.

Figure 7 graphically shows the separate results of computer simulation of the ejector variant with a mixing chamber of 12 mm, where $a = d_3^2 / d_0^2 = 12^2 / 5.5^2 = 4.76$.

Here, the channel is fully open for the pumped medium to enter the mixing chamber, so the relative flow rate is $q = q_{\max}$. The calculation conditions were as follows. Gas (air) pressure at the nozzle inlet is 519875 Pa at a gas temperature of 2000 °C. The ambient gas (air) pressure is 101325 Pa, temperature 20 °C, total number of cells: 733201, calculation time: 19147 s, and number of iterations: 1500. The calculated value of ejector thrust (modulo) is 6.775 N ($F_{\max} = 6.775$ N).

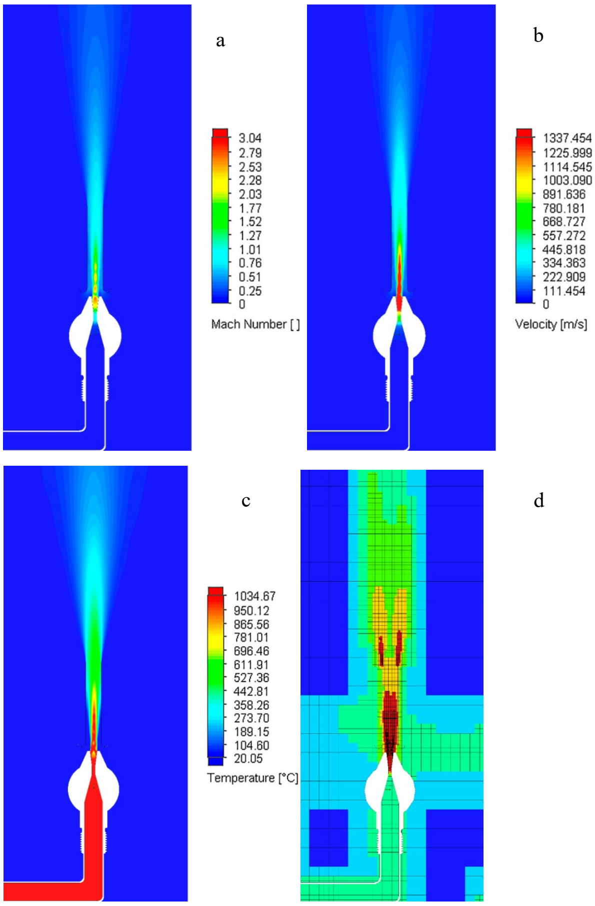


Figure 7. The computer simulation results of the ejector variant with a mixing chamber of 12 mm (operating mode under the condition $q = q_{\max}$), a. velocity, b. Mach number, c. temperature, d. calculation mesh

Figure 8 graphically shows the separate results of computer simulation of the ejector variant with a mixing chamber of 12 mm. Here, the channel for the pumped medium flow into the mixing chamber is completely blocked, so the relative flow rate is $q=0$. The calculation conditions were as follows. Gas (air) pressure at the nozzle inlet is 519875 Pa at a gas temperature of 2000 °C. The ambient gas (air) pressure is 101325 Pa, temperature 20 °C. Total number of cells: 651566. Calculation time: 18868 s. Number of iterations: 1500. The calculated value of ejector thrust (modulo) is 1.993 N ($F = 1.993$ N).

According to the computer simulation results of the ejector with a mixing chamber of 12 mm, we can conclude that the range of thrust variation for this variant of the ejector is ($0.294 < k_F < 1.0$). Figure 9 graphically shows the separate results of computer simulation. The presented example considers an ejector equipped with two mixing chambers in series, 12 mm and 20 mm diameter, $a = d_3^2 / d_0^2 = 20^2 / 5.5^2 = 13.22$. Here, the channel is fully open for the pumped medium to enter the mixing chamber, so the relative flow rate is $q = q_{\max}$. The calculation conditions were as follows.

Gas (air) pressure at the nozzle inlet is 519875 Pa at a gas temperature of 2000 °C. The ambient gas (air) pressure is 101325 Pa, temperature 20 °C. Total number of cells: 749594. Calculation time: 20789 s. Number of iterations: 1500. The calculated value of ejector thrust (modulo) is 7.478 N ($F_{\max}$ = 7.478 N).

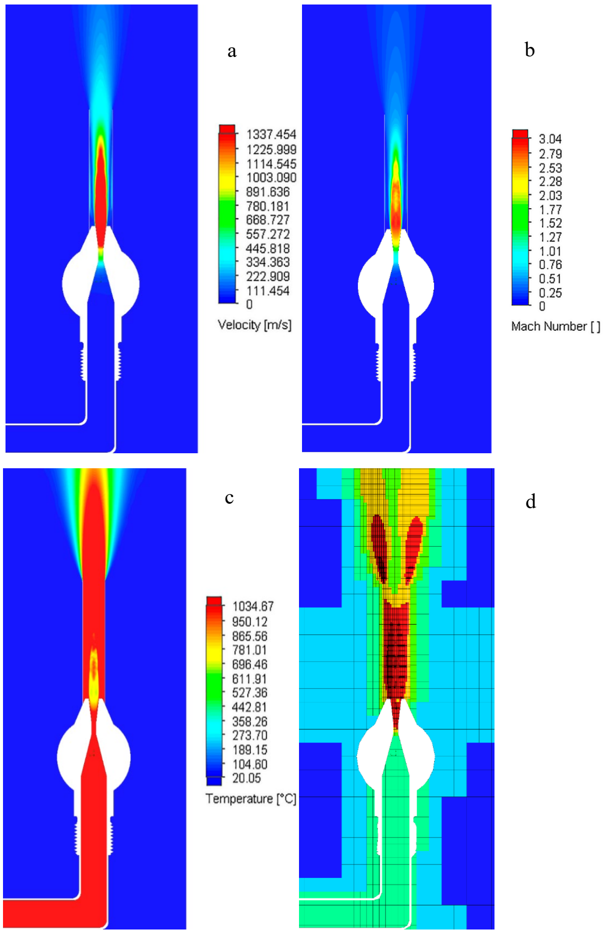


Figure 8. The computer simulation results of the ejector with a mixing chamber of 12 mm (operating mode under the condition q=0), a.velocity, b. Mach number, c. temperature, d. calculation mesh

