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Thrust Vector Control within a Geometric Sphere, and the Use of Euler's Tips to Create Jet Technology

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Abstract

This study aims to study the issues of choosing promising directions for the development of jet technology with the creation of energy-conserving technologies. The purpose of this article is to study the issues of choosing promising directions for the development of jet technology with the creation of energy-saving. Methodological approaches have been developed for solving inventive problems within the framework of training modern designers-inventors. A new patentable jet unit has been developed and presented, which makes it possible to control the thrust vector within a complete geometric sphere (when the thrust vector is capable of deviating to any angle ranging from +180° to -180°). For the first time, demonstration versions of a nozzle apparatus capable of realizing such flow reversals through annular channels are shown. The results of computer modeling of nozzle devices are focused on energy, production, and processing of hydrocarbons when distributing energy flows at process facilities. The individual results of the ongoing work can also be used in other industries, for instance, in the creation of small-sized high-speed unmanned vehicles for search and rescue operations. Proposals have been prepared to improve the methodology for solving inventive problems as part of the development of Leonard Euler's ideas.

Keywords: CFD; Energy Conservation; Design; Nozzle Apparatus; Thrust Vector; Computer Simulation; Hydrodynamic Control.

1. Introduction

The most pressing problem is the reduction of energy costs in production processes, including the extraction and processing of oil and gas. Specialists from Gubkin University are studying and designing promising injection equipment and turbomachines [1-4]. In these promising systems, the flow channels have a mesh structure. In general, a mesh structure is an image of a larger geometric area with smaller individual cells. In jet systems, large mixing chambers are replaced by a series of smaller mixing chambers that are connected to each other, forming a flow channel with a mesh structure. During physical and numerical experiments, extreme conditions of liquid and gas flow through nozzles equipped with velocity vector control systems (traction vector in aviation terminology) were considered for the first time, i.e., velocity vectors (thrust vectors) in the geometric sphere control of angle deviation in the range from plus 180° to minus 180° [1, 4]. The resulting problem is the need to prepare designers for the choice of scientific directions for the further development of applied research through the development of promising reticulated jets. The mesh nature of the mechanical flow part of the turbine ensures the strength and rigidity of the low-mass rotor design. The jet control system as an integral system is characterized by low mass and high reliability (due to the small number of moving parts).

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It is well known that production systems for the production, transportation, and processing of oil and gas actively use advanced scientific developments in other areas of production, such as aviation technology and advanced aircraft engines. In this regard, a generalization of experience in system analysis of the design and construction of machines is not limited to specific disciplinary frameworks, but considers the problem of the general positions of mechanical sciences, including the use of interdisciplinary and interprofessional methods of organizing research. It is also known that the mesh structure of solid walls makes it possible to solve a number of important technical problems. Thus, the peculiarities of gas-dynamic processes were studied during the creation of aircraft [5], in which a mechanized wing is made with the possibility of a controlled change in its geometric shape. In some jet apparatuses, the nozzles are mounted on a fixed disc support [6] or on a rotating disc support [7].

Supersonic ejectors and nozzle apparatuses for various purposes are being investigated. Currently, comprehensive studies are focused on investigating the relationship between dimensional design parameters, working fluid state parameters, and ejector performance [8–10]. Detailed reviews of recent numerical and experimental studies of the ejector and its applications are provided [11]. High-velocity flows cover various modern areas of experimental and numerical studies in fundamental scientific problems of internal and external gas dynamics and in some new practical problems [12]. Such high-speed gas flows occur during the movement of aircraft (planes, rockets, and descent vehicles) and in many other technical devices. The development of hypersonic aircraft will require the modeling of hypersonic flows using new computational methods. Nowadays, non-mechanical control of high-velocity flows is a widely studied topic in scientific research [12]. The injection of the secondary air flow near the nozzle exit creates an asymmetry in the distribution of pressure on the wall and lateral loads on the nozzle, which are also lateral components of the thrust vector [13]. To change the thrust vector, several methods are sometimes used in combination [14, 15]: 1) the use of differential throttling when using several combustion chambers; and 2) an alternative solution that requires injection of a secondary flow from the slot (hydrodynamic control of the thrust vector).

The options for mesh nozzles for ejectors are known [16–18]. Ejector designs with curvilinear (curved) mixing chambers are known but poorly studied [19, 20]. The adjustable nozzle is sometimes made in the form of a diaphragm [21–23]. For known thrust vector (velocity vector) control systems, the largest flow deflection angle (at the nozzle outlet) can vary from +20° to -20° [15, 23, 24]. The adjustable nozzle can be equipped with a conical central body that can move in the axial [25] or radial directions [26]. Research continues on a nozzle with deflectors of various shapes [27], including those with a cruciform nozzle outlet channel [28]. Various aviation jet systems are considered to enhance thrust [29], including hybrid systems [30, 31]. It was noticed that when using the ejector, the thrust in each mode increased, the acoustic noise was controlled, and its decrease was revealed [29].

When studying an ejector with a curved mixing chamber, the research results for S-shaped air ducts should be considered. The large curvature of advanced S-shaped air ducts causes a strong secondary flow, which seriously affects the uniformity of the flow [32-34]. Fully developed turbulent flow in channels with weak and strong longitudinal curvatures has been studied using direct numerical simulation [34].

Nowadays, numerous significant interdisciplinary technological achievements can be seen in aerospace and power engineering [35]. They cover the increased use of computers at every stage of product design, various simulation, computation, optimization, and artificial intelligence methods, and significant breakthroughs in materials science, including high-precision and additive manufacturing methods, electrification options for flow machines, and the use of non-traditional fuels. Various methods are being studied for flow control (passive and active control, both in low-speed and high-speed flows) to improve efficiency, lift-to-drag ratio, boundary layer stabilization, and aircraft handling [35].

The publications present a thorough analysis of unmanned aerial vehicles (drones) with a fixed wing. In addition, a statistical analysis of key design parameters of such aircraft is performed [36].

The practical use of a swarm of intelligent robots that can collectively perform a task and solve a problem is a current research problem [37-39], and this problem is actively being considered within the framework of the use of neural networks [40]. This is due to the high computational complexity and lack of accurate assessment models [41, 42]. The potential for accidents highlights the urgent need to take effective measures to reduce the risks of mid-air collisions [43, 44]. Drone swarms have gained great popularity because, as a group, they can perform highly intelligent tasks [45]. Effective regulation of the behavior of an unmanned vehicle in flight has become a pressing and imperative issue that requires solutions [46]. These publications illustrate the fundamentals of swarm systems and provide future predictions.

The listed publications are now being reviewed to assess the current level of technology development. Without knowledge of the level of technological development, it is impossible to imagine the process of developing and patenting new technical solutions, and it is impossible to imagine a high-quality educational process in the training of designers.

The main tasks within the framework of the presented article are: identifying promising directions for the development of science and technology in the field of jet technology and complex jet systems, as well as improving the methodology for designing jet devices when training modern designers and inventors.

2. Research Methodology

To explain the research methodology, a flow chart is presented in Figure 1.

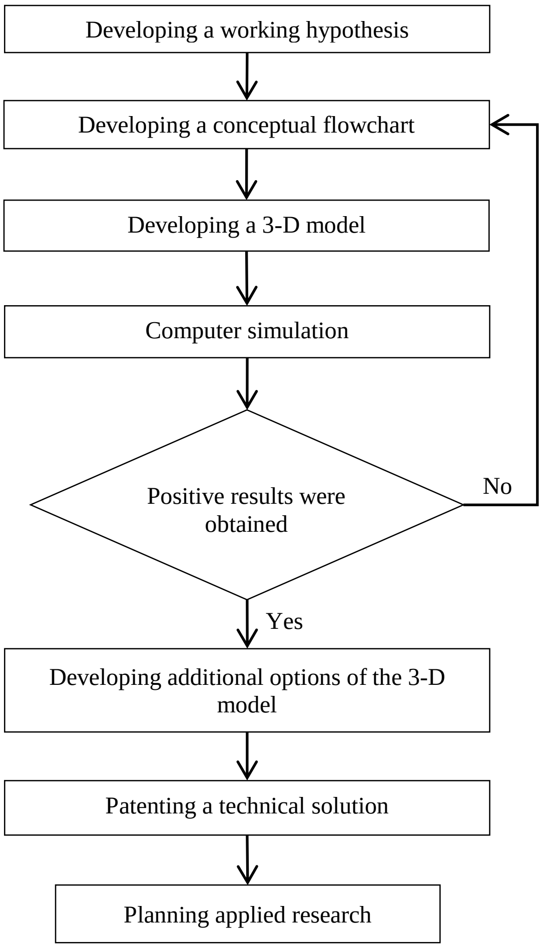


Figure 1. A flowchart explaining the research methodology

In accordance with the flowchart (Figure 1), the methodology involves developing a working hypothesis in the field of jet technology. The need to develop such hypotheses is due to the fact that new scientific information has appeared that radically changes the opinion about the technical capabilities of nozzle devices, in particular, and jet devices in general. We are talking about an ejection process using a controlled nozzle to deflect the thrust vector (velocity vector) in any direction within the full geometric sphere. The main concept is related to the study of gas-dynamic and hydrodynamic processes in the channels of jet systems of any complexity. Scientific research and design work are conducted within the framework of the progression of Euler's ideas. A patentable circuit diagram is being developed. Based on this scheme, three-dimensional (3D) models with control systems are developed. Next, computer modeling is performed based on the developed three-dimensional models. The results are analyzed, and if positive results are obtained after computer modeling, they proceed to create a series of 3D models. Next, new technical solutions are patented. Plans are being developed for developing applied scientific research.

When carrying out research and development work [1-4], an interdisciplinary approach and proven methodology were used. Within the framework of this methodology, the entire set of work processes implemented in channels during the flow of gases, liquids, and other fluids is systematically considered. First of all, the possibility of creating computerized ejection processes is assessed when developing special equipment for advanced oil and gas production technologies. In accordance with modern trends in science and technology, a transition to advanced digital, intelligent manufacturing technologies using machine learning and artificial intelligence is also planned. In accordance with modern trends in science and technology, various ejection thrust amplifiers and control systems for unmanned vehicles for various purposes (for instance, unmanned vehicles for mineral exploration and for performing search and rescue operations) are also considered. This paper discusses issues related to the development of jet technology and the further progression of Euler's ideas. To achieve this goal, we plan to use the scientific groundwork, namely: published articles and patented technical solutions (RF patent No. 2781455, RF patent No. 214452 and RF patent No. 2778961), available to the authors of the paper [1-4].

