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REVIEW OF EJECTOR NOZZLES. PART 2 – MIXERS AND ADDITIONAL INFORMATION

*The **subject of this** article is ejector nozzles, which are intended for the thrust augmentation of jet engines and their corresponding flow mixers. The **goal** is to soften the acuteness of contradictions between the required high performance (especially thrust augmentation) and compactness and between the conflicting objectives of achieving a high mixing rate with low total primary flow pressure losses within a short overall length. The **tasks** to be solved are as follows: revealing ways for thrust augmentation and external drag minimization of ejector nozzles through analysis of turbofan forced lobe mixer investigations, experimental studies of the shape and location of additional air intakes, experimental studies of shapes of afterbodies, and ejector investigations from other fields of engineering. The **following methods were used**: search of corresponding information sources on the Internet and analysis based on operational experience in the aviation branch. The following **results** were obtained: in terms of found information sources, the most effective devices for mixing up the primary and the secondary flows within short mixing ducts are forced lobe mixers; their advantages and disadvantages are formulated; and three mechanisms responsible for the mixing process behind the lobe mixers were revealed. A large number of experimental investigations of the characteristics of both the additional air intakes and afterbodies of the fuselages and nacelles were considered. The development of both experimental and theoretical ejector investigations in other engineering branches was analyzed. **Conclusions**. The scientific novelty of the results obtained is as follows: 1) information from numerous sources of literature that characterizes lobe mixers as devices for improving the ejector nozzle efficiency, and development of these mixer study by both theoretical and experimental methods were collected in the review article; 2) recommendations as for selection the shape and location of additional air intakes and afterbodies were revealed; 3) very limited applicability of the ejector models, developed in other fields of engineering, for turbojet engine thrust augmentation was stated. Thus, the development of a design methodology for thrust-augmenting ejector nozzles for micro-turbojets has been revealed. The goal and challenges of the following research are outlined.*

***Keywords:** gas-turbine engine; thrust augmenting ejector nozzle; thrust augmentation; entrainment ratio; primary nozzle; ejector mixing chamber.*

Introduction

Development of engines for Unmanned Aerial Vehicles (UAVs) is substantially related with searching of the methods to increase thrust and decrease specific fuel consumption of existing engines, which are already in serial production stage. In this case, application of an ejector nozzle can be an effective modification.

In modern manned aircraft, ejector nozzles are used to increase thrust at hovering, vertical takeoff and landing modes, to augment thrust during maneuvering, to reduce harmful emissions, exhaust gas temperature (thus, infrared perceptibility), and noise level.

Within a gas ejector, energy of a high-speed primary gas flow it transferred to a secondary flow by means of viscous forces; as a result, total mass flow rate increases, and, in proper conditions, it is possible to augment jet nozzle thrust with ejector.

In the first part [1] of the article, authors of this publication presented review of studies devoted to investigation of thrust augmenting ejectors intended for gas-turbine engines. It was shown, that this problem was studied by analytical methods, 1D, 2D and 3D numerical simulation methods, as well as by experimental methods, and the results were published in numerous papers. However, results presented in the literature are often contradictory. It is caused by presence of great number of factors, influencing on the flow interaction within an ejector and, particularly, on the thrust generation; consequently, theoretical investigations are based on different initial assumptions and leaded to different results. Within considered sources, it was not succeed to find any logically expounded designing method of thrust augmenting ejectors for UAV turbojets. Thus, development of this method is an urgent problem.

The review showed that one of the major processes, influencing ejector nozzle thrust, is the flow mixing. In case of incomplete mixing, as a rule, the thrust decreases. Length of a cylindrical ejector, required for complete mixing of the flows, is too large. As the increase of ejector shroud length unfavorably influences weight and hydraulic drag; it is necessary to optimize the length, and also to search methods and devices, which can intensify mixing of the flows.

In the first section of this paper, it was presented a review of publications on gas flow mixer development, including those, which are used in turbofan engine exhaust units, with the aim of comparative analysis of possible structures, searching methods of their designing, and analysis of their influence on ejector exhaust unit properties. In the second section, the early performed review of ejectors is supplement with the analysis of studies on application of additional air intakes of secondary flow and analysis of afterbodies air flow. In the third section, ejector application in other fields of engineering are considered.

