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Interdisciplinary Studies of Jet Systems using Euler Methodology and Computational Fluid Dynamics Technologies

Yuri A. Sazonov [1], Mikhail A. Mokhov [1*], Anton V. Bondarenko [1], Victoria V. Voronova [1], Khoren A. Tumanyan [1], Egor I. Konyushkov [1]

[1] National University of Oil and Gas, Gubkin University, Moscow, Russian Federation.

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Abstract

This study aims to conduct interdisciplinary research using computerized solutions to inventive problems in fluidics. The chosen direction of work relates to the scientific search for new opportunities for extremal control of the thrust vector within a complete geometric sphere (with the range of rotation angle change for the thrust vector being ±180° in any direction). This study assesses the prospects for the emergence of patentable innovative solutions for maneuverable unmanned vehicles. One of the most urgent tasks is to increase the process efficiency in forming fluid medium flow, expanding opportunities for controlling this flow parameter. The research uses an interdisciplinary approach with simulation modeling. The authors of the paper reveal new possibilities for using an ejector with two curved mixing chambers to create special jet units. Calculations (CFD) have confirmed the performance of the simulator ejector when controlling the thrust vector with 90° and 180° rotation. Manufacturing physical micromodels used additive technologies to allow simulation modeling under laboratory conditions. Using "data mining" methods, it was shown for the first time that, based on Euler's ideas and methodology, it is possible to create a new methodology for teaching and solving inventive problems. The research results apply to power engineering and unmanned vehicles. Some results of scientific studies can be used to create special computer programs working together with artificial intelligence to create advanced techniques and technologies.

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

1. Introduction

Enhancement of the technical characteristics of machines while ensuring their economic efficiency growth is a base and always relevant task for all production sectors. Such improvements almost always involve solutions to optimization problems. The analysis of publications is performed within the framework of establishing a new innovative Euler school in the fields of fluidics, gas dynamics, and hydrodynamics. The authors attribute the feasibility of creating such a school to the appearance of new patented jet systems designed to control the thrust vector within a complete geometric sphere, with the thrust vector angle in the range of +180° to -180°.

The solution of optimization problems is usually reduced to solving direct and inverse problems [1] in the field of gas dynamics and hydrodynamics. Here, the interaction of a fluid medium with a solid wall is studied, e.g., fluidics (in general), jet devices, and turbomachines (in particular). At the same time, an already-known design scheme and

* Corresponding author: mikhal.mokhov@mail.ru

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schematic diagram (or a model as an object for optimization) should be an input. It is necessary to create a new population M consisting of N models (new models) to obtain new results using genetic algorithms. In the literature, one can find mention that the initial population is created “usually randomly.” However, if we aim to obtain a new result, it is reasonable to include new models in population M that can be attributed to the group of patentable technical solutions. It is possible (and advisable) to use algorithms based on the theory of inventive problem solving [2]. We will also consider the fact that genetic algorithms are one of the directions in the topic of artificial intelligence (AI). Inventive tasks of creating new schematic diagrams (new models to replenish population M) are primary tasks relative to the abovementioned direct and inverse tasks [1] because, first of all, a new schematic diagram is developed and further transformed into a full-fledged computational scheme, and direct and inverse problems can be solved after specifying all necessary parameters.

If we re-read old publications [3, 4], we notice that the correspondence between Euler and Segner reflected the basic knowledge based on which fluidics in general and turbomachinery in particular began to develop actively. Euler was the first to create mathematical models linking the parameters of the fluid medium with the geometric parameters of solid walls. These models opened a new direction for the rapid (accelerated) development of fluidics and turbomachines, with an infinitely large number of possible variants for practical implementation [5, 6]. Any change in geometrical parameters (shape and dimensions) entails correspondingly changing machine properties under special optimal application conditions. Nowadays, it is difficult to find an example in these fields of science and technology where the results of Euler’s theoretical developments with variants of power distribution between parallel flows are absent. In addition, the example [3] showed how, by optimizing the shape and dimensions of solid walls, it is possible to go from an analog (Segner turbine) to a new and more efficient variant (Euler turbine). The transformation proposed by Eule through changing the solid wall shape and size is the basis of any theory for solving inventive problems; it is also the basis for evolutionary algorithms, including genetic algorithms aimed at the future according to the concepts of such a direction in science as “Foresight” [7, 8]. The noted genetic algorithms are now popular due to the emerging opportunities for the practical use of AI. Intelligent data analysis (data mining), including old data analysis [3, 4], can be practically helpful for forecasting in the field of fluidics development and for training people (or for AI training). For further analysis, we have chosen technical objects in which the interaction of a fluid medium with a solid wall is visible. During such work, it is possible to analyze in more depth the connections between the current level of fluidics development and the level of this technique development at the origin stage of gas dynamics and hydrodynamics.

One of the most urgent scientific and practical tasks is improving the efficiency of the process designed to form a fluid medium flow with the possibility of controlling the parameters of this flow, which we can consider as a continuation and development of Euler’s ideas. One of the favorite research directions in this area relates to control systems for unmanned vehicles. A specific control system [9] makes it possible to perform unique maneuvers in flight, with uniform or non-uniform division of power into three controllable flows.

Nowadays, the requirements for the accuracy of high-speed control of aircraft generally, and unmanned vehicles in particular, have increased [10-12], which is particularly important for a swarm of unmanned vehicles [13-15]. For unmanned vehicles, AI-based learning [16, 17], including large ones [18], improves control performance. AI is applied to avoid collisions with obstacles [19-21]. Aviation technology is witnessing a new turn in the development of air propellers; for example, Kunze & Paull [22] performed a preliminary aerodynamic and thermodynamic analysis of a supersonic air propeller driven by an electric motor. The design actively uses the morphing concept [23]. The morphing concept involves visualizing images in the inventor's thinking activity through transformations. According to this concept, it is easy to go from Euler’s turbine to any known turbine variant, including the Francis turbine [6, 24, 25]. The system considers the interaction of different objects being or moving under various conditions [26]. An aircraft system can have a flexible element introduced into an aircraft system containing distant components (subsystems) also combined with an aircraft (or wing) [1, 27].