Due to the increasing complexity of modern scientific problems, it is advisable to use an additional tool in the form of a transdisciplinary approach. To assess complex processes and phenomena, they are examined from various perspectives. A transition is made from the general to the specific within the framework of deductive logic. Individual reasoning is carried out within the framework of inductive logic when a general conclusion is built on the basis of particular premises and a generalizing statement is derived. The principle of reduction is used, as the reduction of the complex to the simple and the whole to the properties of the parts.

We also rely on the philosophy of technology [47] and the theory of solving inventive problems [48]. We do not exclude the possibility of practical use of the results of holistic forecasting [49].

3. Results

3.1. Development of Conceptual Flowcharts for Advanced Jet Technology

As part of ongoing research, new approaches to the creation of jet technology are considered. Prepared for patenting, the technical solution under development is related to the field of jet technology. A variety of applications are considered, including jet pumps and compressors, jet amplifiers with control systems, and jet propulsion systems for dynamic positioning systems with thrust vector control. The invention can be used, inter alia, in the oil and gas industry to improve the efficiency of technologies in the production and processing of hydrocarbons, in the development of offshore fields with underwater placement of process equipment.

Among the known technical solutions, the closest to the proposed one is a jet pumping unit containing sources of a working fluid and a pumped fluid, a jet pump equipped with a system of nozzles hydraulically connected in parallel and placed at the inlet to the working chamber with the formation of an annular channel. The source of the working fluid is hydraulically connected to the inlets of the nozzles, and the sources of the pumped fluid are hydraulically connected to the annular channel [4]. The disadvantage of this technical solution is the relatively narrow range for regulation of the operating parameters of the flow at the outlet of the working chamber. This limits the scope of application of such a jet unit.

Expanding the range of operating parameters of the flow at the working chamber outlet is a technical problem to be solved by the proposed technical solution. This problem is solved by the jet unit containing sources of working and pumped fluids, a jet apparatus equipped with a system of nozzles hydraulically connected in parallel and mounted at the inlet to the working chamber forming an annular channel, in which U-shaped pockets are located and inlet channels isolated from each other are formed in them. One nozzle is installed in each of the inlet channels, which hydraulically connect the working chamber with the sources of the pumped fluid through shut-off control devices, while the source of the working fluid is connected to the inlets of the nozzles through a hydraulic distributor. Multidirectional outlet channels are made in the working chamber, each of which communicates with a separate inlet channel, ensuring the supply of a mixture of the working and pumped fluids from the periphery to the center of the working chamber.

The achieved technical result consists in providing a controlled redistribution of the flow energy over the area of the outlet channel in the working chamber. It is possible to adjust the parameters of the flow momentum and the velocity distribution curve in the cross-section at the outlet of the working chamber with simultaneous creation of conditions for controlling the thrust vector within the geometric hemisphere or within a complete geometric sphere.

The essence of the developed jet unit is illustrated by the following figures: Figure 2 shows a diagram of the jet unit; Figure 3 shows the A-A section; Figure 4 shows a diagram of a jet unit with a central nozzle; Figure 5 shows a three-dimensional computer model of the working chamber (option); Figure 6 shows a three-dimensional computer model of the working chamber (option), where solid impermeable walls are demonstrated using a computer effect of “transparency”, which helps in describing the structure; Figure 7 shows a three-dimensional computer model of the working chamber (section showing half of the detail), where solid impermeable walls are shown using a computer effect of “transparency”; Figure 8 shows the results of computer simulation (CFD) – a range of velocities for conditions with uniform distribution of gas over the outlet channels of the working chamber; Figure 9 shows the results of computer simulation (CFD) – a range of velocities for conditions with non-uniform distribution of gas over the outlet channels of the working chamber; Figure 10 shows the results of computer simulation (CFD) – a range of velocities for conditions with an uneven distribution of gas over the outlet channels of the working chamber, for an option of a jet unit using a central nozzle.

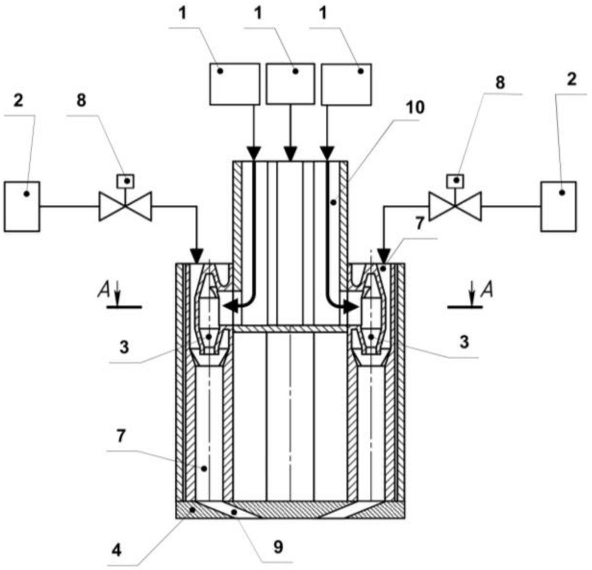


Figure 2. A diagram of the jet unit

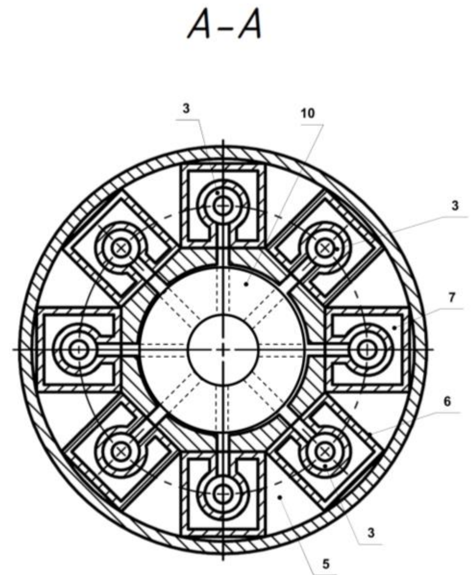


Figure 3. A diagram of the jet unit – the A-A section

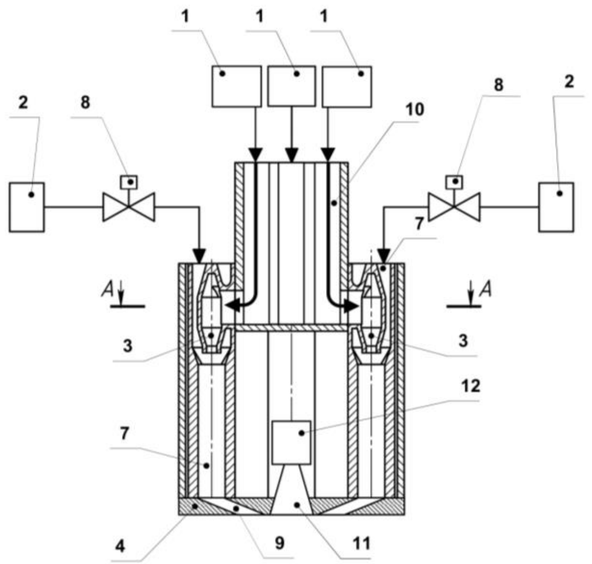


Figure 4. A diagram of the jet unit with a central nozzle

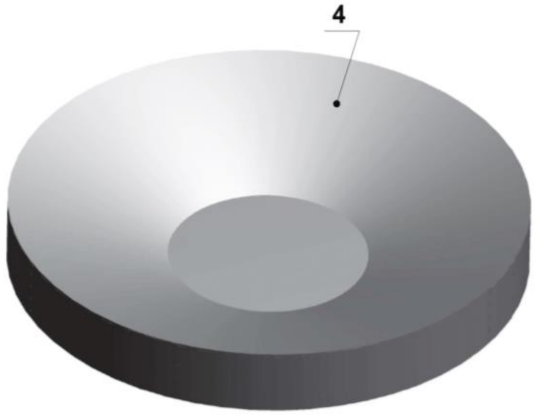


Figure 5. A three-dimensional computer model of the working chamber (option)

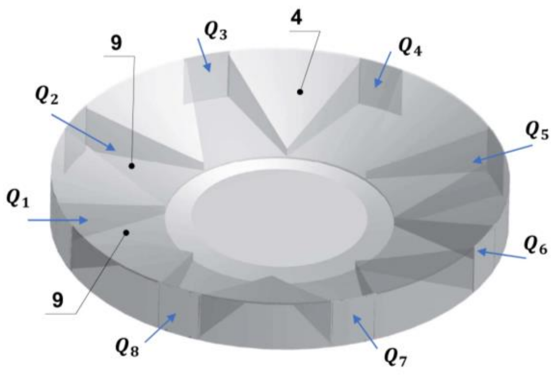


Figure 6. A three-dimensional computer model of the working chamber (option), where solid impermeable walls are demonstrated using a computer effect of "transparency".

