Проведено експериментальне дослідження аеродинамічних характеристик конструктивної схеми "крило – мотогондола з двоконтурним двигуном". Дані отримані при роботі перспективної системи нейтралізації тяги двоконтурного двигуна великого ступеня двоконтурності при посадці пасажирського літака. Актуальність проведених досліджень обумовлена поліпшенням експлуатаційних характеристик пасажирського літака. На основі проведеного аналізу функцій і принципових схем реверсивних пристроїв на транспортних і пасажирських літаках запропонований перспективний метод нейтралізації тяги двоконтурного двигуна з великим ступенем двоконтурності. Фізична сутність методу нейтралізації тяги двигуна полягає в істотному обмеженні потоку повітря в двигун способом повороту робочих лопаток вентилятора в момент посадки літака. Розроблена спеціальна методика проведення вагового та дренажного експерименту з моделлю мотогондоли турбореактивного двоконтурного двигуна в аеродинамічній трубі. Отримані експериментальні дані дозволяють оцінити граничні можливості досліджуваного методу нейтралізації тяги для зменшення довжини пробігу літака. Дренажним експериментом і візуалізацією шовковинками виявлено відрив потоку на зовнішній поверхні моделі мотогондоли з повністю закритим входом. Наявність відриву потоку зумовило виявлене ваговим експериментом збільшення лобового опору моделі мотогондоли приблизно в 2,5 рази. У ваговому експерименті встановлено, що наявність екрануючої поверхні (наближення мотогондоли двигуна до злітно-посадкової смуги) збільшує лобовий опір моделі мотогондоли приблизно на 14 %. У дренажному експерименті встановлено, що це збільшення лобового опору обумовлено істотним перерозподілом тиску по поверхні моделі мотогондоли. Дослідження показали, що ідея закриття входу в двигун великого ступеня двоконтурності в момент посадки літака є одним з перспективних методів зменшення довжини дистанції пробігу літака

Ключові слова: реверс тяги, нейтралізація тяги, вентилятор, мотогондола, двоконтурний двигун, аеродинамічна труба, дистанція пробігу

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EXPERIMENTAL RESEARCH INTO AERODYNAMIC CHARACTERISTICS OF A NACELLE WITH THE ENABLED SYSTEM OF ENGINE THRUST NEUTRALIZATION

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1. Introduction

Reverse devices of powerplants (PP) with air-jet engines are commonly used in transport and passenger aircraft fleets. Given an increase in the thrust-to-weight ratio of modern aircraft (AC) for standard take-off and landing, these devices will definitely find wider application [1, 2].

The reverse is used in combination with the main (wheel) aircraft braking system, which makes it possible to reduce the load on the primary aircraft braking system and to shorten the braking distance. Application of thrust reverse is required at a low coefficient of adhesion between aircraft wheels and a runway at the landing stage. PP in a passenger (transport) aircraft must provide for both direct and reverse (negative) thrust. A reverse device is such an AC element that must be equally aligned with both PP and a glider [3, 4]. Taking these requirements into consideration results in a significant increase in the direct operating costs for modern turbojet two-circuit engines (TJTE). The need to bring down financial cost and to save energy resources necessitates an analysis of consistency in the characteristics of PP and a glider, specifically, the choice of the type of a reverse device and its position at AC [1, 4].

The advent of TJTE with a large by-pass ratio (m>4...6) gave rise to an impetus in the development of reverse devices. The emergence of TJTE with a very large by-pass ratio (m>8) justified the research into design of reverse devices of new generation. It has become relevant to develop reverse devices based on the new principles for the organization of a workflow [1, 5]. The application of such devices would improve operational characteristics of modern and prospective aircraft.

2. Literature review and problem statement

In TJTE, the reverse of a gas flow is implemented through the deviation of part or the entire jet that comes out of the engine by using various shutters. In different engines a reverse device is designed in a different structural technique [6, 7]. Requirements to reverse devices, their function, basic characteristics, as well as the results of modelling and field studies, and the basis for a gas-dynamic calculation, are reported in papers [1, 6, 8, 9]. The necessary degree of thrust reverse required for aircraft braking within a runway (RW) is determined, first and foremost, by the landing weight of an aircraft and the landing approach speed [7]. However, the papers demonstrate diagrams and application results of the long-known principles of aircraft braking at the landing stage. Such schemes are not always appropriate for application for modern and prospective airplanes.