Figure 10 graphically shows the separate results of computer simulation. The presented example considers an ejector equipped with two mixing chambers installed in series, 12 mm and 20 mm in diameter. Here, the annular channels for the pumped medium flow into each mixing chamber are fully closed, so the relative flow rate q=0. The calculation conditions were as follows. Gas (air) pressure at the nozzle inlet is 519875 Pa at a gas temperature of 2000 °C. The ambient gas (air) pressure is 101325 Pa, temperature 20 °C. Total number of cells: 753047. Calculation time: 21710 s. Number of iterations: 1500. The calculated value of ejector thrust (modulo) is 0.713 N (F = 0.713 N).

According to the computer simulation results of the ejector equipped with two mixing chambers installed in series, 12 mm and 20 mm in diameter, we can conclude that the range of thrust variation for this variant of the ejector is ($0.095<k_F<1.0$). At the stage of patenting a series of new technical solutions [4], calculations confirmed the performance of the ejector system for thrust control as applied to compressible media.

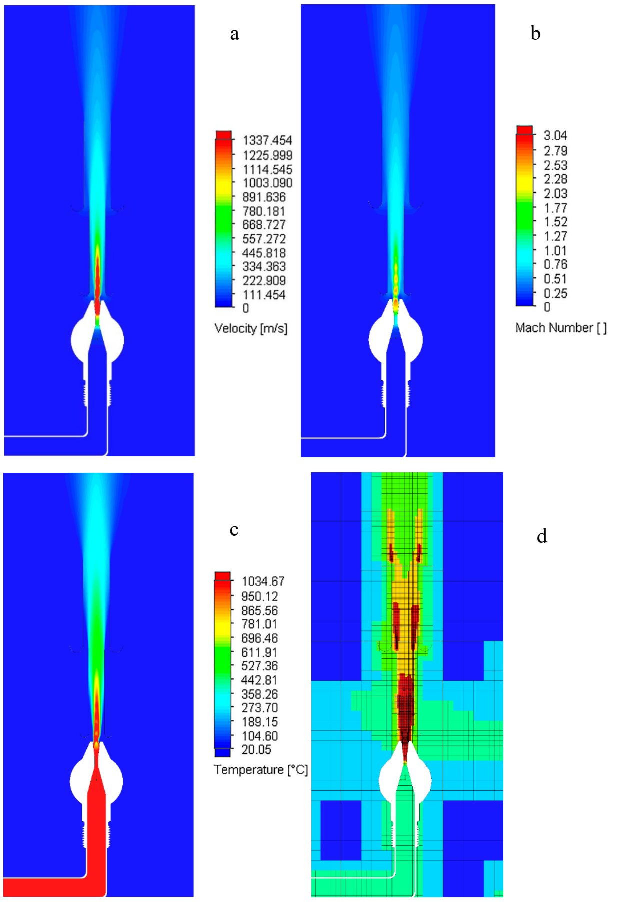
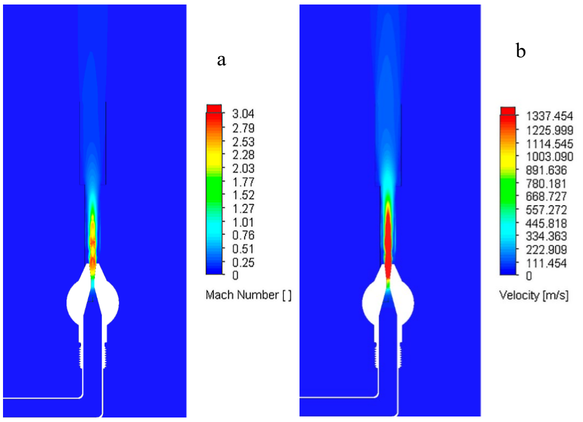


Figure 9. The computer simulation results of the ejector equipped with two mixing chambers installed in series, 12 mm and 20 mm in diameter (operating mode under the condition q=$q_{\max}$), a. velocity, b. Mach number, c. temperature, d. calculation mesh



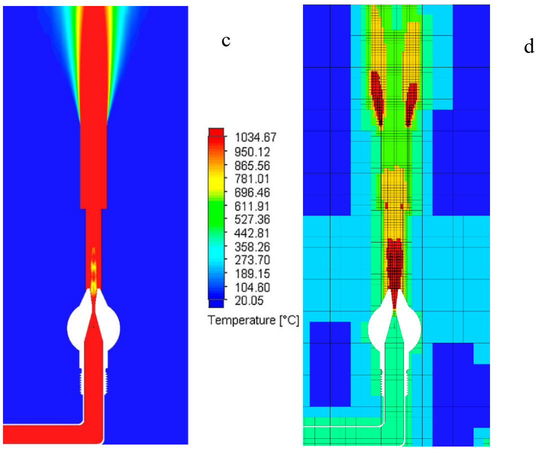


Figure 10. The computer simulation results of the ejector equipped with two mixing chambers installed in series, 12 mm and 20 mm in diameter (operating mode under the condition q=0), a. velocity, b. Mach number, c. temperature, d. calculation mesh