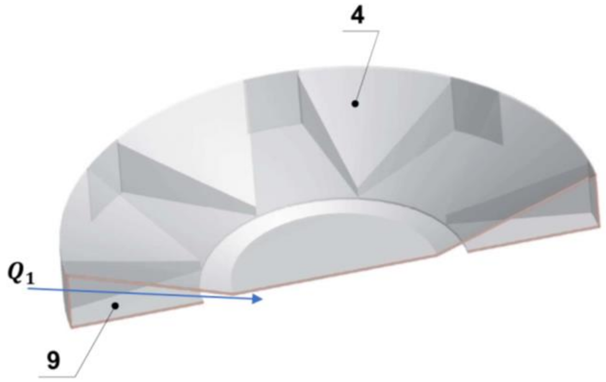
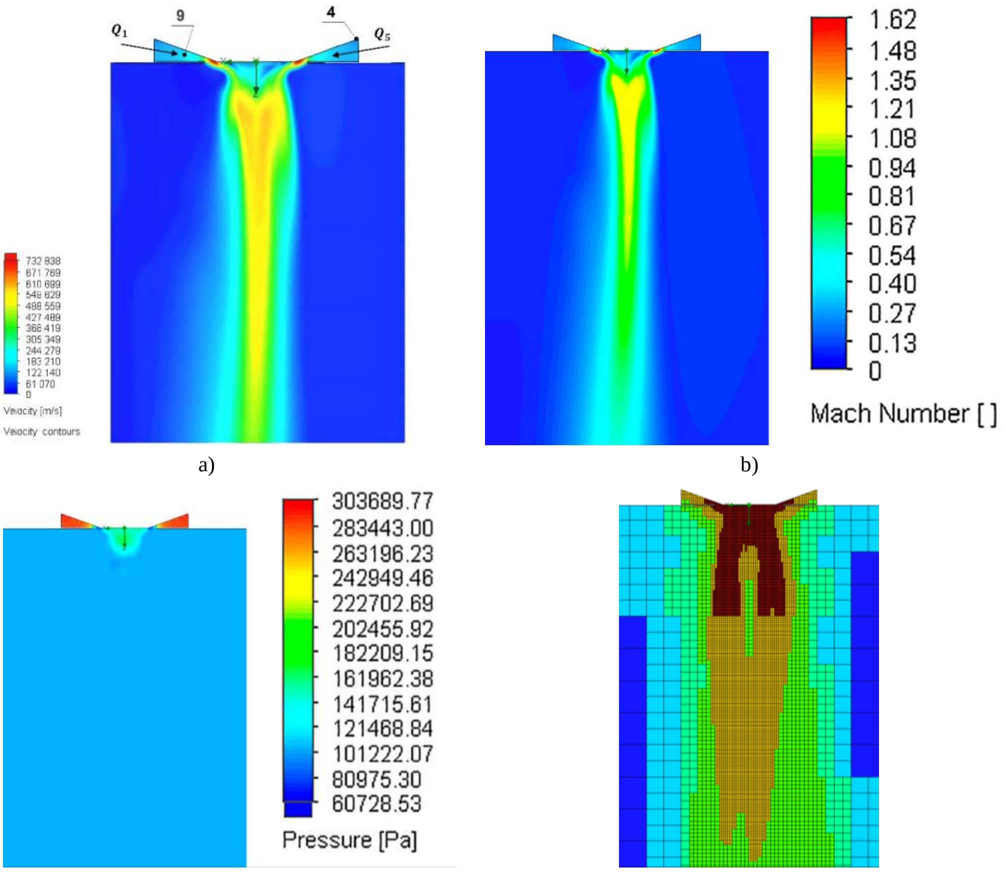


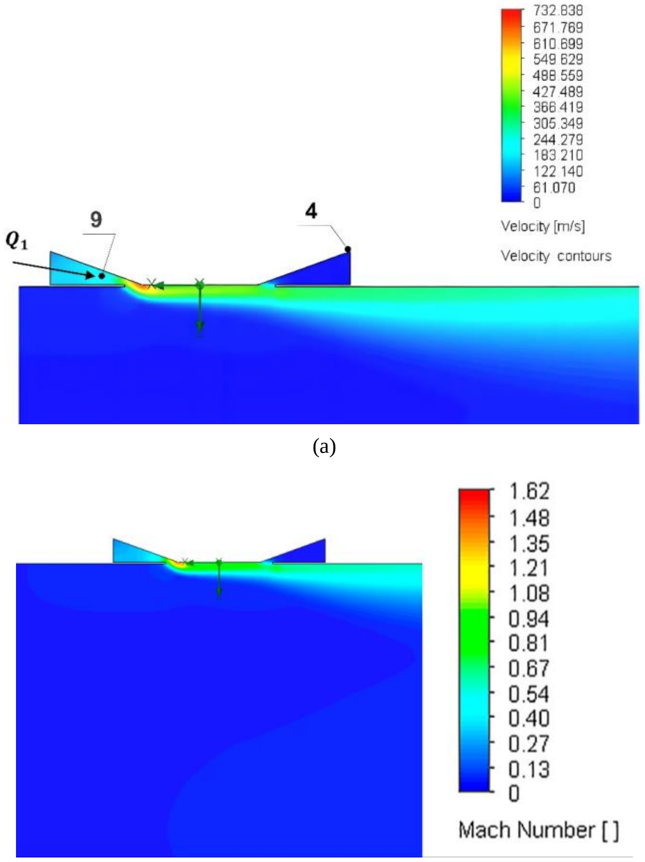
Figure 7. A three-dimensional computer model of the working chamber (section demonstrating half of the detail), where solid impermeable walls are shown using a computer effect of "transparency".



a) b)

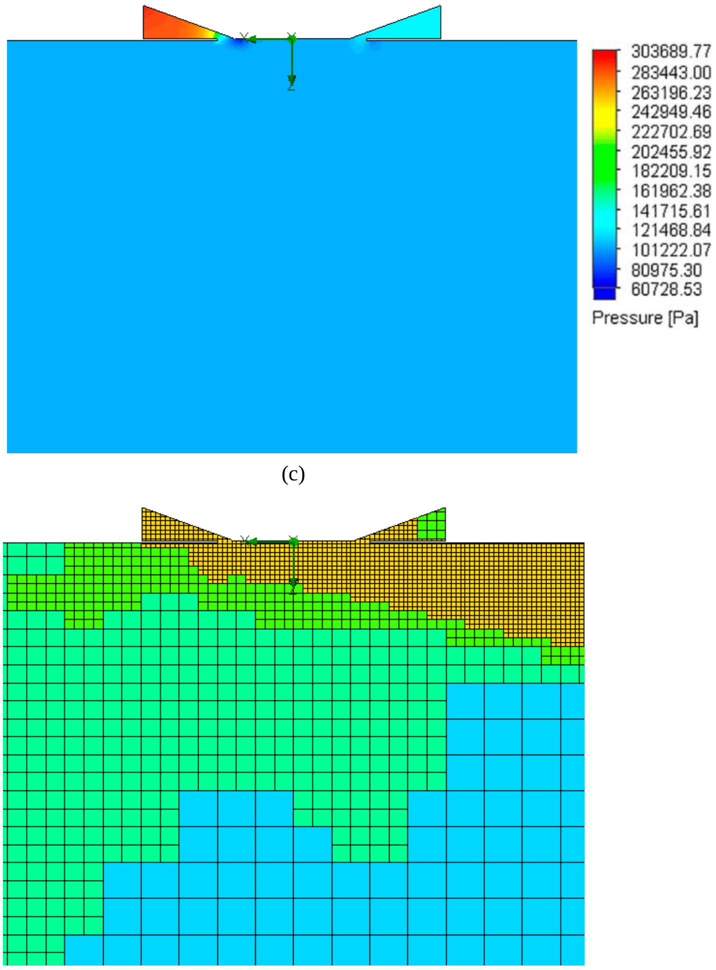
c) d)

Figure 8. Computer simulation results under conditions of uniform gas distribution along the outlet channel of the working chamber (an example): a) velocity; b) Mach number; c) pressure; d) calculation grid



(a)

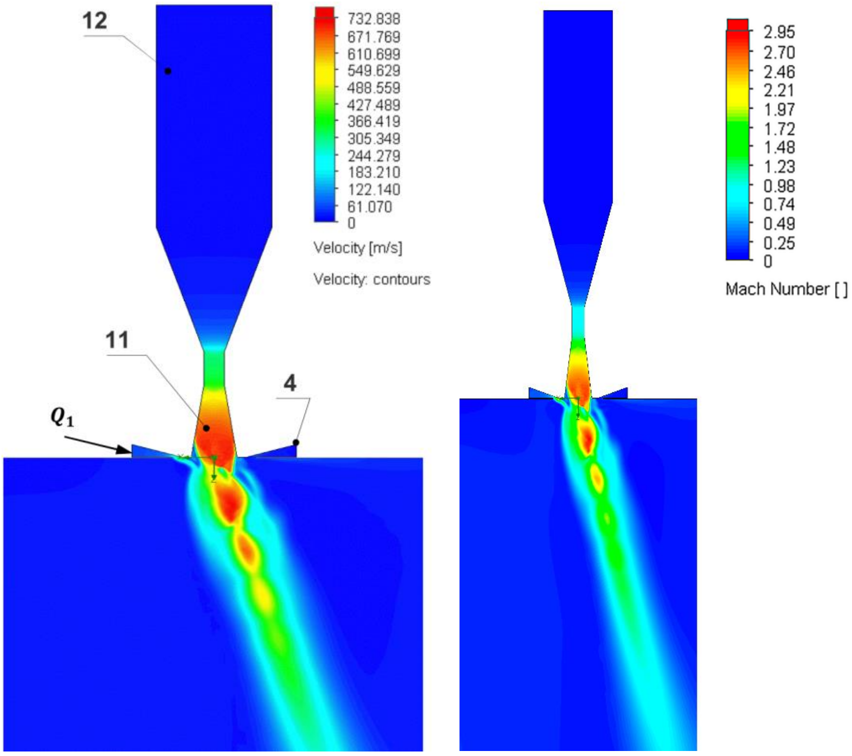
(b)



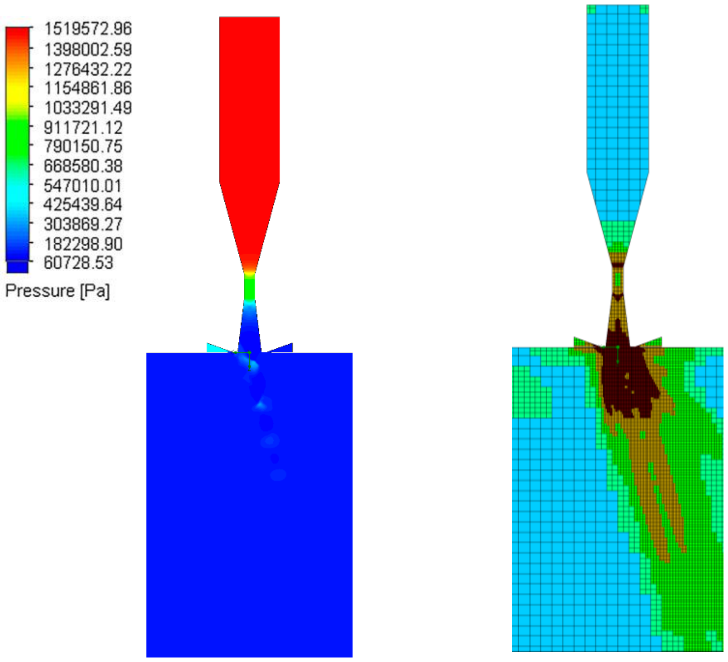
(c)

(d)

Figure 9. Results of computer simulation for conditions with non-uniform distribution of gas over the outlet channels of the working chamber (an example): a) velocity; b) Mach number; c) pressure; d) calculation grid



a) b)



c) d)

Figure 10. Results of computer simulation for conditions with non-uniform distribution of gas over the outlet channels of the working chamber for a jet unit using a central nozzle (an example): a) velocity; b) Mach number; c) pressure; d) calculation grid.