Ejectors are widely applied in mechanical engineering, aerospace, and power engineering [28-30], including carbon-free technologies [31, 32]. Bencharif et al. [33] and Chen et al. [34] used AI for optimal ejector design. Yan et al. [35] and Zhang et al. [36] investigated multiflow ejectors of different structures. Han et al. [37] analyzed the effect of mixing chamber size on ejector performance. Kartas [38], Bayles & Nash [39], Volker & Sausner [40] investigated the curved ejector. When pumping gas-liquid mixtures, it is necessary to correct the length of the mixing chamber in the ejector [41]. Wang & Wang [42] studied the processes of phase transitions in velocity flows in ejector channels. Song et al. [43] and Zaharia et al. [44] actively apply additive technologies in fluidics engineering. Yan et al. [45] analyzed a two-stage ejector. Zheng et al. [46], Yu et al. [47], Zheng et al. [48], Yan et al. [49] analyzed the complex effects of several ejector design parameters. Yan and Wang [50] utilized electrically actuated valves to control ejectors. Various schemes of ejector or jet apparatus using moving elements exist [51, 52]. In the example, where the variable is the rotation angle of the thrust vector, the control is performed by the angular movement of the nozzle placed in a spherical joint [53, 54]. In an example where the variable is the critical cross-sectional area at the nozzle, the control is performed by linear movement of the central body [55-57]. Ejector systems can directly use many types of energy [58]. There are examples of using several different working fluids in an ejector [59-61]. Tashtoush et al. [62] performed the gas dynamic and economic calculations to evaluate the ejector performance. In energy conversion technologies, the most promising are ejectors equipped with adjustable nozzles. Lysak et al. [63] and Balalaev [64] continue to develop variants of a unified theory, generalizing the results of studying processes in ejectors. Over the last three years Sazonov et al. [5], Sazonov et al. [6] have formed a new direction for scientific research in fluidics engineering (in general) and in ejectors (in particular). This direction relates to the disclosed new possibilities for extremal control of the thrust vector within the complete geometric sphere (at that, the range of rotation angle change for the thrust vector is ±180° in any direction). Here, we see the prospects for the emergence of patentable innovative solutions in energy generation and distribution (in general) and maneuverable unmanned vehicles (in particular).

We can intermediate conclude that the gaps in the literature (among open publications) relate to the practical lack of information on the nature of the technical idea origin and the "patentable new technical solution" itself. Mostly one-sided (within one specialty) discussions of individual technical solutions occur, mainly considering only successful results. For example, gas-dynamic processes in a machine during computer simulations do not consider specific economic evaluations of the finished product, and inventive work is isolated from systematic mathematical calculations. We suggest the more active use of an interdisciplinary approach in developing innovative equipment and technologies.

The main goal of the ongoing interdisciplinary studies is to search for methods for computerized solutions of innovative inventive tasks within human training and, in the future, for solving innovative scientific and practical problems within training and active using AI. At this research stage, the intermediate goal is to evaluate the possibilities of associative thinking techniques when working with large amounts of scientific and technical information, using fluidics examples.

2. Research Methodology

Figure 1 presents a flowchart explaining the research methodology.

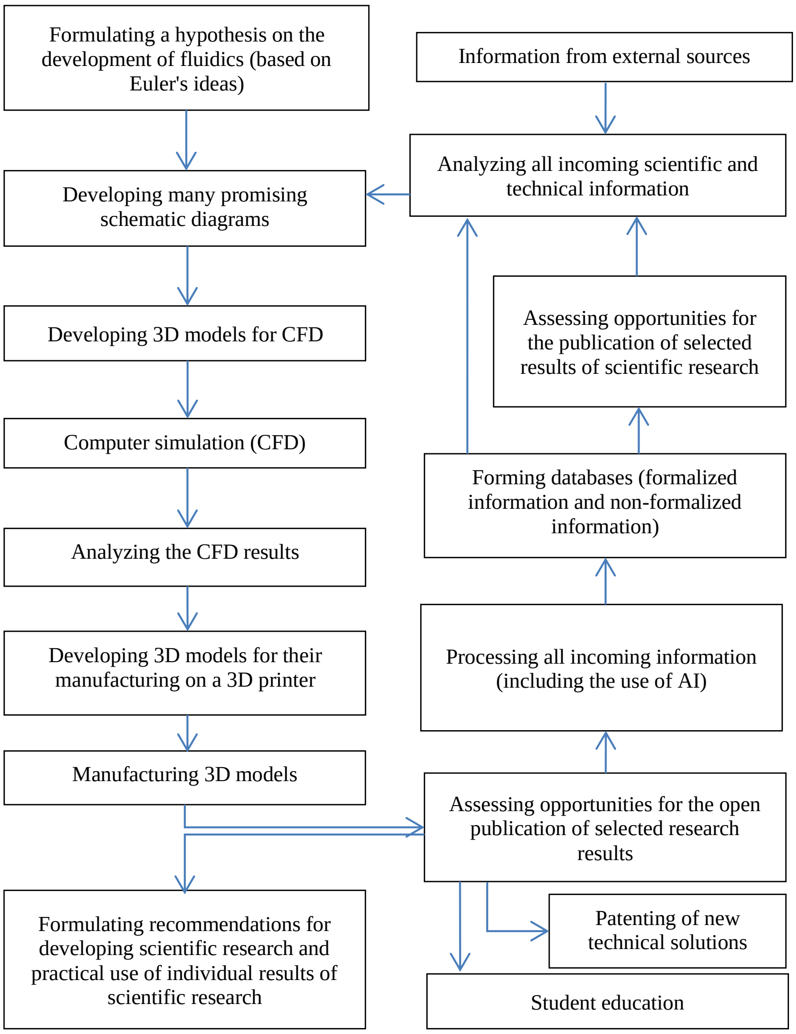


Figure 1. Flowchart of the methodology used in conducting the research

In this study, formulation of a hypothesis on developing fluidics relies on Euler's ideas. Developing a set of promising schematic diagrams uses the theory of inventive problem solving (creating a new population M consisting of N new models using the genetic algorithms) and information from external open sources (papers, patents, technical documentation). Developing 3D models for CFD rests on schematic diagrams. Simulation computer modeling involves the solution of many variants for direct and inverse problems. Developing low-cost 3D models for their manufacture on a 3D printer aims to carry out simulation physical modeling of individual systems in laboratory conditions. The methodology includes analyzing research results, processing all incoming information (including all experiments, regardless of the intermediate evaluation of each experiment's results), forming databases, which include formalized and non-formalized information, assessing opportunities for open publication of individual research results, using part of the information for student training, and patenting some of the new technical solutions. Part of the obtained novel information remains closed to replenish the database and prepare expert opinions on various issues. We plan to train and use AI to work with information flows within the described methodology.