4. DISCUSSION

4.1. Discussion of Different Versions of the Jet Device

Jet devices implement the injection process to transfer the kinetic energy of one stream to another through direct contact (blending). The nozzle, accepting chamber, blending chamber, and diffuser are the main components of the jet apparatus. The study of a jet device as a whole, or its separate element in particular, considers the interaction of fluid medium with a solid wall. The solid wall can be fixed or movable. For any point on the solid wall surface, it is possible to specify coordinates ($x_i(t)$, $y_i(t)$, $z_i(t)$) within the 3D space where,

i =0 – the jet device (for the working medium);
i=1 – the receiving chamber (for the pumped medium);
i=3 – the mixing chamber; i =4 – diffuser.

For some jet device (ejector) designs, the coordinates of point under consideration may be constant over time (t):

$$\begin{cases} x_i(t) = \text{idem} \\ y_i(t) = \text{idem} \\ z_i(t) = \text{idem} \end{cases} \tag{1}$$

At the same time, for other designs of the jet device (ejector), the coordinates of the point under consideration may change over time (t) when it moves within a segment or when the solid wall under consideration moves continuously along a particular trajectory:

$$\begin{cases} x_i(t) = \text{var} \\ y_i(t) = \text{var} \\ z_i(t) = \text{var} \end{cases} \tag{2}$$

The flow regime in each element of the jet device can be stationary or unsteady. At that, gas dynamic or hydrodynamic parameters of the fluid medium can be constant or variable over time (in particular, density ρ_i, pressure P_i, mass flow rate Q_i, and temperature T_i):

$$\begin{cases} \rho_i(t) = \text{idem} \\ P_i(t) = \text{idem} \\ Q_i(t) = \text{idem} \\ T_i(t) = \text{idem} \end{cases} \tag{3}$$

$$\begin{cases} \rho_i(t) = \text{var} \\ P_i(t) = \text{var} \\ Q_i(t) = \text{var} \\ T_i(t) = \text{var} \end{cases} \tag{4}$$

The shape, dimensions, and coordinates of solid walls, according to Equations (1) and (2), are determined during the design process when creating a 3D model of the product under development. Gas-dynamic or hydrodynamic parameters of the fluid medium, according to Equations (3) and (4), are calculated during computer simulation using CFD technologies. Figures 6-10 graphically show examples with computer simulation results for conditions where the working gas temperature is much higher than the pumped medium temperature ($T_0(t) >> T_1(t)$).

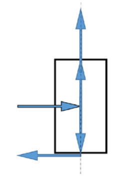
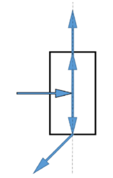
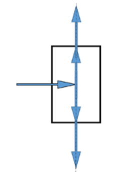
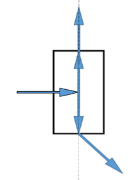
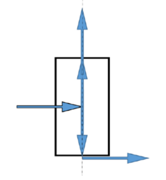
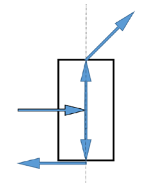
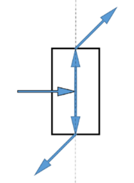
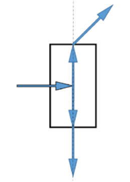
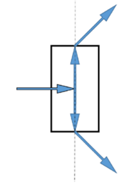
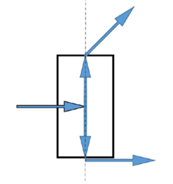
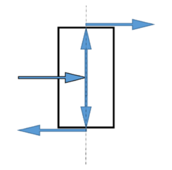
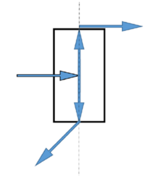
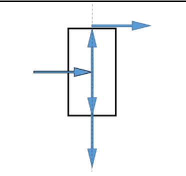
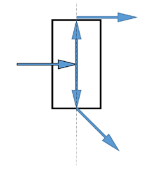
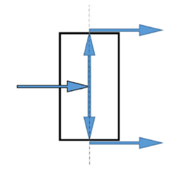
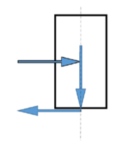
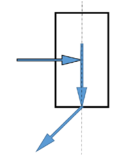
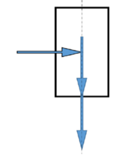
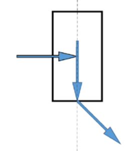
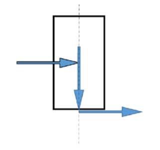
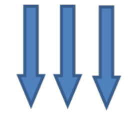
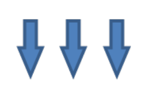
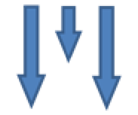
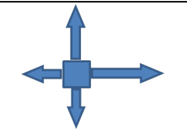
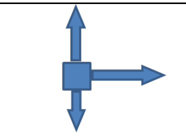
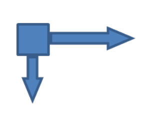
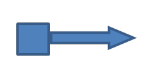
The authors of this paper have previously shown new possibilities [1-4] in the field of thrust vector (velocity vector) control as part of the scientific groundwork preparation. They showed for the first time that nozzle devices and ejector systems make it possible to control the thrust vector within the complete geometric sphere in the broadest variation range, making it possible to reconsider the capabilities of jet fluidics in general from new positions. Within the philosophy of technology, we propose to derive a version of the next generalization.