At the stage of patenting a new technical solution, the purpose of computer simulation (CFD) is only to confirm the operability of the design being developed. More detailed calculations and solutions to optimization problems are planned to be carried out later – at the stage of developing a preliminary design and technical design. The Flow Simulation (FloEFD) software package was used for computer simulation and computational study (CFD). In the modeling process, the complete system of Navier–Stokes equations was solved, which is described by mathematical expressions for the laws of conservation of mass, energy, and momentum. By default, the turbulence parameters were set automatically. To calculate the turbulent parameters for closing the Navier–Stokes equation system, the turbulent viscosity model “$k - \varepsilon$” was applied. During the computer simulation, the computational grid was automatically adapted.

The gas (air) pressure at the inlet in all channels 9 (exemplified in Figure 8) is 303,975 Pa at a gas temperature of 500°C. The gas (air) pressure of the environment is 101,325 Pa at a gas temperature of 20°C. Total cells: 853,403. Computation time: 24,534 s. Number of iterations: 1,500.

The gas (air) pressure at the inlet in all channels 9 (exemplified in Figure 9) is 303,975 Pa at a gas temperature of 500°C. The gas (air) pressure of the environment is 101,325 Pa at a gas temperature of 20°C. Total cells: 830,302. Computation time: 25,246 s. Number of iterations: 1,500.

The gas (air) pressure at the inlet in central nozzle 11 (exemplified in Figure 910) is 1,519,875 Pa at a gas temperature of 2000°C. The gas (air) pressure at the inlet in channel 9 (exemplified in Figure 10) is 506,625 Pa at a gas temperature of 500°C. The gas (air) pressure of the environment is 101,325 Pa at a gas temperature of 20°C. Total cells: 855,877. Computation time: 23,952 s. Number of iterations: 1,500.

The proposed jet unit (Figures 2 to 10) contains one or more sources of the working fluid 1, sources of the pumped fluid 2, and a jet apparatus equipped with a system of nozzles 3 hydraulically connected in parallel and mounted at the inlet to the working chamber 4 to form an annular channel 5. The source of working fluid 1 is hydraulically connected to the inlets of nozzle 3. In annular channel 5, there are pockets 6 with the formation of supply channels 7 isolated from each other, in each of which one of the nozzles 3 is installed, and which hydraulically connect the working chamber 4 with the sources of the pumped medium 2 through shut-off control devices 8. In working chamber 4, multidirectional output channels 9 are made, each of which communicates with a separate inlet channel 7.

The working fluid source or sources 1 through hydraulic distributor 10 are connected to the inlets of nozzle 3. The distribution of the working fluid over nozzle 3 can be uniform or non-uniform, depending on the technological problem being solved. With such regulation, the working fluid flow can also be directed to any one nozzle 3. Hydraulic distributor 10 can be structurally made with any number of hydraulic lines (two-way, three-, four- and multi-way) and with different shut-off elements (spool, valve, crane or jetones).

Working chamber 4 and outlet channel 9 can have different designs and geometric shapes, and these shapes determine the direction of the flows at the outlet of each outlet channel 9. The flows leaving through these channels 9 can be directed mainly along a flat surface, a cylindrical surface, a conical surface, or any curved surface, depending on the technical problem being solved.

For instance, Figure 4 shows an embodiment of a jet unit with a central nozzle 11. In the central part of working chamber 4, central nozzle 11 (or a group of nozzle devices) connected to working fluid source 12 can be installed. Working fluid source 12 can be hydraulically connected to working fluid source 1 (such a hydraulic connection is not shown in the figures). When working fluid source 12 is turned off, the jet unit operates in accordance with the scheme shown in Figure 1.

In the cross section, working chamber 4, inlet channels 7, and nozzle 3 may have the shape of a square or a triangle, or other non-traditional shape. A pair of elements, nozzle 3 and supply channel 7, form a classic jet apparatus. In inlet channel 7, the working fluid is mixed with the pumped fluid and an ejection working process is implemented, in which part of the energy from the working fluid flow is transferred to the pumped fluid flow. The flow channels in the group of nozzles 3 and in the group of supply channels 7 can form a mesh structure or grid. A mesh is the representation of a larger geometric area into smaller, discrete cells. For instance, large nozzles are replaced with a set of smaller nozzles that are interconnected to form flow channels in the form of a mesh structure.

The jet unit can be designed in the way that working chamber 4 is cylindrical, and each multidirectional outlet channel 9 provides the possibility of supplying a mixture of the working and pumped fluids in the direction from the periphery to the center of working chamber 4 (Figures 2-4).

The jet unit can be designed so that multidirectional outlet channels 9 of working chamber 4 and individual pumped fluid sources 2 communicate with the surrounding air under conditions of changing properties of atmospheric air at different heights. In this case, atmospheric air enters from the environment into pumped fluid source 2 and then through shut-off control device 8 into supply channel 7. Pumped fluid source 2 may contain a compressor or other device to increase the pressure of the pumped fluid, in this case, to increase the air pressure.

The jet unit can be designed so that multidirectional outlet channels 9 of working chamber 4 and individual pumped fluid sources 2 communicate with the surrounding water environment under conditions of changing properties of sea (river) water at different depths. In this case, water flows from the environment into pumped fluid source 2 and then through shut-off control device 8 into supply channel 7. Pumped fluid source 2 may contain a pump or other device to increase the pressure of the pumped fluid, in this case, the water pressure.

3.2. Description of the Operational Concept of the Jet Unit

The jet unit works as follows. Working fluid source (sources) 1 supplies the working fluid to nozzles 3 located at the inlet of working chamber 4. The pumped fluid from pumped fluid source 2 is supplied to annular channel 5 and further to the working fluid jet, passing through supply channels 7 isolated from each other, which hydraulically connect working chamber 4 with pumped fluid source 2. The pumped fluid starts to be mixed with the working fluid in supply channels 7 isolated from each other, since nozzle 3 is made into a multichannel system of nozzles hydraulically connected in parallel, and each nozzle 3 is mounted in a separate insulated inlet channel 7, which communicates with pumped fluid source 2 through a separate shut-off control device 8. Further, the flows from inlet channel 7 are directed through outlet channel 9 to the outlet of working chamber 4. In working chamber 4, the working and pumped fluids are mixed partially or completely, depending on the technological problem being solved. Liquid or gas, or gas-liquid mixture with different ratios of components can be the working and pumped fluids. From the outlet of working chamber 4, the mixture of the working and pumped fluids enters further into the production line to the consumer’s intake (the production line is not shown in the figures).

Using several shut-off control devices 8 in supply channels 7 isolated from each other, it is possible to provide various flow regimes: stationary or non-stationary, including various options for pulsed flow regimes. The distribution of the pumped fluid through supply channels 7 may be uniform or non-uniform, depending on the technological problem being solved. With such regulation, the pumped fluid flow can also be directed to any one inlet channel 7. The proposed technical solution makes it possible to control the flows of the working and pumped fluids by providing the required conditions for the outflow at the outlet of working chamber 4. The distribution of the flow velocity at the outlet of working chamber 4 can be uniform or non-uniform. The flow rate at individual points at the outlet of working chamber 4 can be constant over time or variable, depending on the technological problem being solved. It is known from the theory of jet apparatuses and the state of the art that with the gradual closing of the flow channel in shut-off control device 8, the mass flow rate of the pumped fluid is reduced to zero, which entails a gradual, stepless decrease in the flow velocity in inlet channel 7 and outlet channel 9. In a particular case, at zero flow rates of the pumped fluid, only the working fluid from nozzle 3 enters through outlet channel 9. Such interconnection of the control processes along with the mesh structure of the channels can be used to control the thrust vector in various jet systems. Shut-off control devices 8 can be controlled remotely and combined into a single digital control system that operates in accordance with a specific computer program, considering the specifics of the technological problem being solved.

The combination of hydraulic distributor 10 with shut-off control devices 8 makes it possible to flexibly adjust the direction of the mixed flow of the working and pumped fluids within the lower geometric hemisphere, as shown in Figures 8, 9, and 10. With this regulation, the mixed flow can be directed to one outlet channel 9, into two channels 9, or into three such channels. The distribution of the working-pumped-fluid mixture through the output channels 9 may be uniform or non-uniform, depending on the technological problem being solved.

Figure 5 shows a 3D computer model of working chamber 4 (option), and Figure 6 shows the same 3D computer model of the working chamber, but here the solid impermeable walls are shown with the use of a computer effect of "transparency", which helps in describing the design. An example is considered in which eight output channels 9 through which flows with mass flow rates of fluids (a working-pumped-fluid mixture) pass for eight channels Q_1, Q_2, Q_3, Q_4, Q_5, Q_6, Q_7, Q_8, respectively. In this example, multidirectional outlet channels 9 of working chamber 4 and separate pumped fluid sources 2 communicate with the surrounding air (in conditions of changing atmospheric air properties at different heights). For this example (according to Figures 5 and 6), Figure 8 shows the results of the computer simulation, demonstrating the range of speeds for conditions with a uniform distribution of gas through outlet channels 9 of working chamber 4. The total flow is directed strictly from top to bottom, and respectively, the thrust vector (vector of the resulting reactive force) is directed from bottom to top, perpendicular to the horizontal plane. In addition, other examples can be considered, where multidirectional outlet channels 9 of working chamber 4 and individual pumped fluid sources 2 communicate with the surrounding aquatic environment (in conditions of changing of sea (river) water properties at different depths).

Figure 7 shows a three-dimensional computer model of working chamber 4 (section showing half of the detail), where solid impermeable walls are shown with the applied computer-generated "transparency" effect. An example is considered in which a gas flow with a mass flow rate Q_1 passes through only one of eight channels 9. In the remaining channels 9 in this example, the mass flow parameters have zero values. Figure 9 shows the results of the computer simulation based on the developed three-dimensional model (according to Figure 7), and shows a range of velocities for conditions with uneven distribution of gas through outlet channels 9 of working chamber 4. In this example, multidirectional outlet channels 9 of working chamber 4 and individual pumped fluid sources 2 communicate with the surrounding air (in conditions of changing atmospheric air properties at different heights). The total flow is directed from left to right, and respectively, the thrust vector (the vector of the resulting reactive force) is directed from right to left along the horizontal plane. In addition, other examples can be considered, where multidirectional outlet channels 9 of working chamber 4 and individual pumped fluid sources 2 communicate with the surrounding aquatic environment (in conditions of changing sea (river) water properties at different depths).