This research uses an interdisciplinary approach [1] combined with simulation modeling. A simulation model usually refers to an abstract dynamic model implemented on a computer to design, analyze, and evaluate the functioning of an object (if it is expensive or impossible to experiment on an actual object if it is necessary to simulate the system behavior in time). Simulation models serve as a means to analyze the system (original) behavior under the conditions of the experimenter [65]. Simulation modeling allows the construction of theories and hypotheses that can explain the observed behavior and use these theories to predict future system behavior. To analyze scientific and technical information, we decided to apply the methods of "data mining" and associative thinking methods relying on Euler’s ideas [3, 4]. When solving optimization problems related to the interaction of fluid media with solid walls, Euler proposed using the transformation technique of geometric shapes with a corresponding change in geometric dimensions.

3. Results

3.1. Developing a Schematic Diagram of a Promising Jet Unit

The schematic diagram variant was developed within the framework of the study of promising jet units using the accumulated scientific groundwork. Figure 2 shows its variant. The noted scientific groundwork includes technical solutions under patents for inventions of the Russian Federation (nos. 2781455 and 2802351) and patents for utility models of the Russian Federation (nos. 214452, 209663, 203833, and 192513).

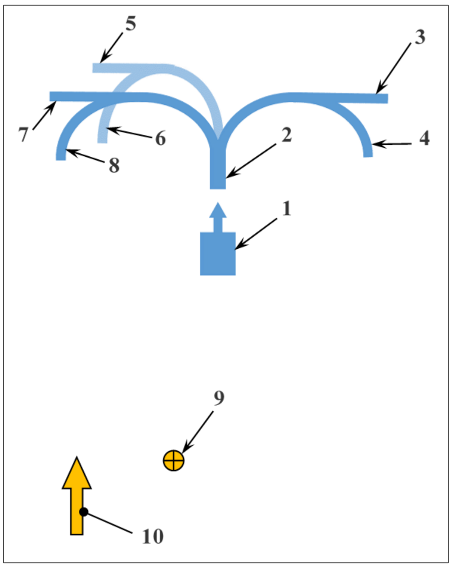


Figure 2. Schematic diagram of a jet unit (variant): 1 – controlled nozzle apparatus; 2 – entrance to the multiflow mixing chamber; 3-8 – outputs from the multiflow mixing chamber; 9 – characteristic point (mass center); 10 – vector of external force.

The variant of the jet unit (Figure 2) should be considered concerning 3D space, and this variant partially corresponds to the model presented in RF patent No. 214452. Channels 4, 6, and 8 direct the flows predominantly along a cylindrical surface, and channels 3, 5, and 7 - along a single planar surface. Through inlet 2, the mixing chamber may receive the medium from the surrounding space. In this example, there are several basic modes of operation when the working medium flows from controlled nozzle apparatus 1:

1) Distributed (uniformly or non-uniformly) through all output channels 3-8;

2) Distributed (uniformly or non-uniformly) only along output channels 3, 5, and 7;

3) Distributed (uniformly or non-uniformly) only along output channels 4, 6, and 8;

4) Directed to one of output channels 3-8.

External force 10 may act on the elements of the jet unit. Characteristic point 9 may occupy various positions relative to the jet unit, considering the solved technical problem: for a movable jet device, the product mass center may be characteristic point 9; for rotating elements, characteristic point 9 may be a point on the rotation axis. We can assume that such a jet unit can be applied to many practical tasks. We may consider nozzle apparatus 1 equipped with a thrust vector control system in conjunction with an engine. If we discuss applied problems in aviation and space, the engine with nozzle apparatus 1 may be, for example, an air-jet engine or a rocket engine (the engine type corresponds to the solved practical problem). Various hybrid propulsion systems are also possible, including the combination of an air propeller with an electric motor and an afterburning rocket engine. Creating unmanned vehicles of various types and for different purposes may duly use the scheme presented in Figure 2. New opportunities are visible for increasing the maneuverability of unmanned vehicles due to the high-speed control of the thrust vector within the complete geometric sphere when performing various unique maneuvers and turns in the atmosphere or outer space (or underwater).

Characteristic point 9 here may be the point of the mass center of the unmanned vehicle. External force vector 10 may be due to the action of a wind gust, for example. Output channels 3-8 may be above mass center 9 known to have a favorable effect on the stability and controllability of an aircraft with vertical takeoff and landing.

3.2. Operating Principle

If we further consider the example of an unmanned aerial vehicle (UAV), we can note the following features (Figure 2). The flow of the working medium from nozzle apparatus 1, due to the use of the control system for jet deflection, can be distributed (uniformly or non-uniformly) only along the output channels 4, 6, and 8. This mode may occur during vertical takeoff and landing of the UAV. The working medium flow from nozzle apparatus 1 can be distributed (uniformly or non-uniformly) only along the output channels 3, 5, and 7. This mode can occur during flight in a horizontal plane after the aircraft takes off. The working medium flow from nozzle apparatus 1 can be distributed (uniformly or non-uniformly) through all output channels 3-8. This mode can occur when performing various maneuvers related to a particular task. This mode may also occur during vertical takeoff and landing of the aircraft if its mass changes over time. The performance of individual elements for such a jet system has been tested on micromodels manufactured using additive technologies.

The developed scheme (Figure 2) can also be applicable in steady-state conditions for the distribution of gas or liquid flows in various branches of production, for example, jet power systems in developing oil and gas fields.

3.3. Computer Simulation

The fluid medium movement through curved channels 3-8 in Figure 2 may cause the loss of thrust. The thrust F_1 due to the operation of nozzle apparatus 1 can be used as a basis or comparison base. When the flow turns by 90°, the thrust is labeled as F_{90} and when by 180° – F_{180}. Figure 3 shows the calculation scheme (and the corresponding 3D model) for simulation modeling. All dimensions are indicated in millimeters.