In general, jet apparatus is a system that includes the following sub-systems with a velocity vector (thrust vector) control system within a complete geometric sphere: a multi-flow nozzle apparatus, multi-flow receiving chamber, multi-flow mixing chamber, and multi-flow diffuser. In general, these sub-systems can change positions in three-dimensional area (including rotational motion participation) and shapes and sizes of separate channels according to Equations (2) and (4). In practice, one or more subsystems are applicable within a single project. In a particular case, and most often in practice, stationary operating modes are considered for jet devices without moving control elements according to Equations (1) and (3). Due to this, for student use, we propose to pass in review the issues about the classification of jet apparatus as philosophical questions about the relationship between the general and the specific, the sophisticated and the simplistic, with the assessment of new opportunities for the search and development of patentable new technical solutions.

4.2. Discussion of Typical Diagrams of Jet Devices for Thrust Vector Control within a Complete Geometric Sphere

As known, physics considers a vector, having modulus and direction simultaneously, as a mathematical model of velocity, force, and related quantities (kinematic or dynamic), also considering vectors with a given specific initial point. Given the prepared scientific groundwork, Table 1 schematically shows the basic operating modes (variants) for a nozzle apparatus capable of controlling the thrust vector within a complete geometric sphere.

Table 1. Operating modes of the nozzle apparatus (jet device)

	1	2	3	4	5
A					
B					
C					
D					
G					
H					

The arrows indicate the flow directions for the different variants. The authors of this paper previously presented the variants shown in lines A, B, C, and D [1]. Considering the patented new technical solution [4], they added lines G and H in Table 1. When using several jet devices, the flows can move along parallel (or equidistant) lines, as schematically shown in line G. At the same time, the outlets from the jet devices may have different directions, as schematically shown in line H. The technical solution [3] makes it possible to adjust the thrust vector in modulus; ideally, the modulus value can vary from the maximum to zero. H5 corresponds to the variant when the thrust modulus is zero, so there are no arrows in the diagram. Several multi-directional jet devices (ejectors) make it possible to adjust the thrust vector in direction as a resultant force within a complete sphere (as schematically shown in examples in line H, variants H1-H4) since a system of several forces can culminate in a force by adding a resulting torque.

The authors reserved lines E and F to describe technical solutions they will present in other papers in 2023; developing new solutions, they will supplement Table 1 with new data. As a basis for the development of these new technical solutions, the authors plan to use the prepared scientific groundwork, partially reflected in patents for inventions of the Russian Federation nos. 2781455 and 2802351, patents for utility models of the Russian Federation nos. 214452, 209663, 203833, and 192513.

4.3. Laboratory Tests of Jet Device Micromodels for Thrust Vector Control within Complete Geometric Sphere

In addition to previously published materials (Table 1, lines A, B, C, D), this paper considered variants of thrust vector control in modulus (Table 1, line G) and created tutorials in the form of micromodels. Within the training of designers, teaching micromodels of jet systems were made using additive technologies to demonstrate the variants and capabilities of the patented technical solution [3]. For example, Figures 11-13 show a 3D (computer) jet device model of six ejectors installed in parallel.

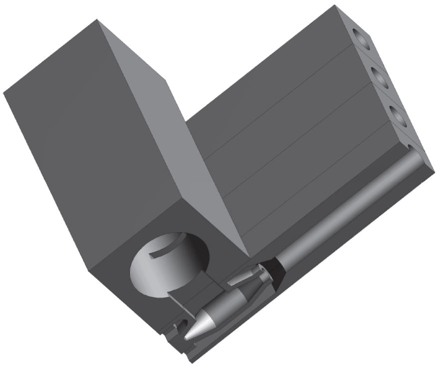


Figure 11. 3D model of the jet device (cutaway isometry)

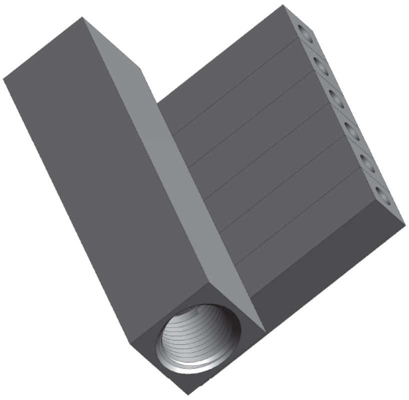


Figure 12. 3D model of the jet device consisting of six ejectors installed in parallel (variant according to the patent [3])

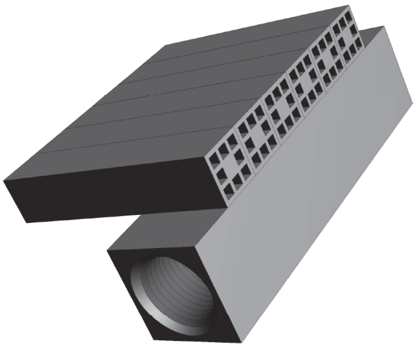


Figure 13. 3D model of the jet device (view from the mesh inlet for the pumped medium)

This 3D computer model was a basis for making a physical micromodel for training classes. Figure 14 shows a photo of a physical micromodel of the jet device made using a 3D printer. It has six output channels from six ejectors operating in parallel. Let us label these channels (and ejectors) by numbers from left to right: No. 1, No. 2, No. 3, No. 4, No. 5, and No. 6. To visualize the effects, we used variants with laboratory hydraulic tests.

In a training laboratory experiment, the mesh inlet to the ejector (or several ejectors) was blocked using a thin-walled impermeable diaphragm to reduce the thrust of an individual ejector (or several ejectors). Figure 16 shows an example with a diaphragm in the shape of a rectangle viewed from the side of the mesh inlet for the pumped medium when the diaphragm closed this inlet for two central ejectors (No. 3 and No. 4).