1. Analysis of Investigations of Lobed Turbofan Mixers

In the first approximation, lobed mixer nozzles increase mixing by providing a much greater interface between the hot core flow and cooler fan flow. By mixing the core and fan flow in this manner, a small but significant performance gain can be realized. The level of gain depends on the trade-offs between the degree of mixing of the two streams and the viscous losses incurred in the mixing process [2].

1.1. Analysis of Experimental Researches of Lobed Turbofan Mixers

R. W. Paterson [3] stressed that from an engine design standpoint, the two important characteristics of mixer nozzles are the ability to achieve thrust augmentation as well as a more uniform nozzle exit plane velocity profile relative to either separate primary and secondary stream discharge configurations or common tailpipe configurations having no forced mixing element.

In 1980, H. Kozlowski et al. [4] concluded that increasing the number of lobes from 12 to 18 offered a performance improvement; scalloping the mixer lobes can improve overall performance; increasing the radial penetration of the mixer also offered potential gains; but care must be taken to avoid high pressure losses or separation. In 1982, R. W. Paterson [3] noted that at the nozzle exit, the velocity and temperature field was well mixed-out with nearly uniform distribution in the azimuthal direction. Flow detachment did not occur in the lobe region. On the base of velocity, temperature and total pressure distributions, the author concluded that convection by the mean radial-azimuthal velocity field, represented the dominant mechanism for nozzle mixing and the extent of nozzle mixing by this circulation depends upon the ratio of radial (which is proportional to lobe penetration angle) to axial velocity rather than on the absolute magnitude of the radial velocity component. In 1984, R. W. Paterson [5] noted two features of the axial velocity field: 1) strong penetration of low axial velocity stream fluid into the middle of the primary lobe region; 2) an outward displacement of high axial velocity primary stream fluid. A two-stream mixing process dominated by large-scale, radial-circumferential convection rather than turbulent diffusion at the interface between the two streams.

In 1999, S. A. Skebe et al. [6] presented results of experimental investigation of 3D flow field in three planar mixer lobe models, which provide complete, rapid, and low loss mixing of two flows. The principal result of this study was that the flows within forced mixers were predominantly inviscid, with boundary layer effects confined to lobe surface regions. Thus, the streamwise vortex array emanating from the trailing edge of such convoluted lobe surfaces was basically inviscid in origin. The authors also stressed that the parallel-sided mixer had less boundary layer thickness that sinusoidal mixers.

1.2. Analysis of Investigations of Lobed Turbofan Nozzles Using CFD Models

In 1977, G. C. Paynter et al. [7] presented results of the first numerical study (3D compressible viscous) of flowfield in turbofan mixers. It was concluded that substantial discrepancy between prediction and experimental data can be traced to the incorrect assumption that the free mixer outlet flow was axisymmetric. In 1978, D. W. Roberts et al. [8] presented results of 3D CFD analysis of mixing of two flows in a mixer between a primary flow and a fan flow.

In 1980, L. A. Povinelli et al. [2] presented results of 3D viscous CFD calculations and experimental investigations of flow mixing downstream of a turbofan mixer. It was shown that the generation of streamwise vorticity plays a significant role in determining the temperature distribution at the nozzle exit plane; the centerbody shape and the horseshoe-shaped vortexes may be important to the mixing process. In 1980, B. H. Anderson et al. [9] presented results of CFD investigations of turbofan forced mixer nozzles. The calculation procedure [10, 11] was based on the decomposition of the velocity field into primary and secondary flow components which were determined by solution of the equations governing primary momentum, secondary vorticity, thermal energy and continuity. The authors managed to simulate horseshoe-shaped vortexes behind forced mixer. The complex secondary flow structure that was found to exist in this forced turbofan mixer nozzle was pressure controlled rather than