Figure 10 shows the results of the computer simulation based on the developed three-dimensional model (according to Figure 4), demonstrating the range of velocities for conditions with non-uniform gas distribution over outlet channels 9 of working chamber 4 for the jet unit option with a central nozzle 11 connected to the working fluid source 12. In this example, multidirectional outlet channels 9 of working chamber 4 and individual pumped fluid sources 2 communicate with the surrounding air.

The mesh structure of the channels also makes it possible to reduce the dimensions and weight of the product with the activation of heat exchange processes.

The proposed technical solution enables the process of controlling the flows of hot gasses to be organized, while the moving parts of shut-off control devices 8 can work reliably in a cold pumped fluid (for instance, in cold ambient atmospheric air, or in cold ambient water environment). Furthermore, the control of high-speed flows and the thrust vector will not require the use of any moving parts that come into contact with aggressive hot gases at the outlet of nozzles 3 and 11, which increases the reliability of the jet unit as a whole.

The proposed technical approach ensures a systematic distribution of flow energy across individual sections at the exit from working chamber 4, which makes it possible to correct the diagrams of momentum and velocity in the cross section, thereby providing conditions for controlling the thrust vector within the geometric hemisphere. Thrust vector control is possible within the entire geometric sphere by using two proposed water-jet installations in tandem configuration. Options for applying more complex technical systems using three (or more) jet units are possible, while expanding the technical capabilities for controlling the thrust vector or the flows of gases, liquids, and gas–liquid mixtures. The developed technical solution has been prepared for patenting, and an application for invention No. 2023114597 has been officially registered.

4. Discussion

- **Discussion of the conceptual flowchart of the Euler turbine and opportunities to use and develop Euler's scientific and design ideas**

In the field of the history of turbines, materials from the correspondence between Leonhard Euler and Janos-Andros Segner have been partially preserved [50]. As it is known, Leonard Euler proposed to jointly consider the rotating part (turbine rotor) and the stationary part (turbine nozzle) at the system level [50, 51]. In addition, Leonhard Euler proposed the use of curved S-shaped pipes to form the flow part of a hydraulic machine, both when creating a rotor and a nozzle apparatus.

Many of Euler's ideas on the creation of hydraulic machinery are reflected in correspondence with Segner [50]. In this correspondence, one can find most of the essential recommendations suitable for the design of promising turbines and other blade machines. Euler's ideas and his theory were used earlier and are still actively used in the design of various jet and turbomachine devices. It can be stated that during his lifetime, Euler predicted the future for many centuries ahead and created a scientific basis for this future in the spirit of holistic forecasting and foresight research. As they often say now, the best way to predict the future is to create it. After a slight transformation, the phrase from a contemporary work of 2010 [52] can be used: the term "foresight" itself was coined recently, and before that, Euler did not understand that he was already engaged in foresight, and predicted and created the future with his work.

Analyzing the legacy of this great scientist [50], we can consider in more detail the variant of the Euler turbine presented in Figures 11 to 13. The figures schematically show only one of several channels of the rotor and a channel of the fixed nozzle. It can be logically understood that a compact arrangement of a group of channels (representing a group or set of curved Eulerian tubes) is sufficient to form a flow path similar to that of modern wing machines. For clarity, some important (basic) points are shown in the diagram with corresponding numbers: 1-nozzle flow inlet channel; 2-nozzle flow outlet channel; 3-rotor inlet channel; 4-rotor outlet channel.

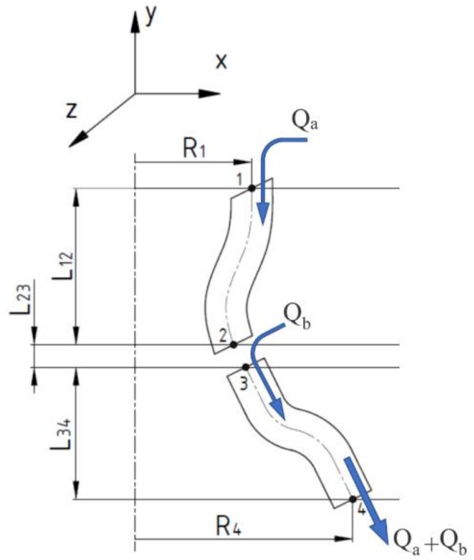


Figure 11. Euler turbine schematic (basic version)

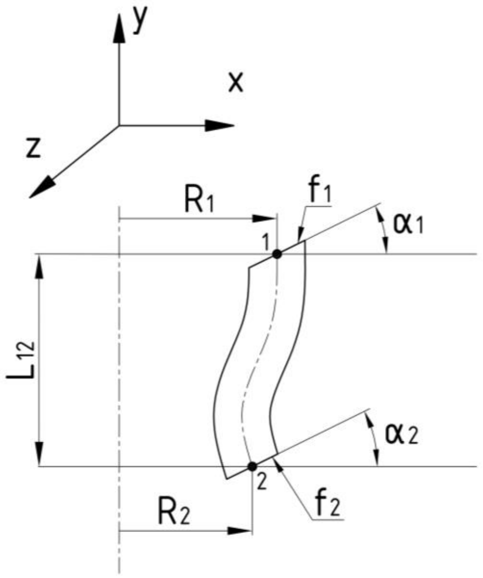


Figure 12. Nozzle apparatus schematic for the Euler turbine (basic version)

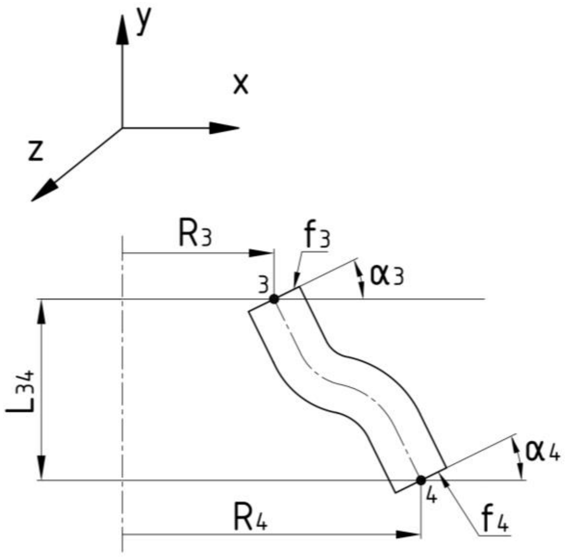


Figure 13. Rotor schematic of Euler turbine (basic version)

The following conventions have been adopted for basic geometric dimensions and basic points (with the corresponding numbers 1-4) in Figures 11 to 13:

- The average radius at the inlet of the nozzle (guide) apparatus R_1 corresponds to point 1; the average radius at the outlet of the nozzle apparatus R_2 corresponds to point 2; the average radius at the rotor inlet R_3 corresponds to point 3; and the average radius at the rotor outlet R_4 corresponds to point 4;
- f_1 is cross-sectional area of the channel at the inlet of the nozzle apparatus; f_2 – cross-sectional area of the channel at the outlet of the nozzle apparatus; f_3 – cross-sectional area of the channel at the rotor inlet; f_4 – cross-sectional area of the channel at the rotor outlet;
- $\propto_1$ is an angle of inclination of the inlet section of the nozzle apparatus relative to the horizontal plane; $\propto_2$ – an angle of inclination of the outlet section of the nozzle apparatus relative to the horizontal plane; $\propto_3$ – an angle of inclination of the inlet section of the rotor relative to the horizontal plane; $\propto_4$ – an angle of inclination of the outlet section of the rotor relative to the horizontal plane;
- L_{12} is linear dimension of the nozzle apparatus; L_{23}– linear dimension in the gap between the nozzle apparatus and the rotor; L_{34} – linear dimension of the rotor;
- Q_a is a mass flow rate of the working gas (or liquid) through the channel of the nozzle apparatus; Q_b – a mass flow rate of the pumped gas (or liquid) through the rotor channel; Q_{41} – a mass flow rate of the mixture of working and pumped gas through the first channel of the rotor; Q_{42} – a mass flow rate of the mixture of working and pumped gas through the second channel of the rotor; in the example in Figure 14, the following condition is accepted $Q_a + Q_b = Q_{41} + Q_{42}$.

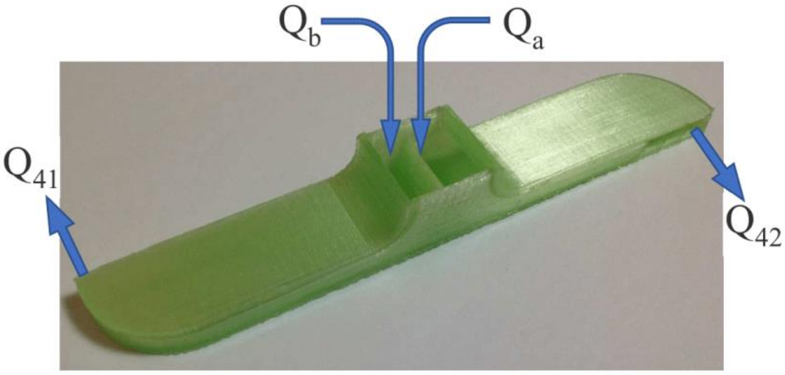


Figure 14. A micromodel of a rotor for Euler turbine (option)