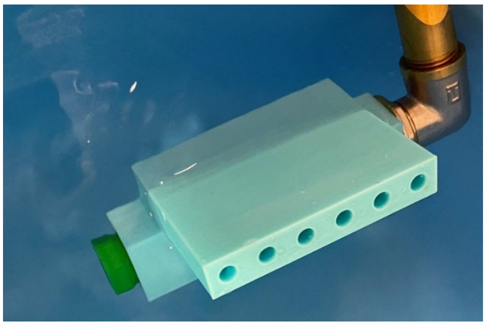


Figure 14. Physical micromodel of a jet device manufactured using a 3D printer

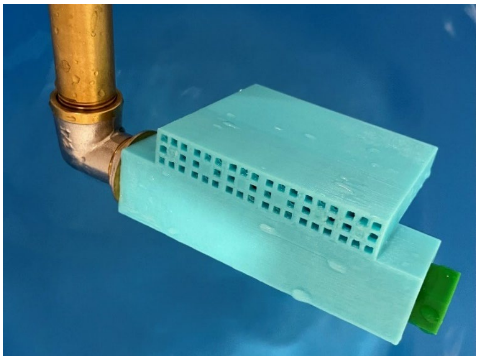


Figure 15. Physical micromodel of a jet device (view from the mesh inlet for the pumped medium)

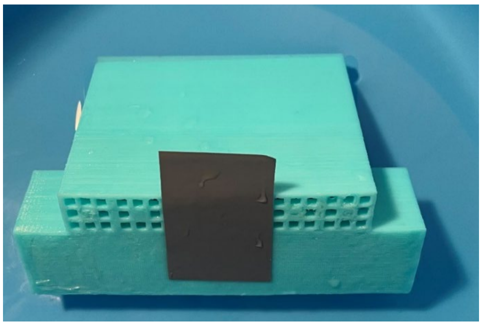


Figure 16. Example of a block of six ejectors with diaphragm viewed from the side of the mesh inlet closed for the pumped medium for two central ejectors (No. 3 and No. 4)

Figure 17 shows a micromodel of the jet device (hydraulic test mode, all inlets for the pumped medium are open: No. 1, No. 2, No. 3, No. 4, No. 5, No. 6).

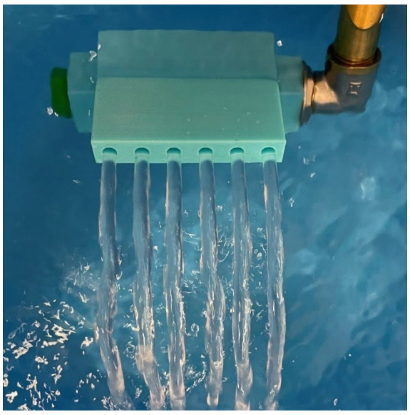


Figure 17. Micromodel of the jet device (test mode - all inlets for the pumped medium are open: No. 1, No. 2, No. 3, No. 4, No. 5, No. 6)

The operating mode of ejectors in Figure 17 corresponds to variant G1 (in the mode notation, the letter corresponds to the line and the following digit, to the column number in Table 1). Figure 18 shows a training demo with the diaphragm. For two ejectors on the right side (No. 5 and No. 6), the diaphragm closes the inlet for the pumped medium. The flow velocity at the outlet for these two ejectors has dropped, which is noticeable by the form of the flows from the outlet channels.

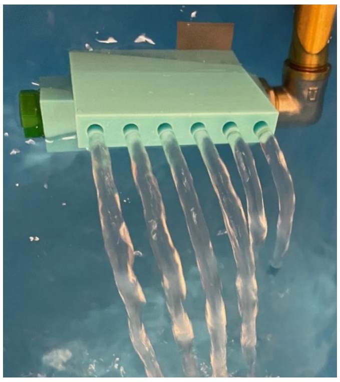


Figure 18. Demo with the diaphragm: for two ejectors on the right side (No. 5 and No. 6), the diaphragm closes the inlet for the pumped medium

The operating mode of ejectors in Figure 18 corresponds to variant G3 in Table 1. The diaphragm is in the background on the pumped medium inlet side.

Figure 19. Demo with the diaphragm: for two ejectors in the center (No. 3 and No. 4), the diaphragm closes the inlet for the pumped medium

The operating mode of ejectors in Figure 19 corresponds to variant G4 in Table 1.

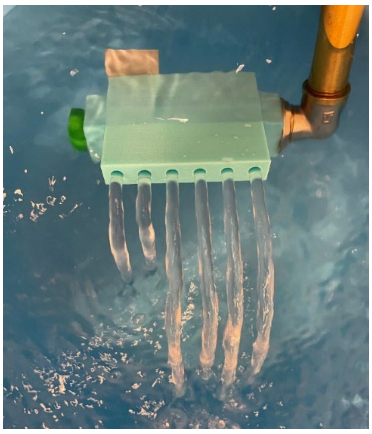


Figure 20. Demo with the diaphragm: for two ejectors on the left side (No. 5 and No. 6), the diaphragm closes the inlet for the pumped medium

The operating mode of ejectors in Figure 20 corresponds to variant G5 in Table 1.