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turbulence controlled and dominated the mixing process. This conclusion was supported by the low flow field sensitivity to the use of either a k-ε or wake turbulence model. In 1981, B. H. Anderson et al. [12] presented results of finite difference computations [10, 11] of flow mixing for three configurations of lobe mixers. It was shown that: 1) the dominant mechanisms in turbofan forced mixers were associated with the pressure driven secondary flows arising within the lobe region upstream of the mixer and their development in the mixing region; 2) secondary flow generation at the lobe exit was caused by three principal mechanisms: vorticity due to turning (flap vorticity), passage vorticity, and horseshoe vorticity. In 1982, M. J. Werle et al. [13] subdivided the calculation process into three stages: a pre-analysis (2D orthogonal coordinate system generation, its following rotation about the axis of symmetry and initialization); mixer flow calculation (numerical solution of the governing equations); post processing and analysis of the computed results (movement of the computed results to a more convenient output planes to facilitate comparison with other results, and calculation of general performance parameters for the overall mixer nozzle). In 1984, J. P. Kreskovsky et al. [14] stressed that the inlet streamwise vorticity (generated by radial deflection of the fan and turbine streams within the lobes) plays an important role in the mixing process. In the same time, authors noted that the predictions were insensitive to the turbulence model.

In 1984, L. A. Povinelly et al. [15] presented results of computation of three different lobe mixers using the CDF model [14]. On the base of these calculations, they postulated three mechanisms responsible for the generation of transversal flow within the lobes themselves. The first one is due to the basic turning of the fan and core streams in opposite radial directions, which is the main, and basically an inviscid phenomenon and results in outward radial core flow adjacent to inward radial fan flow (Fig. 1, a). The second mechanism is "horseshoe" vorticity and is due to the interaction of upstream duct boundary layers with the lobe (Fig. 1, b). However, inspection of the experimental radial and tangential velocities at the lobe exit plane in the present experiments did not indicate that any significant effects were caused by this second mechanism. The third mechanism is "passage" vorticity, which occurs as the core flow approaches the lobe exit and encounters the narrow gap between the centerbody and the bottom of the fan trough (Fig. 1, c), the vortex forms as flow washes up around the side of the fan troughs.

In 2005, N. J. Copper et al. [16] considered numerical simulation of the vortical structures in a circular lobed jet mixing flow, using four different turbulent models (kε standard, kε Realizable, kω standard, and kω Shear Strain Turbulence (SST)). The kε Realizable turbulent model provided the most accurate prediction of the lobed jet mixing flow.

2. Analysis of Researches of Additional Air Intakes and Afterbodies

For turbojet ejector nozzle operation, secondary air is required, which can be taken from turbojet primary air intakes or from auxiliary air intakes, located near the ejector nozzle. In addition, for verification of CFD analysis, it is important to have experimental data about afterbodies (fuselage or nacelle) air flow. Thus, it is well worth to analyze briefly open sources devoted to these air intakes and afterbodies air flow.

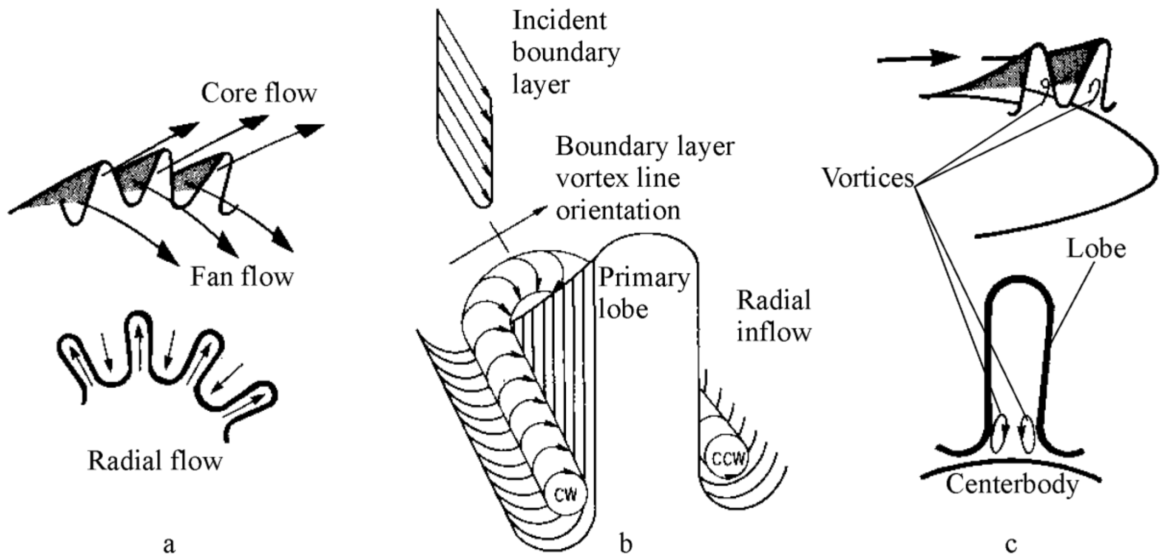

Fig. 1. Three mechanisms generating transversal flow within the lobes by [15]

In 1944, J. R. Henry [17] summarized experimental data of power plant installation pressure loss characteristics of duct components.