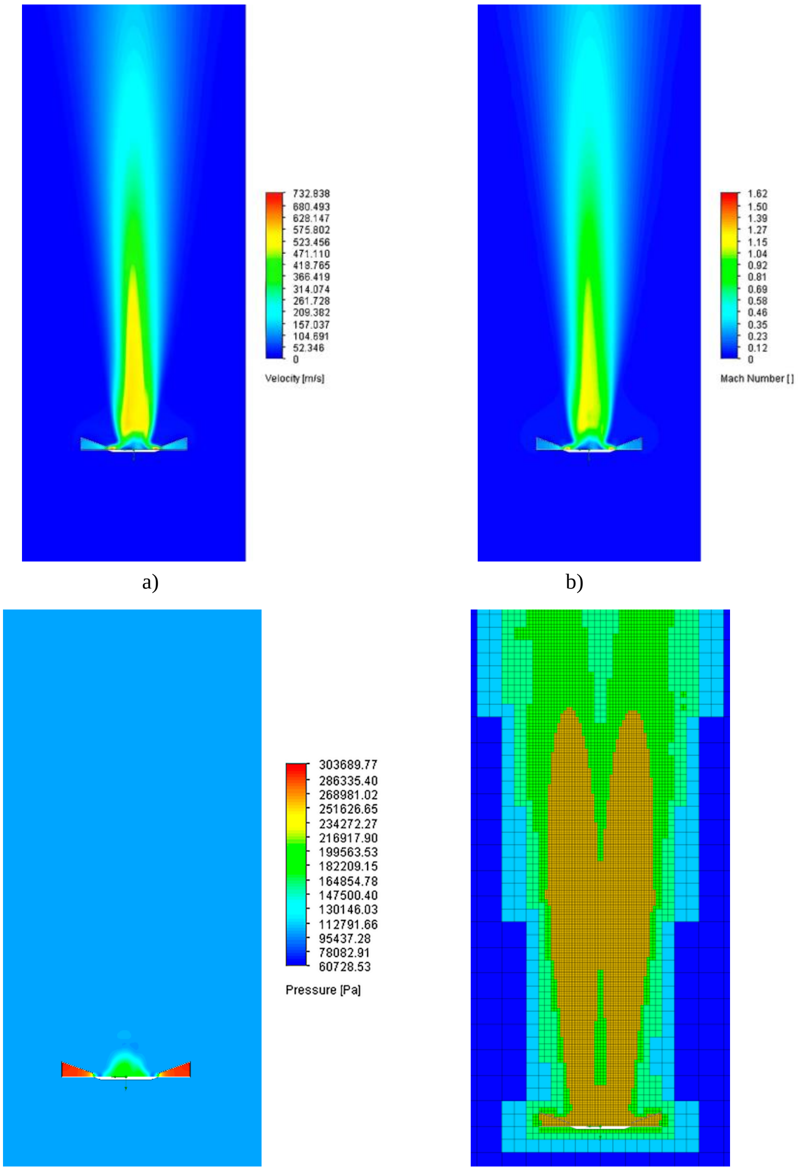
As noted, previous studies [1-4], the scientific groundwork prepared by Euler is far from being fully explored. Furthermore, there are large reserves for the further progression of Euler's ideas, including within the framework of hybrid systems together with ejection processes (when the parameter Q_b takes non-zero values, and the cross-sectional area of the channel at the nozzle outlet f_2 is less than the cross-sectional area of the channel at the rotor inlet f_3).

The scheme of the Euler nozzle apparatus (Figure 12) was used as the basis for the development of the jet unit, as shown in Figures 2-10. All outlet channels of the nozzle apparatus were oriented toward the center of the entire structure.

Figure 14 shows a photograph of a training micromodel of a rotor made using a 3D printer.

In this example (Figure 14), the working gas Q_a (either a liquid or a gas-liquid mixture) is fed into the center of the rotor. For this, the nozzle apparatus shown in Figures 2-10 can be used. When controlling the thrust vector, the working gas flow Q_a can be directed to the rotor channels according to Figure 14 or in any other direction, depending on the technical problem being solved. The pumped fluid Q_b enters the channels of the rotor from the surrounding space (according to Figure 14). In this example, two flows Q_{41} and Q_{42} are formed in the rotor channels. Preliminary tests of this micromodel confirmed various possibilities for converting the kinetic energy of a gas (liquid) flow into electrical energy. Such a turbine is also capable of rotating the propeller of a drone (an unmanned aerial vehicle during vertical takeoff and landing) in the thrust booster mode.

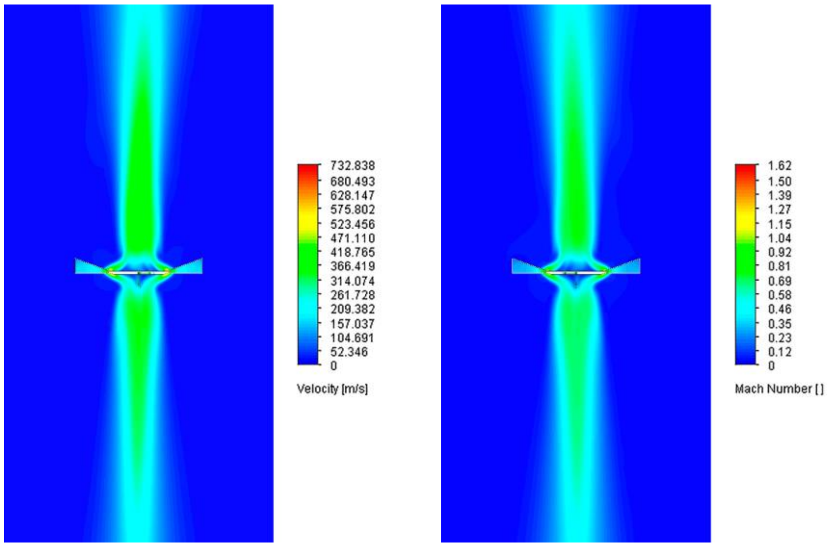
Figures 15 to 17, as an example, present the results of computer modeling for various variants of the nozzle apparatus described above. These examples consider options using a movable diaphragm located in the central part of the nozzle apparatus.



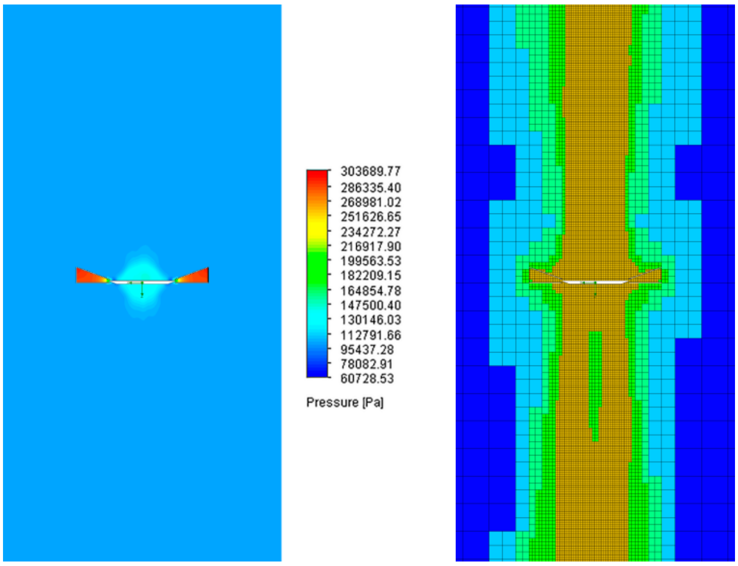
a) b)

c) d)

Figure 15. Results of computer simulation for conditions with uniform gas distribution along the outlet channels of the working chamber, the central diaphragm is in the lowest position: a) velocity; b) Mach number; c) pressure; d) calculation grid.

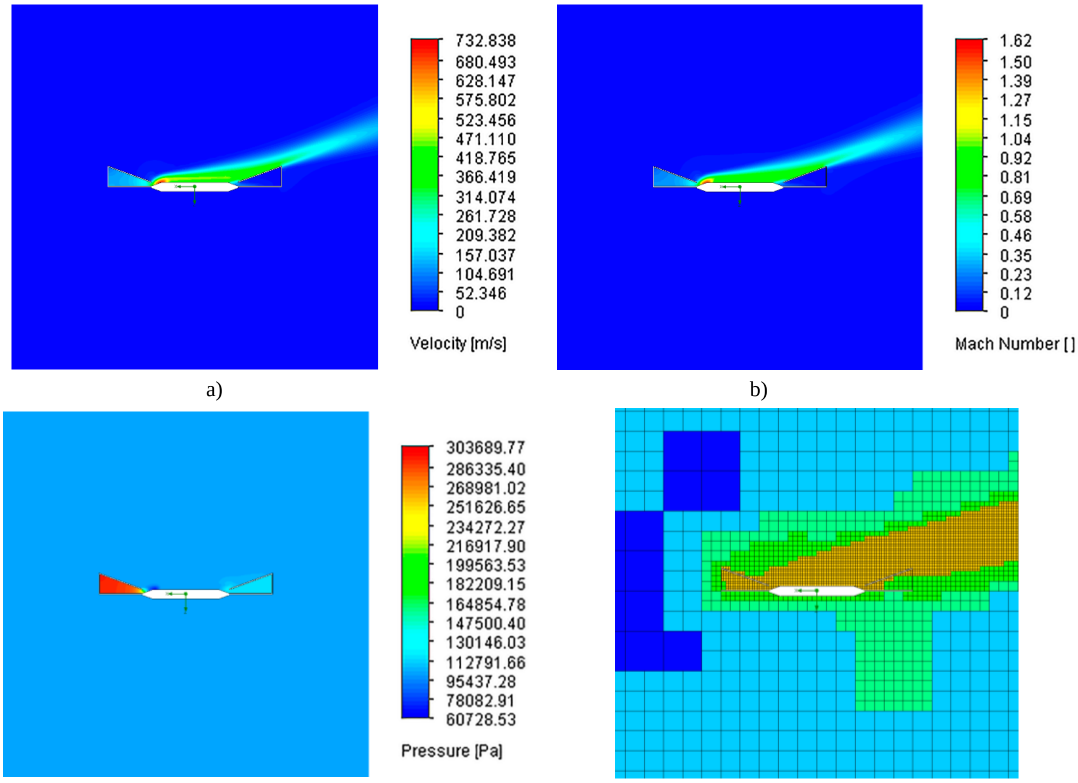


a) b)



c) d)

Figure 16. Results of computer simulation for conditions with uniform gas distribution along the outlet channels of the working chamber, the central diaphragm is in the middle position: a) velocity; b) Mach number; c) pressure; d) calculation grid.



a) b)

c) d)

Figure 17. Results of computer simulation for conditions when the central diaphragm (option) is in the lowest position and the working gas is supplied only to the channels on the left side of the nozzle apparatus: a) velocity; b) Mach number; c) pressure; d) calculation grid.