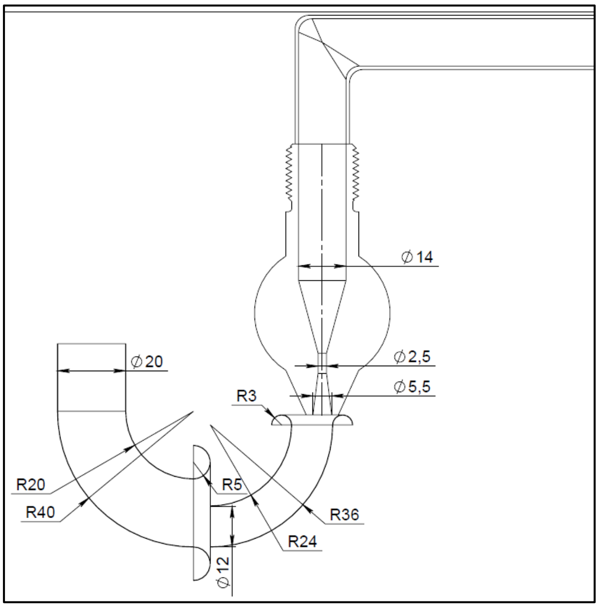


Figure 3. Calculation scheme for the simulation

For an ejector with two curved mixing chambers, the fluid flow is formed in a Laval nozzle with a critical cross-sectional diameter of 2.5 mm, with a 90° flow rotation in the curved mixing chamber of 12 mm diameter and a final flow rotation (in total) of 180° in the curved mixing chamber of 20 mm diameter. Using transformation techniques (e.g., by shifting in space the individual elements of this jet system), it is possible to remove the mixing chamber with a 20 mm diameter from operation. In this case, we obtain a variant with a final flow rotation of 90°. If we remove both mixing chambers with 20 mm and 12 mm diameters from the operation, it will be a variant without flow rotation (the calculated angle of flow rotation is zero).

Computer simulation (CFD) used the FlowSimulation (*FloEFD*) software package to create a 3D model in SolidWorks. The complete system of Navier-Stokes equations, described by mathematical expressions of the laws of conservation of mass, energy, and momentum, was solved with the turbulence parameters set automatically by default; the turbulent viscosity model was "$k - \varepsilon$" Computer parameters: Operating system: Windows 10; Processor type: Intel(R) Core (TM) i5-6200U CPU @ 2.30 GHz; processor frequency: 2401 MHz; RAM: 8065 MB.

Initial data: the fluid medium is gas (air); the gas pressure at the nozzle inlet is 1519875 Pa at a gas temperature of 2000°C; the ambient gas pressure (air) is 101325 Pa and temperature 20°C.

Figures 4-7 graphically depict selected computer simulation results.