Study [4] described a dependence of the aircraft kinetic energy absorption by different braking means on the RW travel duration. It is shown that the overall reduction in kinetic energy of an aircraft at any time is determined by the sum of the effects of various kinds of resistances. However, quantifying the contribution of components of drags is complicated, which is a relevant field of experimental research into various means and techniques of AC braking at the landing stage.

In modern aviation, the widespread TJTE are those with a large by-pass ratio that do not mix flows [1, 3, 5]. In this case, not the entire gas flow coming out of the engine is almost always reversed, but only the air from the second circuit. At the same time, the first circuit continues to work for a direct thrust, with engine's rotations close to maximum (at full reverse). Structurally, such a system is executed quite simply; there are two main directions for it.

In the first direction, air is forwarded by special shutters, located closer to the output device of the second circuit. In the closed position (reverse is off), they form a channel of the second circuit and the outer surface of a nacelle by their internal and external surfaces, respectively (for example, A318, A319, A320-100/200, A321-100/200, A340-200/300).

In the second direction, enabling the thrust reverse shifts the rear part of a nacelle's body backwards, thereby opening, along the engine's circumference, those profiled grids that it closes by itself when the reverse is off. In this case, a kinematic mechanism pushes special deflectors into a flow of the second circuit, which redirect it to the above-specified grids (for example, B737, B757, B767, C-17 Globemaster III, A320-100/200, A340-500/600, An–124, Il-76TD-90VD, Tu-204 and others).

There are planes that do not have any thrust reverse of jet engines (Yak-42, BAe146-200). Both AC have a well-developed wing mechanization, which greatly improves their takeoff and landing characteristics.

The reverse on aircraft with turboprop engines is implemented by rotating a propeller blades (a blade's angle of attack changes from positive to negative) at a constant direction of rotation. Such a type of the reverse device can be used also at airplanes with turbopropfan and piston engines. Thrust reverse due to the rotation of propeller blades (a propfan) significantly increases the maneuverability of an aircraft, both in the air and on the ground. This effect is particularly effective when landing on a short-length RW [10, 11]. The practical application of this method for thrust reverse has the greatest efficiency. A complex flow pattern with the possible emergence of an unstable engine work under conditions when an aircraft travels along RW requires special experimental research into a full-scale engine with a simulation of an external airflow.

Paper [12] reports results of experimental research, using a silk tuft technique, into a flow pattern around a model of propeller at its work in the profiled ring, and without a ring, under the mode of thrust reverse during a wind-tunnel test (WTT) at a propeller device. The authors compared flow-around schemes with the results of weight measurements of aerodynamic forces on the propeller and in the profiled ring. It should be noted that one of the problems related to the turbopropfan engines with a super-high by-pass ratio with rotary hood propellers (NK-93, CRISP) is to ensure the required magnitude of thrust reverse from the moment of AC braking until its full stop [1]. In this case, application of the traditional design of reverse devices is almost impossible. Generalizing studies into thrust reverse of such turbopropfan engines are not yet available.

When constructing contemporary reverse systems, one takes into consideration the practice of studying gas-dynamic effects that occur in the region of the nacelle and wing at airplane landing [13, 14]. Apparently, the best result could be achieved by triggering a reverse device earlier and by minimize the time period when a nose wheel touches ground and aircraft movement is leveled [15, 16]. However, no such studies have been found in the scientific literature. In terms of effectiveness, the second-best thing is to eliminate an undesirable interaction between a reversed jet and an aircraft's glider [16, 17]. And the least effective way for improvement is the later throttling of PP engine [18]. Implementation of all measures on enhancing the effectiveness of a reverse device at an aircraft would make it possible to obtain a substantial reduction in the length of the run.

Depending on the structural characteristics of aircraft, papers [19–22] explore the design features of engine nacelles taking the aerodynamic effects into consideration. However, these papers fail to fully account for the complexity of a workflow in an engine, the spatial nature of flow around a nacelle at the stage of landing.