The pressure of the working gas (air) at the inlet is 303975 Pa at a gas temperature of 500 C, as shown in Figure 15. The pressure of the gas (air) in the environment is equal to 101325 Pa at a gas temperature of 20 C. Total cells: 896561. Calculation time: 23405 s. Number of iterations: 1500. As the calculations confirm, when using a movable diaphragm, a transition to thrust vector control in the full upper geometric hemisphere is possible.

The pressure of the working gas (air) at the inlet is 303975 Pa at a gas temperature of 500 C, as shown in Figure 16. The pressure of the gas (air) in the environment is equal to 101325 Pa at a gas temperature of 20 C. Total cells: 891186. Calculation time: 23155 s. Number of iterations: 1500. As confirmed by calculations, when using a movable diaphragm, it is possible to divide the working gas flows for simultaneous control of the thrust vector in the full geometric sphere. In this case, one part of the gas energy is used to control thrust in the upper hemisphere, and the other part is used to control thrust in the lower hemisphere.

The pressure of the working gas (air) at the inlet is 303975 Pa at a gas temperature of 500 C, as shown in Figure 17. The pressure of the gas (air) in the environment is equal to 101325 Pa at a gas temperature of 20 C. Total number of cells: 855565. Calculation time: 26035 s. Number of iterations: 1500. Figures 15 to 17 show examples of technical solutions, which, among other things, can be used to create hybrid unmanned vehicles that have the qualities of vertical take-off and landing vehicles, and at the same time the qualities of aircraft-type devices.

- **Discussion of the prospects for the development of Euler’s ideas, with the possibilities for creating multidimensional systems aimed at solving the most complex problems in the field of control systems**

The Euler machine shown in Figures 11 to 13 can have different versions, depending on the relationship between the basic geometric parameters. When training designers, it is reasonable to consider several issues. Curvilinear Euler pipes (including S-shaped pipes) can have different lengths and shapes, and can be easily adapted to the design of the final product, such as an aircraft. In this case, the aircraft (transport system) and the engine (engines and propulsion units) are considered as a single system (in a single complex) using particular (novel or special) optimization criteria. The energy density in curved Euler pipes can be high, which makes it possible to reduce the size and weight of the jet system as a whole.

Turning the flow in curvilinear pipes (including S-shaped pipes) entails energy losses (decrease in the values of parameters such as the momentum and reactive force). However, in such a pipe, for a certain period, a certain chemical reaction can proceed (and effectively proceeds) with the supply of additional energy to the working fluid in the flow. In the end, this can contribute to an increase in the total energy (an increase in the momentum, and reactive force) in the flow at the outlet of the jet system.

The diagrams and Euler’s correspondence [50] show the following processes. The fluid flow can be divided into several flows or several flows can be combined into one flow (according to Euler) - and this is the foundation for the creation of promising multi-flow jet devices. The jet of liquid (or other working fluid) changes its direction after it has flowed out of the nozzle (according to Euler) - and this is the foundation for creating thrust vector control systems for promising unmanned vehicles for various purposes. This may be determined by the action of gravity, but there may be other mechanisms influencing the flow (with the progression of Euler's ideas). One of the diagrams (according to Euler) shows a bent branch pipe at the nozzle outlet to ensure the flow rotation by 90° (in a particular case); however, the angle of rotation itself, as a parameter, can take on other values in the general case. At the rotor outlet in the Euler turbine, all pipes have curved sections to reverse the flow and create conditions for rotational movement, providing the appropriate torque and angular velocity of rotation.

The mass flow rate of the working fluid (working gas or liquid) is usually distributed uniformly over all rotor channels, but (with the progression of Euler's ideas) this distribution can also be non-uniform in the general case. The operation of the Euler turbine is considered in a limited range of velocities – from the maximum rotation velocity (at zero torque value) to the minimum rotation velocity equal to zero (at maximum torque value). However (with the progression of Euler's ideas), the range of variation of the indicated rotation velocities can be extended in the general case. Usually, the mode of operation at maximum efficiency in the framework of converting the kinetic energy of the fluid flow into mechanical energy on the turbine rotor shaft at the corresponding optimal rotation speed of the rotor is considered the determining, intended, and most efficient mode of operation for the turbine (including the Euler turbine).

However, in the general case (with the progression of Euler's ideas), the rotor velocity in such a machine can have a completely different optimal value if such a machine is used for a different purpose and when using a different optimization criterion, other than the turbine efficiency. The hydraulic machine developed by Euler can be used to solve many other technical problems in general (with the progression of Euler's ideas). The turbine mode of operation for the Euler hydraulic machine can be considered as a particular case. Obviously, when the rotor stops in the Euler hydraulic machine, the flows diverge in different directions. In this case, a special process of controlling such flows (thrust vector control) can open up new possibilities for controlling the resultant force vector and the resultant torque (with the progression of Euler's ideas). This, in turn, gives the designer the opportunity to solve problems in the field of jet logic and control systems for a variety of transport and propulsion systems (when working on land, on water and under water, or in the air with separate options for space engineering).

Following scientific research, two interrelated issues must be jointly considered: thrust vector control and provision of speed vector control in relation to a specific technical object. In this case, we consider a system containing several controlled nozzle devices that ensure the movement of a technical object in three-dimensional space with capabilities for linear and rotational movement relative to the basic axes in this space.

4.1. Some Generalizations

In the course of scientific research conducted in 2021 and 2022 [1-4], including patented technical solutions, scientific groundwork was prepared in the field of jet technology. Based on this scientific premise, in 2023 the question was raised about the possibility of forming a new scientific direction related to the use of ejection processes along with thrust vector control systems in extreme operating conditions within the complete geometric sphere (with the possibility of deflecting the thrust vector at an angle from +180° to -180°). The possibilities of creating a scientific and design school based on the legacy of Leonard Euler within the emerging scientific direction are shown. In the course of scientific research conducted in 2021 and 2022 [1-4], including patented technical solutions, a scientific foundation has been prepared in the field of inkjet technology. Energy, production, and processing of oil or gas are the scope of the results obtained. In some cases, the results can be used in the field of aviation and maritime transport systems.

The presented scientific article successfully addresses the main objectives of the project. First, it identifies promising avenues for advancing thrust vector control in jet systems. Additionally, it uncovers new possibilities for enhancing the design methodology of jet systems, particularly in relation to training modern designers. As a result, a novel approach has been suggested that harnesses Euler's principles and utilizes CFD technologies to tackle inventive challenges in gas dynamics and hydrodynamics.

5. Conclusions

5.1. Scientific Novelty of the Research Design

A new patentable jet unit was developed and presented, which makes it possible to control the thrust vector within a complete geometric sphere (when the thrust vector is capable of deviating to any angle in the range from +180° to -180°). The multivariance of such technical solutions indicates the possibility of creating a scientific and design school within the framework of the emerging scientific direction.

5.2. Theoretical Contribution

The direction for the development of the theory of solving inventive and engineering problems is proposed based on holistic forecasting, which is clearly visible in the scientific works of Leonard Euler. New opportunities for improving the methodology for designing jet devices and complex jet systems were identified as part of the training of modern designers-inventors.

5.3. Significance for Practice

The scope of application of the results obtained includes energy, oil and gas production, and processing (when controlling fluid flows with low or extremely high energy densities). Some results can be used in the field of aviation and marine thrust vector control systems or dynamic positioning systems (for instance, for unmanned vehicles for various purposes).

5.4. Limitations and Future Research

Limitations and difficulties in this research are associated with the multidimensionality of the jet systems studied in the field of gas dynamics and hydrodynamics. The development of research can be associated with the use of new tools, intelligent robots, and artificial intelligence. The development of research will be directed toward a comprehensive and systematic consideration of thrust vector control and in relation to a moving material point (within the framework of fundamental scientific research) or in relation to a moving unmanned vehicle (within the framework of applied scientific research).

6. Declarations

6.1. Author Contributions

Conceptualization, Y.A.S.; methodology, M.A.M.; software, E.I.K.; validation, K.A.T.; formal analysis, V.V.V.; investigation, K.A.T.; resources, Y.A.S.; data curation, I.V.G.; writing—original draft preparation, K.A.T.; writing—review and editing, Y.A.S.; visualization, E.I.K.; supervision, M.A.M.; project administration, M.A.M.; funding acquisition, Y.A.S. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] Sazonov, Y. A., Mokhov, M. A., Gryaznova, I. V., Voronova, V. V., Tumanyan, K. A., Frankov, M. A., & Balaka, N. N. (2021). Development and prototyping of jet systems for advanced turbomachinery with mesh rotor. Emerging Science Journal, 5(5), 775–801. doi:10.28991/esj-2021-01311.

[2] Sazonov, Y. A., Mokhov, M. A., Gryaznova, I. V., Voronova, V. V., Tumanyan, K. A., Frankov, M. A., & Balaka, N. N. (2022). Designing Mesh Turbomachinery with the Development of Euler's Ideas and Investigating Flow Distribution Characteristics. Civil Engineering Journal (Iran), 8(11), 2598–2627. doi:10.28991/CEJ-2022-08-11-017.

[3] Sazonov, Y. A., Mokhov, M. A., Gryaznova, I. V., Voronova, V. V., Tumanyan, K. A., Frankov, M. A., & Balaka, N. N. (2022). Computational Fluid Dynamics (CFD) Simulation of Mesh Jet Devices for Promising Energy-Saving Technologies. Civil Engineering Journal (Iran), 8(12), 2749–2767. doi:10.28991/CEJ-2022-08-12-06.

[4] Sazonov, Y. A., Mokhov, M. A., Tumanyan, K. A., Frankov, M. A., & Balaka, N. N. (2020). Prototyping mesh turbine with the jet control system. Periódico Tchê Química, 17, 1160-1175. doi:10.52571/ptq.v17.n36.2020.1176_periodico36_pgs_1161_1175.pdf.

[5] Morozov, A. V., Nazarov, E. A., & Pokotilo, S. A. (2022). The patent for invention No. 2777459 of the Russian Federation. Method of creating aerodynamic forces on an aircraft wing and a device for its implementation. Moscow, Russia.

[6] Friedmann, G. (1952). US Patent 2623474. Injection mixer. United States Patent Office, Alexandria, United States.

[7] Wheatley, M. J. (1997). Apparatus for energy transfer. UK Patent Application, GB No: 2310005, London, United Kingdom.

[8] Jing, Q., Xu, W., Ye, W., & Li, Z. (2022). The Relationship between Contraction of the Ejector Mixing Chamber and Supersonic Jet Mixing Layer Development. Aerospace, 9(9), 469. doi:10.3390/aerospace9090469.