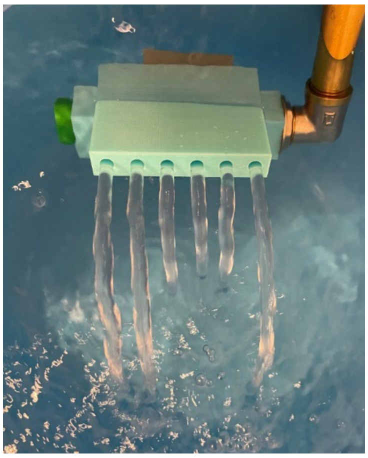


Figure 21. Demo with the diaphragm: for three ejectors (No. 3, No. 4 and No. 5), the diaphragm closes the inlet for the pumped medium

In addition to the hydraulic tests, training sessions involved various pneumatic tests to emphasize the variety and prospect of practical use of such fluidics. We can conditionally call a light, impermeable diaphragm "butterfly wing" because of the analogy with the famous "butterfly effect." Popular culture often refers to the butterfly effect concept when describing an insignificant change in circumstances causing a huge substantial change. Even educational laboratory experiments showed that a negligible change in the weight of the ejector unit (by adding a minor weight of diaphragm F_1) results in a large (significant) change in thrust F in the ejector unit, and this change in thrust is comparable to the changes from the calculation results in Figure 5. In this case, we can write down the mathematical expression ($F_1 << F$), which also indicates that insignificant power is necessary to operate the control system in high energy density reactive jet systems (for example, similar to the variants in Figures 6-10). With the development of the research and training program, the authors plan to quantify such a variant of the butterfly effect in detail since reducing power costs for the control system of high-power reactive jets remains an urgent problem in practical work, fluid dynamics, and gas dynamics. Logically, a specific impermeable movable diaphragm can also control powerful ejectors at industrial facilities during hydrocarbon recovery and refining, and certain versions of ejector with a diaphragm can find practical application in aerospace systems. As applied to the movable control diaphragm installed in the channel for the pumped medium, Equation (2) will take the Equation (5):

$$\begin{cases} x_1(t) = \text{var} \\ y_1(t) = \text{var} \\ z_1(t) = \text{var} \end{cases} \tag{5}$$

This paper also considers separate variants of thrust vector control in modulus and direction (Table 1, line H). As noted, the outlets from the jet devices (ejectors) can have different directions schematically shown in line H in Table 1. To demonstrate this, an educational physical micromodel of a jet device (ejector) shown in Figure 22 has been designed and fabricated.

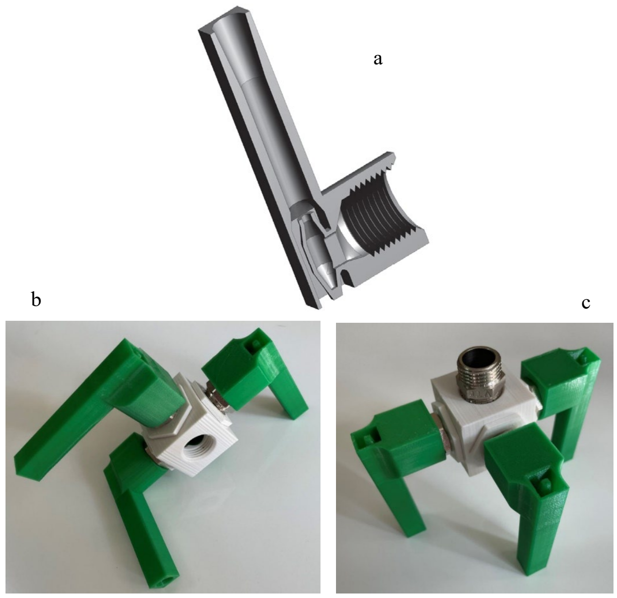


Figure 22. Educational micromodel of the jet apparatus: a. three, dimensional computer model for education of the jet apparatus (ejector), b. photo of the physical micromodel of the jet apparatus (variant 1), c. photo of the physical micromodel of the jet apparatus (variant 2)

As applied to the multi-flow jet device and the diffusers in Figure 22, Equation (4) at i =4 for each flow (with the corresponding number 4j) will take the following form:

$$\begin{cases} \rho_{4j}(t) = \text{var} \\ P_{4j}(t) = \text{var} \\ Q_{4j}(t) = \text{var} \\ T_{4j}(t) = \text{var} \end{cases} \tag{6}$$

The presented example Figure 22 shows three controllable ejectors; accordingly, in Equation (6), additional indices are introduced in the notation of parameters j=1, j=2, j=3 since each ejector can be controlled independently. In addition to the demonstration variant, according to Figure 22, many other variants of the jet system are possible, including hybrid variants based on several schemes from lines A, B, C, D, G, and H in Table 1.

The technical solutions presented in this paper will apply patenting new technologies in oil and gas production. Separate technologies will affect the field of robotics and unmanned vehicles operating in water or airspace. Thus, when preparing a series of new technical solutions for patenting, calculations confirmed the performance of the multi-flow ejector system designed to control the thrust vector for compressible and incompressible media. Fabricated physical micromodels verified the basic operating principles applicable in creating promising patentable systems for thrust vector control in direction and modulus with controlled change of coordinates for the starting point.

Further studies will focus on a more detailed investigation of the ejector workflow at thrust vector control in modulus, including cavitation conditions in liquid media. It is also necessary to consider in more detail the influence of absolute pressure with the change of environmental density, and it seems that examples with vehicles for air and airless space (this topic is quite popular in modern scientific literature) may be of particular practical interest. Further studies also relate to the search for additional possibilities for thrust vector control only in modulus, keeping the thrust vector direction and the initial point coordinates for the application of the resultant force unchanged. The issues of reliability improvement by duplication of jet control systems for critical and expensive products for different purposes might be of research and practice interest.