In 1954, R. J. Salmi [18] presented results of experimental researches of the pressure drag of various blunt-based conical afterbodies at M=0.6…0.9. When a convergent nozzle of the body discharges a jet from the base, boattailing becomes effective in reducing the afterbody drag. With no boattail, the effect of the jet was to aspirate the large annular base area to very low pressures.

In 1955, D. P. Hearth et al. [19] presented analytical method for matching secondary air flow of ejector nozzle to auxiliary air intakes on the base of experimental researches [20, 21]. At Mach numbers below 1.2, the net thrusts appeared to be unaffected by immersing of the inlet in the boundary layer. In 1955, P. C. Simon [22] presented experimental researches of nine circular auxiliary air inlets partially or completely immersed into supersonic turbulent boundary layer. In 1956, D. P. Hearth et al. [23] presented experimental evaluation of eight auxiliary inlets (located in a fuselage boundary layer), which supply secondary air flow to ejector nozzles (of two types) over a wide range of primary pressure ratios and free-stream M=0.64…2.00. Experimentally obtained values of pressure recovery were 68…75 % of the theoretical values, indicating large internal losses.

In 1956, J. R. Henry et al. [24] summarize experimental data of subsonic-diffuser and presented them as functions of geometric variables and flow parameters.

In 1957, R. G. Huff et al. [25] presented experimental study of nine auxiliary air inlets (rectangular, cylindrical and having angular turning) immersed in a turbulent boundary layer.

In 1957, F. V. Silhan et al. [26] presented drag characteristics of a series of conical and circular-arc afterbodies. Separation occurred at the cone-cylinder juncture, resulted in measured drag coefficient at boattail angles 30…45° approximately equal. When the afterbody was shortened, the region of more positive pressures is removed while the peak suction pressures remain so that separation at the cone-cylinder junction which eliminates the high suction pressures becomes beneficial.

In 1957, J. M. Cubbage [27] presented experimental researches of jet effects on the drag of twenty two conical afterbodies with convergent nozzle. The author concluded that the boattail angle for minimum afterbody drag at subsonic speeds was in the 5°…8° range; NPR did not change this angle, and at subsonic speeds slightly influenced the drag coefficient.

In 1968, G. D. Shrewsbury et al. [28] presented experimental study of effect of boattail junction shape on pressure drag coefficients of isolated afterbodies. In 1969, D. E. Harrington [29] presented jet effects on boattail pressure drag of four isolated cylindrical ejector nozzles. The author noted that, at subsonic speeds, the jet caused significant reductions in drag of the 15° boattails. This drag reduction was relatively insensitive to nozzle pressure ratio for values much less than the design value. However, boattail drag was further reduced as the jet pressure ratio was increased to the design condition and beyond. The author concluded that, in general, the effect of increasing secondary flow was to decrease boattail pressure drag by increasing the jet-exit static-pressure ratio. Secondary flow was most effective in reducing boattail pressure drag coefficient at subsonic speeds when the nozzle was operating at or near full expansion or was underexpanded. In 1969, B. J. Blaha et al. [30] presented experimental pressure distributions and boundary layer thickness on three models of afterbody. The authors noted that increasing boundary layer momentum thickness resulted in reduced boattail pressure drag coefficient, particularly at high subsonic speeds.

In 1970, D. Bergman [31] presented experimental researches of engine exhaust flow effect (jet plume shape and jet entrainment) on boattail pressure drag of conical plug-type nozzle. Jet entrainment (detrimental) effect (induced speed-up of boattail flow and lowers boattail pressure) appears at a jet velocity approximating freestream velocity and then increases with nozzle pressure ratio increase; but the jet plume-shape (beneficial) effect (which moves boattail flow streamlines away from the centerline, causing stronger flow recompression on the boattail surface) appears when jet flow become supersonic. In 1981, G. Carson et al. [32] studied experimentally and using CFD methods five axisymmetric boattail CD nozzle configurations. Dependencies of external pressure-drag coefficient vs. Mach number, nozzle pressure ratio and boattail angle were presented, which should also suit for ejector nozzles.