[9] Tatarkanov, A. A. B., Alexandrov, I. A., & Olejnik, A. V. (2020). Evaluation of the contact surface parameters at knurling finned heat-exchanging surface by knurls at ring blanks. Periodico Tche Quimica, 17(36), 372-389. doi:10.52571/ptq.v17.n36.2020.387_periodico36_pgs_372_389.pdf.

[10] Yan, J., Shu, Y., Jiang, J., & Wen, H. (2023). Optimization of Two-Phase Ejector Mixing Chamber Length under Varied Liquid Volume Fraction. Entropy, 25(1), 7. doi:10.3390/e25010007.

[11] Aidoun, Z., Ameur, K., Falsafioon, M., & Badache, M. (2019). Current advances in ejector modeling, experimentation and applications for refrigeration and heat pumps. Part 1: Single-phase ejectors. Inventions, 4(1), 15. doi:10.3390/inventions4010015.

[12] Azarova, O. A. (2023). High Speed Flows. Fluids, 8(4), 109. doi:10.3390/fluids8040109.

[13] Resta, E., Marsilio, R., & Ferlauto, M. (2021). Thrust vectoring of a fixed axisymmetric supersonic nozzle using the shock-vector control method. Fluids, 6(12), 441. doi:10.3390/fluids6120441.

[14] Ferlauto, M., Ferrero, A., Marsicovetere, M., & Marsilio, R. (2021). Differential throttling and fluidic thrust vectoring in a linear aerospike. International Journal of Turbomachinery, Propulsion and Power, 6(2), 8. doi:10.3390/ijtpp6020008.

[15] Sahbon, N., Jacewicz, M., Lichota, P., & Strzelecka, K. (2023). Path-Following Control for Thrust-Vectored Hypersonic Aircraft. Energies, 16(5), 2501. doi:10.3390/en16052501.

[16] Skaggs, B. D. (1997). U.S. Patent No. 5,628,623: Fluid ejector and ejection method. United States Patent Office, Alexandria, United States.

[17] Dodge, A. Y. (1995). U.S. Patent No. 3,188,976. Jet pump. United States Patent Office, Alexandria, United States.

[18] Samuel, L. (1968). U.S. Patent No. 3,385,030. Process for scrubbing a gas stream containing particulate material. United States Patent Office, Alexandria, United States.

[19] Bayles, W. H., & Nash, B. C. (1962). U.S. Patent No. 3,064,878: Method and apparatus for high performance evacuation system. United States Patent Office, Alexandria, United States.

[20] Volker, M., & Sausner, A. (2018). U.S. Patent No. 10,072,674: Suction jet pump. United States Patent Office, Alexandria, United States.

[21] Chanut, P. L. J. (1964). U.S. Patent No. 3,013,494. Guided Missile. United States Patent Office, Alexandria, United States.

[22] Sota Jr, C. G., Callis, G. J., & Masse, R. K. (2007). U.S. Patent No. 7,155,898: Thrust vector control system for a plug nozzle rocket engine. United States Patent Office, Alexandria, United States.

[23] Aerospaceweb.org (2018). Missile Control Systems. Available online: http://www.aerospaceweb.org/question/weapons/q0158.shtml (accessed on September 2023).

[24] Dunbar, W. B., Milam, M. B., Franz, R., & Murray, R. M. (2002). Model predictive control of a thrust-vectored flight control experiment. IFAC Proceedings Volumes, 35(1), 355-360. doi:10.3182/20020721-6-ES-1901.00965.

[25] Bailey, J. M. (1982). U.S. Patent No. 4,355,949: Control system and nozzle for impulse turbines. United States Patent Office, Alexandria, United States.

[26] Hickerson, F. R. (1965). U.S. Patent No. 3,192,714: Variable thrust rocket engine incorporating thrust vector control. United States Patent Office, Alexandria, United States.

[27] Kinsey, L. E., & Cavalleri, R. J. (2013). U.S. Patent No. 8,387,360: Integral thrust vector and roll control system. United States Patent Office, Alexandria, United States.

[28] Plumpe Jr., William, H. (2003). U. S. Patent No. 6,622,472: Apparatus and method for thrust vector control. United States Patent Office, Alexandria, United States.

[29] Cican, G., Frigioescu, T. F., Crunteanu, D. E., & Cristea, L. (2023). Micro Turbojet Engine Nozzle Ejector Impact on the Acoustic Emission, Thrust Force and Fuel Consumption Analysis. Aerospace, 10(2), 162. doi:10.3390/aerospace10020162.

[30] Bhadran, A., Manathara, J. G., & Ramakrishna, P. A. (2022). Thrust Control of Lab-Scale Hybrid Rocket Motor with Wax-Aluminum Fuel and Air as Oxidizer. Aerospace, 9(9), 474. doi:10.3390/aerospace9090474.

[31] Liu, B., Gao, Y., Gao, L., Zhang, J., Zhu, Y., Zang, X., & Zhao, J. (2022). Design and Experimental Study of a Turbojet VTOL Aircraft with One-Dimensional Thrust Vectoring Nozzles. Aerospace, 9(11), 678. doi:10.3390/aerospace9110678.

[32] Wang, C., Lu, H., Kong, X., Wang, S., Ren, D., & Huang, T. (2023). Effects of Pulsed Jet Intensities on the Performance of the S-Duct. Aerospace, 10(2), 184. doi:10.3390/aerospace10020184.

[33] Ahmed, F., Eames, I., Moeendarbary, E., & Azarbadegan, A. (2021). High-Strouhal-number pulsatile flow in a curved pipe. Journal of Fluid Mechanics, 923, 15. doi:10.1017/jfm.2021.553.

[34] Brethouwer, G. (2022). Turbulent flow in curved channels. Journal of Fluid Mechanics, 931, 21. doi:10.1017/jfm.2021.953.

[35] Svorcan, J., Andrić, J., Čantrak, Đ., & Ivanov, T. (2022). Special Collection on advanced practices in aerospace and energy engineering. Advances in Mechanical Engineering, 14(10), 10. doi:10.1177/16878132221125578.

[36] Mitridis, D., Kapsalis, S., Terzis, D., & Panagiotou, P. (2023). An Evaluation of Fixed-Wing Unmanned Aerial Vehicle Trends and Correlations with Respect to NATO Classification, Region, EIS Date and Operational Specifications. Aerospace, 10(4), 382. doi:10.3390/aerospace10040382.

[37] Shahzad, M. M., Saeed, Z., Akhtar, A., Munawar, H., Yousaf, M. H., Baloach, N. K., & Hussain, F. (2023). A Review of Swarm Robotics in a NutShell. Drones, 7(4), 269. doi:10.3390/drones7040269.

[38] Pesci, A., Teza, G., & Fabris, M. (2023). Editorial of Special Issue "Unconventional Drone-Based Surveying." Drones, 7(3), 175. doi:10.3390/drones7030175.

[39] Dinelli, C., Racette, J., Escarcega, M., Lotero, S., Gordon, J., Montoya, J., Dunaway, C., Androulakis, V., Khaniani, H., Shao, S., Roghanchi, P., & Hassanalian, M. (2023). Configurations and Applications of Multi-Agent Hybrid Drone/Unmanned Ground Vehicle for Underground Environments: A Review. Drones, 7(2), 136. doi:10.3390/drones7020136.

[40] Wu, J., Wang, H., Li, S., & Liu, S. (2023). Distributed Adaptive Path-Following Control for Distance-Based Formation of Fixed-Wing UAVs under Input Saturation. Aerospace, 10(9), 768. doi:10.3390/aerospace10090768.

[41] Zhu, D., Chen, Z., Xie, X., & Chen, J. (2023). Discretization Method to Improve the Efficiency of Complex Airspace Operation. Aerospace, 10(9), 780. doi:10.3390/aerospace10090780.

[42] Wu, X., Zhang, M., Wang, X., Zheng, Y., & Yu, H. (2023). Hierarchical Task Assignment for Multi-UAV System in Large-Scale Group-to-Group Interception Scenarios. Drones, 7(9), 560. doi:10.3390/drones7090560.

[43] Fitrikananda, B. P., Jenie, Y. I., Sasongko, R. A., & Muhammad, H. (2023). Risk Assessment Method for UAV's Sense and Avoid System Based on Multi-Parameter Quantification and Monte Carlo Simulation. Aerospace, 10(9), 781. doi:10.3390/aerospace10090781.

[44] Baspinar, B. (2023). Robust Controller Design for a Generic Helicopter Model: An AI-Aided Application for Terrain Avoidance. Aerospace, 10(9), 757. doi:10.3390/aerospace10090757.

[45] Bhamu, N., Verma, H., Dixit, A., Bollard, B., & Sarangi, S. R. (2023). SmrtSwarm: A Novel Swarming Model for Real-World Environments. Drones, 7(9), 573. doi:10.3390/drones7090573.

[46] Li, J., Shen, D., Yu, F., & Zhang, R. (2023). Air Channel Planning Based on Improved Deep Q-Learning and Artificial Potential Fields. Aerospace, 10(9), 758. doi:10.3390/aerospace10090758.

[47] Petrovich, G. P. (2002). Philosophy of technology and creativity of P. K. Engelmeyer: Historical and philosophical analysis. PhD Thesis, Ural State Economic University Press, Yekaterinburg, Russia.

[48] Altshuller, G. S. (2011). To find an idea: An introduction to TRIZ - the theory of inventive problem solving. Alpina Publisher, Moscow, Russia.

[49] Kurdyumov, S. P., & Knyazeva, E. N. (2021). Future and its horizons: synergetic methodology in forecasting. Synergetics and Scientific Forecasting, Moscow, Russia. (In Russian).

[50] Raskin, N.M. (1958). 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, 499–556, Publishing House of the Academy of Sciences of the USSR, Moscow, Russia.

[51] Ackeret, J. (1944). Investigation of a water turbine built according to Euler's proposals (1754). Swiss Construction Newspaper, 123/124. Available online: https://arxiv.org/ftp/arxiv/papers/2108/2108.12048.pdf (accessed on July 2023).

[52] Voronov, Y. P. (2010). Foresight as a tool. Institute of Economics and Industrial Engineering, Siberian Branch of RAS Publication, Novosibirsk, Russia. Available online: https://spkurdyumov.ru/forecasting/budushhee-i-ego-gorizonty/ (accessed on June 2023).