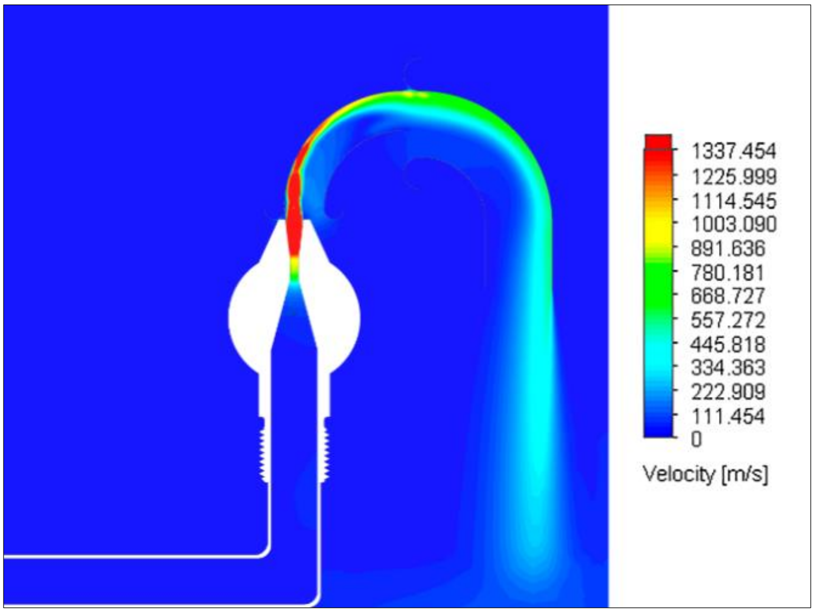


Figure 4. Computer simulation results: velocity

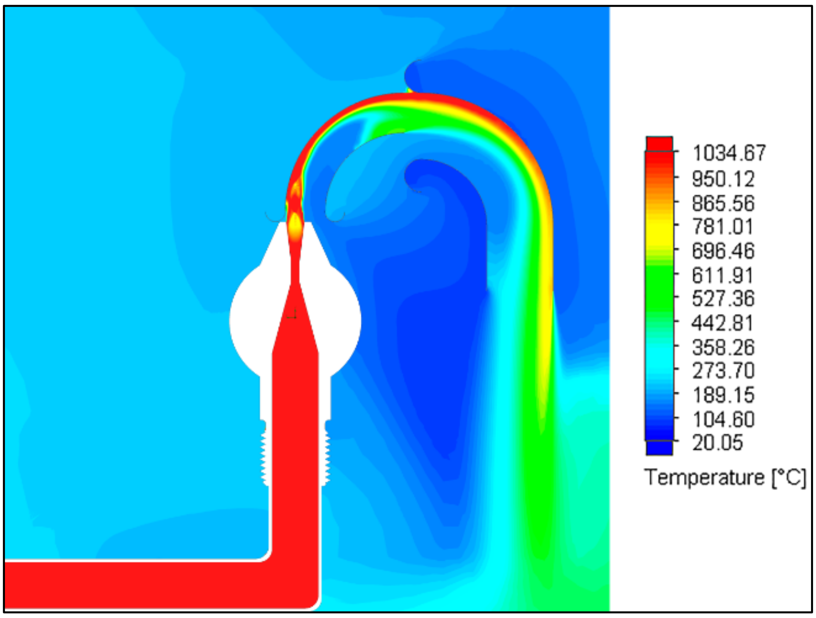


Figure 5. Computer simulation results: temperature

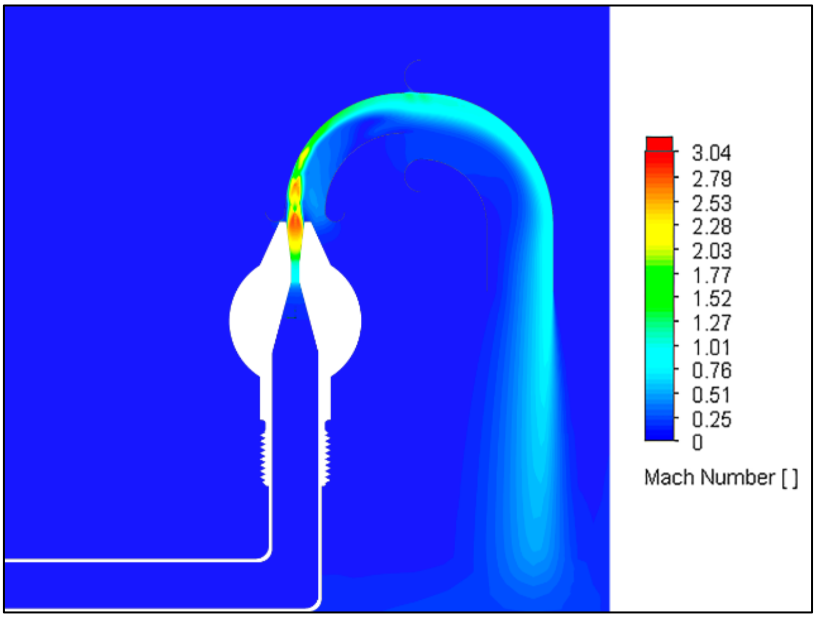


Figure 6. Computer simulation results: Mach number

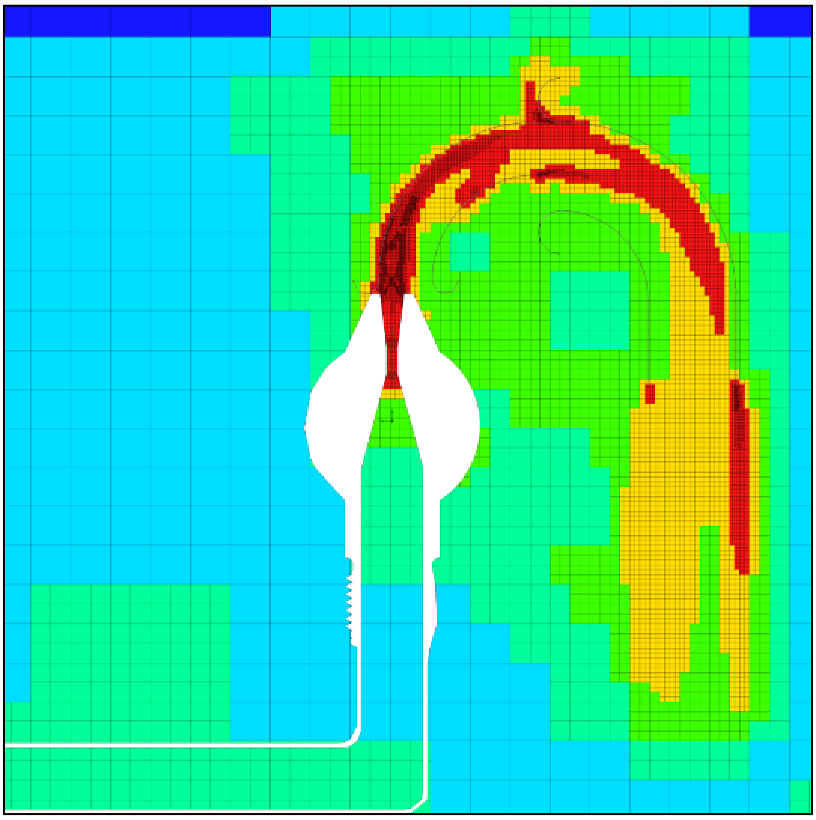


Figure 7. Computer simulation results: Computational mesh

The adaptation of the computational mesh was automatic. Total number of cells: 759341. Calculation time: 23875 s. Number of iterations: 1500. According to the computer simulation results, the nozzle thrust modulo $F_1 = 8{,}348\ N$ (Newton). After turning the flow at an angle of 90° thrust $F_{90} = 8{,}309\ N$ (Newton), at an angle of 180° – thrust $F_{180} = 7{,}160\ N$ (Newton). Therefore, the thrust change after turning the flow by 90° can be estimated through the ratio $(F_{90}/F_1 = 0{,}995)$, by 180° - through $(F_{180}/F_1 = 0{,}858)$.

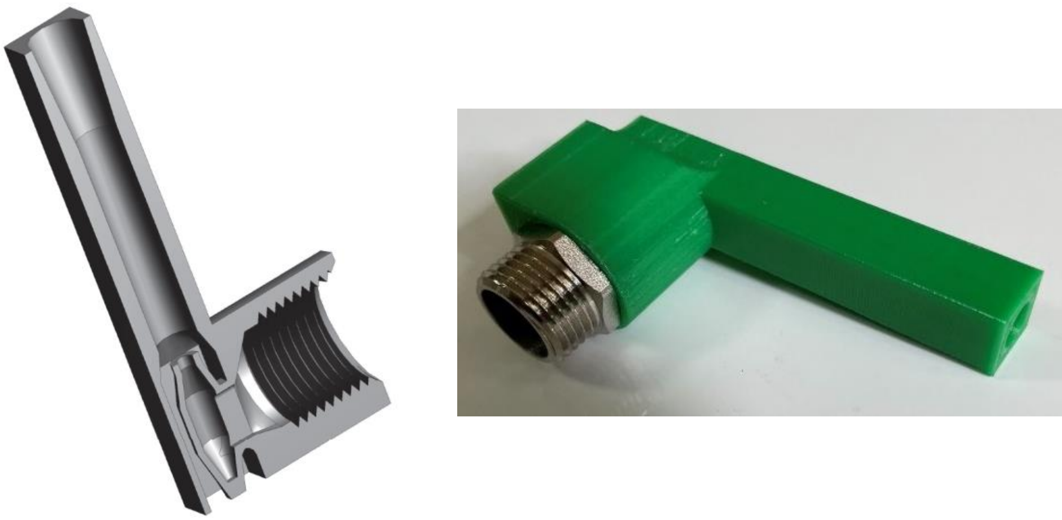
This paper presents selected results of calculations performed at the patenting stage of new technical solutions. Calibration, verification, or detailed checking of the calculation results will occur at the preliminary design during the development of design documentation.

The calculations confirmed the ejector performance at thrust vector control in the example with 90° and 180° rotation. Given the known and current level of the development of aviation and space technology, it is quite possible to assume that with the use of afterburner modes of engine operation, there is a prospect for increasing the thrust modulus and the coefficient F_{90}/F_1 (as well as the coefficient F_{180}/F_1) will be able to take a value that is well above unity. In this regard, it is theoretically possible to create specific jet systems and ejectors for a powerful aircraft, a hybrid rocket, or other specialized engines. Various variants are possible when a solid fuel is placed in the mixing chamber of a multichannel ejector for a solid rocket booster. After burning out of such rocket fuel, atmospheric air can enter the ejector mixing chamber to realize the workflow characteristic of a propulsive jet, naturally with a simultaneous supply of hydrocarbon fuel (or hydrogen, or a mixture of hydrocarbons and hydrogen) to the mixing chamber.