4.4. Expanding the List of Issues for a Design System of Jet Devices, Including Those Intended for Controlling the Thrust Vector Within a Complete Geometric Sphere

In the course of design works and solving inventive problems, it is necessary to consider many interrelated issues when using an interdisciplinary approach becomes inevitable. The issues discussed should include questions about the location of the movable regulating diaphragm within the jet control system for the created product as a whole. For example, let us list the following issues and variants:

- The diaphragm may be at the nozzle outlet (in contact with both the actuating medium and the handled medium);
- The diaphragm may be inside the nozzle (in contact only with the working medium);
- The diaphragm may be in the receiving chamber (in contact only with the pumped medium);
- The diaphragm may be in the mixing chamber (in contact with a mixture of actuating medium and handled medium);
- Other variants for location of movable control diaphragm within the jet system are possible.

Additional questions about structural materials applicable for the movable control diaphragm include, for example:

- Impermeable materials or materials with partial permeability;
- Heat-resistant steels or materials for high operating temperatures with possible cooling system variants;
- Foamed metals or aerogels to reduce the weight of the movable diaphragm elements.

Additional questions about mechanization systems to move movable regulating diaphragm include, for example:

- Hydraulic actuator;
- Pneumatic actuator;
- Electromagnetic actuator;
- Electromechanical actuator;
- Hybrid actuators, for example, for duplicating separate subsystems in a control system, including using computer control programs, in particular, gaining strength AI.

Additional questions about the jet control system for power distribution, for example, for unmanned vehicles, include:

➢ The thrust vector is for a single nozzle or the product as a whole (e.g., for unmanned vehicle as a whole);
➢ The thrust vector control by direction only or not;
➢ The thrust vector control by modulus only or not;
➢ The thrust vector control only for the starting point offset or not;

- ➢ The thrust vector control comprehensively for the product as a whole, including direction, modulus, and starting point coordinates or not;
- ➢ The thrust vector control system allows vertical takeoff and landing in various modes, including afterburner mode or not;
- ➢ The thrust vector control system allows horizontal flight with possible transition to maneuver in any direction within a geometric sphere or not;
- ➢ Opportunities for swarm operations or not;
- ➢ The specifics of changes in aircraft mass, e.g., due to reduced fuel mass in the tanks, are considered or not;
- ➢ How the control system is ergonomic (adapted to the physiology of the human operator, but a series of maneuvers can be automatic and beyond the limited human capabilities, even of a highly trained specialist).

4.5. Some Generalizations

Raised and considered methodological issues on the design of various jet systems, including solving inventive problems [28]. Further, a prepared scientific groundwork [1-4] made it possible to form a scientific direction based on Leonard Euler's legacy and disclosed new opportunities for developing jet (reactive) technology, including through the improvement of thrust vector control systems with thrust vector angles brought to ultimate large values from +180 to -180 degrees within a complete geometric sphere. The authors showed possibilities of creating a scientific and design school within the planned scientific direction. Further development of jet (reactive) technology can relate to using new technological approaches and physical principles, including many hybrid systems (philosophically, we can talk about an infinite number of hybrid systems).

The main field of application of the obtained scientific results relates to power engineering, production and processing of oil and gas, which have not yet fully utilized the reserves of clean reservoir energy and where it is advisable to create new energy-saving equipment and technology. Some results are applicable in aviation and marine transportation systems, for example, for control systems of various unmanned vehicles (geological exploration, search and rescue operations). The project solved its main objectives within the presented scientific paper:

1. Promising directions for the development of hydraulic engineering and jet thrust vector control systems have been identified;
2. New opportunities for improving the methodology for designing a jet-ejection systems have been identified.

5. CONCLUSIONS

5.1. Scientific Novelty

Technical solutions allowing thrust vector control within the complete geometrical sphere, including movable diaphragms, have been developed and patented. We proposed a system approach for solving the problems of thrust vector control for a group of nozzle apparatuses in general and a single nozzle in particular.

5.2. Theoretical Contribution

This paper describes a variant of a patented method for thrust vector control based on the theory of jet devices and ejectors. It shows variants of thrust vector control at controlled change of its modulus, direction, and coordinates of its initial point.

5.3. Practical Importance

This paper proposed variants for solving urgent problems of improving the energy efficiency of equipment and technologies in energy, including hydrocarbon recovery and refining. Certain results are applicable in creating promising thrust vector control systems in aviation and marine unmanned systems.

5.4. Limitations and Future Research

Limitations of the study may be related to the complexity of modern technological systems that constantly require increased computational power. The development of studies may relate to creating fast-acting computerized jet systems for thrust vector control on high-speed unmanned vehicles, for example, underwater or aerospace vehicles.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Y.A. Sazonov, M.A. Mokhov, K.A. Tumanyan, M.A. Frankov, N.N. Balaka, "Prototyping Mesh Turbine with the Jet Control System", International Multidisciplinary Scientific Journal, Vol. 17, No. 36, pp. 1160-1175, Brazil, 2020.

[2] Y.A. Sazonov, et al., "Designing Mesh Turbomachinery with the Development of Euler's Ideas and Investigating Flow Distribution Characteristics", Civil Engineering Journal, Vol. 8, No. 11, pp. 2598-2627, November 2022.

[3] Y.A. Sazonov, et al., "Jet Pumping Unit", RF Patent for an Invention, No. 2, 781 455, October 2022.

[4] Y.A. Sazonov, et al., "Jet Device", RF Patent, No. 2, 802 351, August 2023.

[5] N. El Abbadi, M.S. El Youbi, "Enhancing Wind Energy Forecasting Through Application of Artificial Intelligence Techniques: A Comprehensive Study", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 56, Vol. 15, No. 3, pp. 149-155, September 2023.