In 2024, S. Zhang et al. [33] presented results of numerical simulations of two types of air intakes embedded in a supersonic aircraft wing. The total pressure recovery factor for ram-air intake was greater than for submerged one at M=0.4, and vise versa at higher Mach numbers. In 2024, J. Zhu et al. [34] researched the influence of the double-ducted serpentine nozzle parameters on the flow characteristics and aerodynamic performance of aircraft. Total pressure recovery coefficient, flow coefficient, and axial thrust coefficient all decrease with an increase in aspect ratio, length-to-diameter ratio, and vertical shift.

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3. Analysis of Ejector Researches from Other Fields of Engineering

3.1. Analytical and Experimental Researches

Ejector theory for refrigeration systems was developed in parallel with thrust augmenters [35]. In 1942, J. H. Keenan et al. [36] firstly proposed two models: the constant pressure mixing (CPM) one and constant area mixing (CAM) one to solve the problem of expressing the momentum conservation in the mixing process. In 1950, J. H. Keenan et al. [37], taking into account a real gas properties and thermodynamic irreversibility, pointed out that the ejector designed on CPM model has a better performance than the CAM ejector.

In 1976, C. D. Mikkelsen et al. [38] presented a method for 1D analysis of the constant area ejectors, for the case, when both (primary and secondary) flows are supersonic, for high-energy chemical laser. In 1977, J. T. Munday et al. [39] introduced the concept of the «hypothetical throat», so that the secondary flow (being as if in a convergent nozzle) doesn't mix with the primary flow until it reaches the «hypothetical throat», which is located downstream of the primary nozzle exit. In 1985, B. J. Huang et al. [40] experimentally distinguished three operational modes of cooling ejector: critical (self-similar or double-chocking, when backpressure is below critical one, both primary and secondary flows are chocked and entrainment ratio is constant), subcritical (separation or single-chocking, when backpressure is greater than critical, but lower than breakdown pressure, only primary flow is chocked, and entrainment ratio varies linearly with the backpressure), and back-flow (or malfunction, when backpressure is greater than breakdown pressure, both flows are not chocked, and the entrainment ratio is negative).

In 1998, B. J. Huang et al. [41] used hypothetical throat area as a key variable to determine empirical correlations for ejector two limiting backpressures (which separates three flow modes).

In 1999, B. J. Huang et al. [42] presented modified (comparatively to [37]) 1D semi-empirical model of ejector performance for refrigeration systems (where losses factors were experimentally determined), in order to explain the choking phenomenon of the primary and secondary flows. In 2005, S. B. Riffat et al. presented a review [43] of ejector application in refrigeration systems. In 2007, Y. Zhu [44] described a shock wave model by considering the nonuniform distribution of the secondary flow in the suction chamber. The predictive accuracy of the model is improved compared with the traditional 1D ejector model.

In 2015, B. Tashtoush et al. [45] on the base of results of 1D analysis of ejectors for refrigeration systems, concluded that constant pressure mixing ejectors can achieve higher compression ratio; having the same entrainment ratio, they can reach higher pressure ratios, than constant area mixing ejectors. In 2016, S. K. Karthick et al. [46] presented results of parametric experimental studies of mixing characteristics within a low area ratio rectangular supersonic gaseous ejector. They noted that the entrainment ratio increased in over-expanded mode and decreased in under-expanded mode. In 2016, S. Elbel et al. presented a review [47] of recent research of ejector application in vapor-compression refrigeration systems. In 2016, F. Li et al. [48] presented 1D models for ejector performance predictions at critical point and breakdown point based on constant pressure mixing and constant-pressure disturbing assumptions accordingly. The authors also integrated the two models as the model to predict ejector performance at critical and subcritical operational modes (using bilinear dependence of entrainment ratio from backpressure).

In 2017, J. Liu et al. [35] presented simple 1D model of ejector performance (entrainment ratio and critical back pressure) for refrigeration systems real-time control. The model is based on the thermodynamic principles and ideal gas properties, and then was simplified to linear equations with four unknown parameters, which can be determined by least square method. But the model contained the ejector component efficiencies and geometrical parameters, which must be determined experimentally. In 2018, V. Kumar et al. [49] presented 1D model to determine geometry of a single-phase ejector for refrigeration system.