Thus, the results of the simulation computer modeling confirmed the possibility of using an ejector with two curved mixing chambers to create jet units, such as the one shown in the schematic diagram in Figure 2. The authors perform computer simulations for different designs of jet devices and various ranges of values of operating parameters, and plan to publish the results of calculations and scientific research in subsequent research articles.

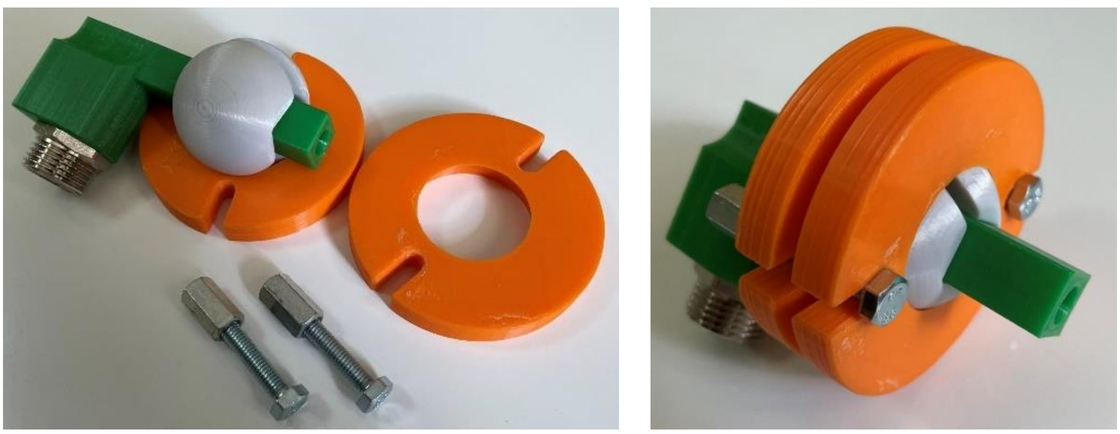
3.4. Simulation Modeling of a Jet Unit using Physical Micromodels

Physical micromodels have been manufactured using additive technologies to allow simulation modeling of the jet unit under laboratory conditions. A version of the controlled nozzle apparatus 1, as shown in Figure 2, was developed. Figures 8 and 9 present the micromodel.



a) b)

Figure 8. Nozzle apparatus in a bloc with a primary ejector: (a) 3D computer model; (b) physical micromodel

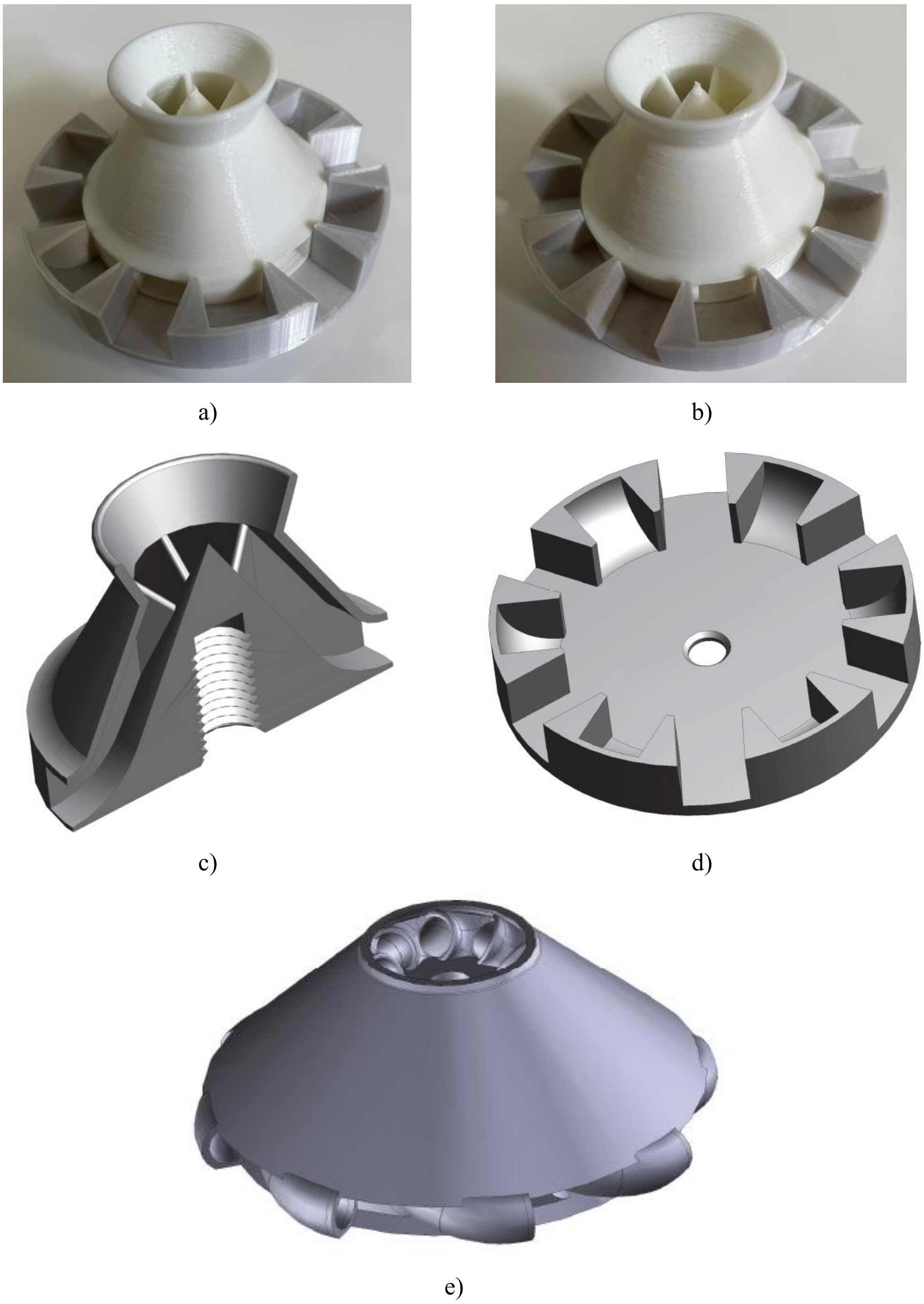


a) b)