Study [23] investigated the effect of air flow in the region of location of the nacelle of an engine with a large by-pass ratio on the characteristics of the wing. To study these effects, the authors used a wind tunnel with a model of a transport aircraft in the landing configuration. The lifting force coefficient and the drag coefficient of the wing profile were derived for different angles of attack. The impact of the type of a nacelle on the characteristics of the wing was examined using photographs of woolen tufts. All tests are performed in the low-speed wind tunnels with Reynolds numbers from 0.5×10^6 to 1.0×10^6. Nacelles with a different inlet diameter are arranged sequentially. It is noted that the maximum angle of attack decreases with an increase in the diameter of a nacelle, while the maximum coefficient of lift force is less affected due to the optimized profile of the nacelle. However, the obtained research results cannot be applied to the analysis of reverse devices based on the new principle of action.

The NASA Aerodynamics Division is actively involved at the stage of integration of aircraft and engine elements using computational fluid dynamics [24]. The applied aerodynamic program includes analysis of an aircraft model and prediction of interference effects from an aircraft and an engine nacelle. These studies do not imply resolving a task on the application of the new principle of aircraft braking at the time of landing. The results of research involving the prediction of effects are incomplete.

The purpose of an experimental study in a small transonic wind tunnel [25] is to implement a jet simulator within the framework of a study into integration of the wing and nacelle with the analysis of behavior of a jet stream. The authors performed an analysis of the shape of a free jet and a jet stream. These experiments enrich the database for aerodynamic studies into interaction between the wing and nacelle. However, it is difficult to apply the results obtained in order to analyze a nacelle with the engine that has a super large by-pass ratio.

Paper [26] provides materials from a Symposium of the German Association of Aerospace Aerodynamics (STAB) and the German society of Aeronautics and Astronautics (DGLR). It gives results of research into the field of numerical and experimental aerodynamics of different aircraft configurations with elements of the optimization of the shape of active and passive devices in a powerplant. However, the studies do not address engines with a super large by-pass ratio, which does not make it possible to predict the application of promising schemes for reverse devices.

Research into aerodynamic phenomena during AC flight must take into consideration the level of impact that the parameters of a working process exert on the environment. Papers [27, 28] consider up-to-date technical and technological issues (aerodynamics, engines, fuel, designs, etc.) related to mitigating the impact of aviation on the environment. However, the studies do not address engines with a super large by-pass ratio, which does not make it possible to reveal the effect of operating characteristics of reverse devices on the environment.

Thus, an analysis of information sources demonstrates that there are specific problems associated with the use of an engine thrust reverse at aircraft:

– cases of unstable operation of engines ("surging") during airplane run using thrust reverse;

– damage to the working blades of compressor from foreign objects, which are thrown by reversible jets from the surface of an airfield;

– distortion of the crew's readings of airspeed during aircraft run;

– a possibility for the occurrence of an important aerodynamic effect: in proportion to deceleration within a narrow speed range along RW, there is a sharp and substantial increase in a lifting force coefficient, which presses the plane to the runway.

All the specifies problems are predetermined by the unsatisfactory external aerodynamics of PP during AC run with the use of thrust reverse. Therefore, it is a relevant scientific task to study the aerodynamic characteristics of the structural scheme "wing – two-circuit engine nacelle" during operation of the engine's reverse device with a large by-pass ratio when landing a passenger plane.

Thus, the present work, in order to resolve an issue on the unsatisfactory external aerodynamics of PP during AC run using existing systems of thrust reverse, set the aim to study a possibility of creating a fan with rotary blades at the input to engine in order to shorten the length of the run.

3. The aim and objectives of the study

The aim of this study is to undertake an experimental study into aerodynamic characteristics of the structural scheme "wing – nacelle with a two-circuit engine". The characteristics are to be studied during operation of a promising system for the neutralization of thrust in a two-circuit engine with a large by-pass ratio when landing a passenger aircraft.

To accomplish the aim, the following tasks have been set:

– to construct a model "wing – nacelle" for the engine with a large by-pass ratio and to devise a procedure for conducting the weight and drainage experiment;

– to explore experimentally the physical essence of the method for neutralizing engine thrust, which implies a substantial restriction on the flow of air that enters the engine, by rotating the fan's working blades at the time of aircraft landing;

– to calculate a typical case of aircraft landing with the engine's thrust neutralization at different by-pass ratios.

4. Development of a procedure for conducting the weight and drainage experiment

Despite the progress in theoretical aerodynamics, determining an aircraft aerodynamic characteristics (ADC) based on testing its models in a wind tunnel has remained the primary and most reliable tool when designing new configurations and improving those already existing. Any suggestions on the formation of configurations, as well as recommendations aimed at improving ADC of existing aircraft, are implemented only after testing them experimentally on models in a wind tunnel [29].