In 2024, D. Xu et al. [50] presented results of experimental investigation of a novel 2D ejector-diffuser system with different supersonic nozzle arrays. Numbers and types of nozzle plates installed on the ejector were varied to study the realizability of avoiding or postponing the aerodynamic choking phenomenon in the mixing section.

In 2024, H. Chen et al. [51] presented results of comparative study of the evolution laws of the design entrainment ratios in the ejectors with cylindrical or conical–cylindrical mixing duct under various operating conditions, based on 1D theoretical models validated through experiments.

But all these models use an assumption that the kinetic energy of the primary and secondary flows at the inlets and the mixing flow at the outlet are negligible, which makes impossible to use them for thrust-augmenting ejector nozzles. Thus, only some elements of the models can be applied.

3.2. Analysis of researches Using CFD Models

In 2004, Y. Bartosiewicz et al. [52] considered evaluation of six well-know turbulence models (kε standard, kε realizable, RNGk–ε, RSM, kω standard, kω-SST) for study of supersonic ejectors of refrigeration application. The kω-SST turbulence model agreed best with experiments and RNDkε was a bit worse.

In 2012, Y. Yu. Shademan et al. [53] presented results of CFD investigation of geometry influence of four convergent primary nozzles on the turbulent characteristics of incompressible fluid flow. The authors considered six turbulence models (Spalart-Allmaras, kε standard, realizable and RNG, kω standard and SST, and the Reynolds Stress Model (RSM)) and concluded that, RSM produces more accurate results for the prediction of turbulent fluctuations. In 2013, W. Chen et al. [54] presented results of CFD analysis of ejector parameters to maximize both the ejector entrainment ratio and the pressure ratio together for natural gas transportation. In 2017, L. Wang et al. [55] presented results of CFD simulations of ejector primary nozzle geometrywith the purpose to improve primary mass flow rate and entrainment ratio. In 2017, K. Zhang et al. [56] presented results of numerical investigation of the effect of nozzle position on entrainment ratio and pressure increase ratio of the refrigeration system ejector and noted non-linear dependence of entrainment ratio from nozzle position. In 2019, B. M. Tashtoush et al. in review [57] have analyzed ejector geometry for refrigeration systems, mathematical models, visualization attempts, various refrigeration systems and working fluids. The authors also stressed that, there exist some contradictions in the findings among research publications.

In 2020, G. Pradeep et al. [58] numerically studied the entrainment ratio and the transition from the critical to the mixed flow regime of supersonic ejector intended for refrigeration technique. In 2020, W. Ye et al. [59] numerically studied flow structures in so-called multi-strut mixing ejector (version of flat multiple jet ejector) for refrigeration systems. The authors noted extremely complicated flow structure inside the ejector, and the fact that the secondary flow made great influence on the general flow structure. In 2025, J. Galindo et al. [60] presented results of CFD research of the sensitivity of a jet ejector of refrigeration system to variations in the inlet temperatures. It was noted significant influence of mesh parameters.

Thus, because different authors gave preference to different turbulence models, there is a necessity in numerical experiments to select both reasonable turbulence model and reasonable mesh parameters for problems of specific class.

Conclusions

1. One of the known methods of aircraft jet engine thrust increase is based on application of ejector nozzles.

2. Ejectors are also used in multitude of other fields of engineering.

3. Literature analysis showed that one of the major processes, influencing on ejector nozzle thrust, is mixing of the flows.

4. There is a lot of publications devoted to both experimental and CFD investigations of lobed mixers, which indicates that, significant thrust augmentation increase can be realized due to their application into ejector nozzles. The level of gain depends on the trade-offs between the degree of mixing of the two streams and the viscous losses incurred in the mixing process.

5. When using lobed mixers, large-scale secondary flows, not viscous diffusion, are the key to low-loss efficient mixing. There are three mechanisms responsible for the generation of transversal flow within the lobes themselves (the first one is due to the basic turning of the fan and core streams in opposite radial directions; the second mechanism is "horseshoe" vorticity; and the third mechanism is "passage" vorticity).

6. Optimization of additional air intake location and afterbody shape can substantially reduce external drag and, thus, increase effective thrust augmentation.