Figure 9. Controlled nozzle apparatus (variant): (a) parts of the nozzle apparatus equipped with a primary ejector and spherical joint; (b) assembled physical micromodel

Figure 10 shows a secondary multiflow (multichannel) ejector with a rotary distributor disk (variant). In addition, this figure shows 3D computer models of a multiflow ejector and a rotary distribution disk. The ejector in this variant has six flow channels (or six mixing chambers). As an associative analog, the scheme of a multiflow (multichannel) rotor, which was part of the turbine developed by Euler (Figure 10(e) shows a variant of such a rotor in a 3D model), with nozzle apparatus channels and rotor channels in this machine made of S-curved tubes, was considered. Euler's recommendations on using such curved elements are still relevant and in demand among designers and researchers engaged in solving optimization problems in the profiling of the flow part in fluidics (in general) and turbomachines (in particular).

As known, the invention object may be a method of using a previously known device for a new purpose. Here, the known Euler rotor can be applied. The Euler rotor is used to realize an ejector process, with curved channels providing new possibilities to control the thrust vector. This direction of inventive and scientific works using Euler's ideas has good prospects for further development under modern conditions.



a) b)

c) d)

e)

Figure 10. Secondary multiflow ejector equipped with a swiveling distribution disk (variant): a) output radial channels are open; b) output radial channels are installed opposite the deflectors; (c) 3D computer model of a multiflow ejector; (d) 3D computer model of a rotary distribution disk; (e) 3D computer model of Euler (variant).

a) b)

Figure 11. Physical micromodel of a jet unit (variant): a) output radial channels are open; b) output radial channels are installed opposite the deflectors

Hydraulic tests of the fabricated micromodel visualized the working process more clearly. Figures 12 and 13 graphically show separate photos with the test results. Note that the pneumatic tests also yielded similar results.

a) b) c)

Figure 12. Results of hydraulic tests of a physical micromodel of a jet unit with output radial channels installed opposite the deflectors when the working medium flow from the controlled nozzle apparatus a) is distributed uniformly through all six output channels; b) is directed to two output channels; c) is directed to one output channel.

In the example in Figure 12, the channels direct the flows mainly along a cylindrical surface. The medium from the surrounding space enters each mixing chamber through the inlet. Considering the UAV example, Figure 12 shows the following features. This example simulates the operating mode during the UAV vertical takeoff and landing. The water only helps to visualize the process better. Pure pneumatic tests give a similar distribution of power and forces (thrust) in the flows at the outlet of the jet system.

Considering the UAV example, Figure 12 shows the following features. This example simulates the operating mode when flying in the horizontal plane after the aircraft has taken off. Here, water only helps to visualize the process better. Pure pneumatic tests give a similar distribution of power and forces (thrust) in the flows at the outlet of the jet system.

The working medium flow from the nozzle apparatus may be distributed (uniformly or non-uniformly) through all twelve output channels in the rotary distribution disk; this example shows six radial output channels directed along a single plane and six channels directed mainly along a cylindrical surface due to deflectors. This mode may occur during various and more complex maneuvers associated with a particular task and during vertical takeoff and landing if the aircraft mass changes over time. The angular movement of the rotary distributor disk here is combined and synchronized with the operation of the spherical joint and primary ejector. In such cases, a part of the working medium, mixed with the pumped medium from the surrounding space, is partly directed into the open radial channels and partly into the deflectors in the rotary distributor disk. Figure 14 shows an example of such a case.

a)

b)

c)

d)

Figure 13. Results of hydraulic tests of a physical micromodel of a jet unit with open output radial channels when working medium flow from the controlled nozzle apparatus a) is distributed uniformly through all six output channels; b) is directed into three output channels; c) is directed into one output channel; d) is directed into one output channel, but at complete immersion of the primary ejector under water.

Figure 14. Secondary multiflow ejector equipped with a rotary distributor disk (variant): outlet radial channels and deflectors are partially open

The performed simulation computer modeling, combined with simulation physical modeling, shows that the schematic diagram in Figure 2 can be a basis for the continuation and development of scientific and design work. The developed model and its variants can be a part of the previously mentioned list of *N* models (when creating a new population *M* consisting of *N* models within the genetic algorithms). The presented model reveals new possibilities for extremal control of the thrust vector within the complete geometric sphere (at that, the range of rotation angle change for the thrust vector is ±180° in any direction). The designs and models presented in this paper only explain the technology aimed at controlling the thrust vector in modulus and direction with the possibility of changing the coordinates of its starting point. The number of designs for such jet plants can be huge, depending on the practical application.

4. Discussion

4.1. Discussion of Intermediate Results

As known, “data mining” uses all kinds of classification, simulation, and prediction methods, applying genetic algorithms and associative thinking techniques. Techniques are necessary to discover knowledge hidden in large volumes of initial "raw" data.

The ongoing research considers the Euler turbine [3, 4] only in the braking mode with the stopped rotor, with an angular velocity of ω=0. This approach to analyze Euler’s development was previously unknown. This hydraulic machine in static state corresponds to the description of a jet unit containing a multichannel nozzle and a multichannel mixing chamber assembled from curved tubes. The flow from the nozzle inlets the mixing chamber, which communicates with the surrounding space. In a particular case (for a turbine), the outputs from the curved tubes on the rotor aim to solve the problem of torque generation. However, in general, it is possible to take all geometrical parameters as variables, and it is possible to conduct all kinds of transformations with the initial scheme to solve a new problem. Euler transformed Segner's turbine, changing the shape and size of the channels, and obtained a qualitatively new hydraulic machine (Euler’s turbine), evident from the preserved correspondence [3]. This paper proposes to use Euler's knowledge and ideas for another purpose: Euler’s hydraulic machine is applied as an analog for creating a jet unit for thrust vector control relying on associative thinking. This non-trivial approach significantly expands the field of practical application of Euler’s ideas and hints. When viewed this way, Euler’s drawings and texts contain some “hidden knowledge” that is practically useful and applicable today to solve current topical problems. This “hidden knowledge” is available for interpretations of gas dynamics and hydrodynamics in the form of regularities using mathematical functions and graphical representations based on the results of calculations.