[6] P. Wu, H. Wang, G. Liang, P. Zhang, "Research on Unmanned Aerial Vehicle Cluster Collaborative Countermeasures Based on Dynamic Non-Zero-Sum Game under Asymmetric and Uncertain Information", Aerospace, Vol. 10, No. 8, p. 711, August 2023.

[7] W. Pan, L. Qin, Q. He, Y. Huang, "Three-Dimensional Flight Conflict Detection and Resolution Based on Particle Swarm Optimization", Aerospace, Vol. 10, No. 9, p. 740, August 2023.

[8] Q. Zhuang, X. Cheng, P. Yue, X. Guo, K. Li, "Study on Failure Criteria and the Numerical Simulation Method of a Coal-Based Carbon Foam under Multiaxial Loading", Aerospace, Vol. 10, No. 8, p. 721, August 2023.
[9] G. Friedmann, "Injection Mixer", US Patent 2623474, December 1952.
[10] M.J. Wheatley, "Apparatus for Energy Transfer", UK Patent GB, No.2310005, August 1997.
[11] Y. Zhang, J. Dong, S. Song, X. Pan, N. He, M. Lu, "Numerical Investigation on the Effect of Section Width on the Performance of Air Ejector with Rectangular Section", Entropy, Vol. 25, No. 1, p. 179, 2023.
[12] R.M. Ualiyeva, A.N. Kukusheva, M.K. Insebaeva, K.K. Akhmetov, S.B. Zhangazin, M.S. Krykbayeva, "Agrotechnological Methods of Plant Feeders Applying for Spring Wheat Agrocenoses - North-Eastern Kazakhstan Varieties", Journal of Water and Land Development, August 2023.
[13] R. Koirala, Q.L. Ve, B. Zhu, K. Inthavong, A. Date, "A Review on Process and Practices in Operation and Design Modification of Ejectors", Fluids, Vol. 6, No. 11, p. 409, November 2021.
[14] R.M. Ualiyeva, M.M. Kaverina, L.N. Ivanko, S.B. Zhangazin, "Assessment of Spring Wheat Varieties for Pest Resistance", OnLine Journal of Biological Sciences, Vol. 23, No. 4, pp. 489-503, April 2023.
[15] O.A. Azarova, "High Speed Flows", Fluids, Vol. 8, No. 4, p. 109, March 2023.
[16] Y. Wang, N. Wang, "Influence of the Projectile Rotation on the Supersonic Fluidic Element", Aerospace, Vol. 10, No. 1, p. 35, December 2022.
[17] D. Kim, M. Asli, K. Hoschler, "On the Potentials of the Integration of Pressure Gain Combustion with a Hybrid Electric Propulsion System", Aerospace, Vol. 10, No. 8, p. 710, August 2023.
[18] B.D. Skaggs, "Fluid Jet Ejector and Ejection Method", US Patent, No. 6,017,195, January 2000.
[19] M. Volker, A. Sausner, "Suction Jet Pump", US Patent, No. 10, pp. 672-674, March 2014.
[20] C.G. Sota Jr., G.J. Callis, R.K. Masse, "Thrust Vector Control System for a Plug Nozzle Rocket Engine", US Patent, No. 7155898, January 2007.
[21] L.E. Kinsey, R.J. Cavalleri, "Integral Thrust Vector and Roll Control System", US Patent, No. 8387360, March 2013.
[22] W. Plumpe Jr., "Apparatus and Method for Thrust Vector Control", US Patent, No. 6622472, September 2003.
[23] G. Cican, T.F. Frigioescu, D.E. Crunteanu, L. Cristea, "Micro Turbojet Engine Nozzle Ejector Impact on the Acoustic Emission, Thrust Force and Fuel Consumption Analysis", Aerospace, Vol. 10, No. 2, p. 162, February 2023.
[24] X. Zhang, H. Dang, B. Li, "Prediction of Aircraft Surface Noise in Supersonic Cruise State", Aerospace, Vol. 10, No. 5, p. 439, May 2023.
[25] C. Wang, H. Lu, X. Kong, S. Wang, D. Ren, T. Huang, "Effects of Pulsed Jet Intensities on the Performance of the S-Duct", Aerospace, Vol. 10, No. 2, p. 184, February 2023.
[26] J. Svorcan, J. Andric, D. Cantrak, T. Ivanov, "Special Collection on Advanced Practices in Aerospace and Energy Engineering", Advances in Mechanical Engineering, Vol. 14, No. 10, p. 168781322211255, October 2022.
[27] D. Mitridis, S. Kapsalis, D. Terzis, P. Panagiotou, "An Evaluation of Fixed-Wing Unmanned Aerial Vehicle Trends and Correlations with Respect to NATO Classification, Region, EIS Date and Operational Specifications", Aerospace, Vol. 10, No. 4, p. 382, April 2023.
[28] Y.A. Sazonov, "Fundamentals of Calculation and Design of Pump-Ejector Installations", (SUE) Oil and Gas Publishing House of Gubkin University, Moscow, Russia, 2012.
[29] H. Shayeghi, A. Ghasemi, "A New Hybrid Algorithm for Short Term Load Forecasting", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 22, Vol. 7, No. 1, pp. 38-45, March 2015.
[30] Yu.P. Voronov, "Foresight as a Tool", Institute of Economics and Industrial Engineering, Siberian Branch of RAS Publ., Novosibirsk, Russia, 2010.
[31] N.M. Raskin, "Euler's Questions of Technique. Leonhard Euler", Collection of Articles in Honor of the 250th Anniversary of the Birth, presented to the Academy of Sciences of the USSR, Publishing House of the Academy of Sciences of the USSR, pp. 499-556, Moscow, Russia, 1958.

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