7. There is also a numerous literature as for research of ejectors from various branches of engineering. But all models described there use an assumption that the kinetic energy of the primary and secondary flows at the inlets and the mixing flow at the outlet are negligible, which makes impossible to use them for thrust-augmenting ejector nozzles. Thus, only some elements of the models can be applied.

8. In numerous CFD researches of industrial ejectors, different authors gave preference to different turbulence models, thus, there is a necessity in digital experiments to select both reasonable turbulence model and reasonable mesh parameters for problems of specific class.

9. Features of geometric shape and flow nature at mixing of the flows within lobe mixers, and also the fact, that at a reasonable length of turbojet ejector nozzle, it is not possible to provide complete flow mixing inside it, stipulate the necessity of numerical study of the processes in lobe mixers and corresponding ejector nozzles using 3D numerical methods.

10. To reach the stated goal, it is necessary to solve the following problems:

– Develop mathematical model of UAV’s power plant with turbojet and ejector nozzle;

– Develop engineering designing method of ejector nozzle for micro-turbojet;

– Verify this method in an existing engine.

Contribution of authors: conceptualization – **Sergiy Yepifanov**; review and analysis of information sources – **Ruslan Tsukanov**.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

All the authors have read and agreed to the published version of this manuscript.

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ОГЛЯД ЕЖЕКТОРНИХ СОПЕЛ. ЧАСТИНА 2 – ЗМІШУВАЧІ ТА ДОДАТКОВА ІНФОРМАЦІЯ

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Предметом вивчення в статті є ежекторні сопла, призначені для підвищення тяги реактивних двигунів, і відповідні змішувачі потоків. **Метою** є зменшення гостроти протиріч між потрібними високими характеристиками ежекторів, зокрема коефіцієнтом збільшення тяги, й компактністю; між суперечливими цілями досягнення високого темпу змішування з малими втратами повного тиску первинного потоку в межах короткої загальної довжини. **Задачі:** виявлення шляхів підвищення тяги та мінімізації зовнішнього опору ежекторних сопел шляхом аналізу досліджень пелюсткових змішувачів турбореактивних двоконтурних двигунів, експериментальних досліджень форми та розміщення додаткових повітрозабірників, експериментальних досліджень форми хвостових частин фюзеляжу та мотогондоли, досліджень ежекторів з інших галузей техніки (як експериментальних так і з використання моделей обчислювальної гідродинаміки). Використовуваними **методами є:** пошук відповідних джерел у мережі Internet та їх аналіз виходячи з власного досвіду роботи в авіаційній галузі. Отримано наступні **результати.** На основі знайдених джерел інформації виявлено, що найефективнішим пристроями для забезпечення найповнішого змішування первинного і вторинного потоків у коротких камерах змішування є пелюсткові змішувачі; сформульовано їх переваги та недоліки; висвітлено три механізми, що відповідають за процес змішування за пелюстковими змішувачами. Розглянуто велику кількість експериментальних досліджень характеристик додаткових повітрозабірників і хвостових частин фюзеляжу та мотогондол. Проаналізовано розвиток як експериментальних, так і теоретичних досліджень ежекторів в інших галузях техніки. **Висновки.** Наукова новизна отриманих результатів полягає в наступному: в одній оглядовій статті зібрано інформацію з багатьох літературних джерел, що характеризує пелюсткові змішувачі, як пристрої для покращення ефективності ежекторних сопел, переваги й недоліки таких змішувачів, розвиток дослідження цих змішувачів теоретичними (з використанням обчислювальної гідродинаміки) та експериментальними методами. Виявлено рекомендації щодо вибору форми та розміщення додаткових повітрозабірників та хвостових частин фюзеляжу та мотогондол. Констатовано вельми обмежену користь моделей ежекторів, розроблених в інших галузях техніки, для підвищення тяги турбореактивних двигунів. Таким чином виявлено шляхи для розроблення методики проєктування ежекторного сопла для підвищення тяги мікро-турбореактивних двигунів. Намічено мету та задачі подальших досліджень у цій галузі.

Ключові слова: газотурбінний двигун; ежекторне сопло для підвищення тяги; коефіцієнт підвищення тяги; відношення вторинної витрати до первинної; первинне сопло; камера змішування ежектора.

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