Associative thinking helps to free oneself from basic stereotypes from the standardized, stereotype thinking by solving problems from different points of view, and reasoning from the positions of various professions. Associative thinking acts as a primary tool to solve inventive problems. The association is a connection between concepts and representations that arises in their understanding (one of the representations triggers another mind’s idea - this is the birth of associations). Of most interest are the following types of associations: “cause-effect,” “similarity of concepts,” “contrast,” “generalization,” “addition,” and “whole and parts.”

When using the Euler transformation technique, it is necessary to accept the initial condition that all parameters can change their values, and it concerns both geometrical parameters a_{ia} for solid walls and gas dynamic (hydrodynamic) parameters b_{ib} for fluid medium:

$$\begin{aligned} a_{ia} &= var \\ b_{ib} &= var \end{aligned} \tag{1}$$

Here, we consider the corresponding sets A and B as follows:

$$\begin{aligned} a_{ia} &\in A \\ b_{ib} &\in B \end{aligned} \tag{2}$$

We consider that we know the number of parameters za, which describe the geometry of solid walls, and each such parameter can get its number (index):

$$1 \leq ia \leq za \tag{3}$$

Here, we know the number of parameters zb, which describe the properties of the fluid medium, and each such parameter can get its number (index):

$$1 \leq ib \leq zb \tag{4}$$

When moving from general to particular or from a universal mathematical model to specific performance for a physical model, designers take several parameters as constant values. This approach significantly simplifies designing but leads project participants, as a rule, to create so-called “single-mode machines,” which have the maximum efficiency only for one operating mode (for the optimal mode). At other ones, the efficiency of the machine decreases. Known multimode machines are still a rare exception to this rule.

Developing Euler’s idea, to solve any practical optimization problem, we should also consider a set C consisting of parameters $c_{ic} \in C$ that characterize the properties of structural materials used in manufacturing the product (in forming solid walls with which fluid media interact).

Solving practical problems involves obligatory economic evaluations. In this connection, we should also consider the set D of parameters $d_{id} \in D$ characterizing the economic structure in production. Thus, in general (according to the example from the preserved Euler's correspondence [3]), we can denote by symbols the functional dependence of economic profit P on the listed sets:

$$P = F_P(A \ B \ C \ D) \tag{5}$$

In such problems, the number of parameters changing over time can be hundreds and thousands. The F_P function also transforms over time during technical and economic development within each firm and each country. The already fantastic complexity (multidimensionality) of interrelations between the above parameters and sets forces us to look for opportunities for more active application of computer simulation (including AI). Today, open press mainly considers direct problems within sets $(A \ B)$, for example:

$$B = F_B(A) \tag{6}$$

In general, function F_B determines some fluid medium parameters for a given geometry in a 3D model. In computer simulation, a set of numerical values and databases with calculation results for one or several variants of the problem more often represents such a function.

More complicated tasks within the sets $(A \ B \ C \ D)$ are more likely to involve closed information, as economic competition in the economy only increases over time. In this regard, the intermediate conclusion is that the training and use of AI are likely to be carried out within closed projects, and the work on creating special closed training programs designed for using digital complexes with AI isolated from each other will be relevant. Closed information (commercial information, in particular) hinders the development of interdisciplinary approaches to solving urgent problems in engineering and technology. Nevertheless, we propose a systematic approach to overcome such barriers and obstacles to developing technology in general and inventive work in particular.

4.2. Discussion of Typical Schemes for Thrust Vector Control

Table 1 schematically shows the basic operating modes (variants) of the jet unit designed for thrust vector control. We have previously presented other variants of the schemes in the publication [5] during the scientific groundwork preparation. In Table 1, the arrows show the flow directions. The operating mode of the jet unit in Figure 12a corresponds to variant F2 (in the mode symbolic notation, the letter corresponds to the line, and the subsequent digit corresponds to the number of the column from Table 1).

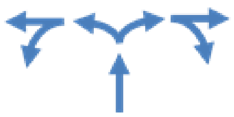
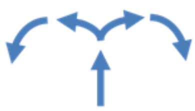
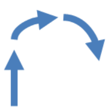
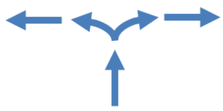
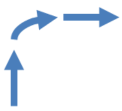
The operating mode in Figure 12c corresponds to variant F3.

The operation mode in Figure 13a corresponds to variant F4.

The operation mode in Figure 13c corresponds to variant F5.

Variant F1 corresponds to the arrangement of the output channels in Figure 14.

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

	1	2	3	4	5
F					

In continuing scientific research, new schemes (for thrust vector control) will supplement the contents of Table 1. The data in Table 1, combined with previously published materials [5], form an information base for developing scientific and design works aimed at solving complicated problems of thrust vector control under extreme conditions within the complete geometric sphere. Here, the thrust vector is adjusted in modulus and direction according to the change in the starting point coordinates.

4.3. Discussion on Developing the Theory of Inventive Problem Solving

One of the main goals in the theory of inventive problem solving [2] is the gradual refusal of the "trial and error method" when creating expensive physical models and samples of new technology. This theory prefers the use of cheaper mathematical methods for solving inventive problems. As modern practice shows, computer simulation (CFD) may be a mathematical tool for solving these problems, with a good prospect for connecting additional forces from AI. As the results show, the fundamental scientific research conducted by Euler can serve as a base for solving inventive problems and forming a new series of applied scientific research in the field of jet devices for various purposes, including the control of the thrust vector within the geometric sphere.

5. Conclusion

This research yielded results characterizing scientific novelty that developed new variants of jet plants with sequential connections of mixing chambers to control the thrust vector within the complete geometrical sphere. Data mining methods showed that, based on Euler's ideas and methodology, it is possible to create a new technique for developing modern genetic algorithms within the framework of fundamental and applied research in fluidics. As part of the theoretical contribution to science, a systematic approach to developing the theory of inventive problem solving is proposed by connecting genetic algorithms and associative thinking methods. The obtained scientific results make it possible to solve current practical problems. The work directions for the computerized solution of inventive problems within the framework of human training and in the future to solve innovative scientific and practical problems within training and active use of AI are described and proposed. This research disclosed new possibilities for extreme thrust vector control within the geometric sphere. The research results can be applied to the energy industry and unmanned vehicles for various purposes. Simultaneously, multiparameter problems remain a significant and unsolved problem. In this regard, future studies in thrust vector control systems aim to connect thrust and velocity vectors with specific designs of unmanned vehicles operating on land, underwater, or in the air.

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, A.V.B.; 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. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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