A weight experiment is a direct method for measuring forces and momenta using the aerodynamic balance. This method is traditionally considered to be the most accurate and reliable method in aerodynamics. However, in a general case, WTT conditions do not fully correspond to field conditions; therefore, results of experimental studies require the introduction of methodological corrections in order to approach actual flight conditions. Magnitudes of corrections depend on the extent of differences between geometric parameters of a model and AC, techniques to fix a model, and differences between test conditions and flight conditions. In addition, the weight experiment has several limitations. For example, conducting experimental investigations at low velocity of flow around an AC surface of very small size (up to 10 cm) is difficult in existing wind tunnels given their current equipment, and sometimes impossible at all. In this case, results of many performed wind-tunnel experiments are contradictory and cannot allow for a reliable basis for constructing clear theoretical positions. Therefore, experimental setups must be specially modernized.

The above studies employed a wind tunnel with low subsonic speeds T-1, of the closed type with an open working part that has a cross-section in the form of an octahedron, it is equipped with the three-component scale ZKT-1. The wind tunnel is fitted with a system for smooth control over flow velocity in the range from 1.5 to 50 m/s. The aerodynamic contour T-1 with the enumeration of basic parts is described in paper [29]; basic specifications of the wind tunnel are given in Table 1.

Table 1

Basic specifications for the wind tunnel T-1

Flow velocity in working part: maximum/minimum	50 m/s/1.5 m/s
Reynold's number per 1 m	to 3×10^6
Full pressure	atmospheric
Speed head	to 2.05 kPa
Range of angle of attack α	–15°...25°
Dimensions of working part: width×height×length (m)	1.0×0.7×1.3
Nozzle waisting degree	5
Fan diameter	1.5 m
Relative diameter of fan bushing	0.5
Fan rotations number/maximal/	1,000 rpm
Drive electric motor power	30 kW
Aerodynamic quality of wind tunnel/with grids/	2.7

Paper [30] addressed determining a degree of perfection of the wind tunnel T-1 experimentally. It provides the experimentally determined indicators of the wind tunnel T-1 perfection: quality of wind tunnel χ, flow turbulence in a working part ε, a field coefficient in the wind tunnel's working section μ_i, a range of change in flow velocity in a working part of the wind tunnel. An analysis of data suggests their compliance with actual conditions set for measuring tools. This ensures high reliability of results from aerodynamic tests, reproducibility of the obtained results in other wind tunnels, resistance to the possible impact of external random factors.

In order to conduct an experiment in the wind tunnel T-1, we fabricated a fiberglass model of a TJTE nacelle on a pylon. Photograph of the model inside a working part of the wind tunnel T-1 is shown in Fig. 1

.

Fig. 1. Photograph of the physical appearance of a working part of the wind tunnel T-1 with a model of the two-circuit engine

The manufactured model corresponds to TJTE with a by-pass ratio of m=15. The drained model of a TJTE nacelle on the pylon was made with a flow channel, which can be fully or partially closed with plugs (Fig. 2).

Determining a pressure distribution at the surface of a body is one of the most common types of experiment in wind tunnels. It is required for determining total pressure forces, local allocation of forces and the nature of flow near the surface of any aerodynamic shape of the body. Pressure distribution on the surface of a body is determined using specialized drained models, whose surface has small-diameter openings – static pressure receivers. The disadvantage of the drainage method is the difficulty in selecting the number and arrangement of openings when studying the pressure distribution at the surface of the wing and fuselage at their varying positions relative to the flow direction. In this case, particularly difficult is to drain the thin socks and wing edges.

a *b*

Fig. 2. Model's physical appearance: *a* – with a closed outer contour; *b* – model with a fully closed input

During test, the model was fixed at the vertical holder of the aerodynamic scale ZKT-1. The scale directly measures frontal drag X_a, lifting force Y_a, and longitudinal moment M_z of the fixed model. To account for the influence of a separating surface (the impact of RW), we used a stationary flat wooden screen.

To investigate the distributed characteristics, the surface of the model of an engine nacelle was fabricated drained, of the collector type; the drainage of the model was performed according to specifications from [31]. At the inner side of the nacelle, along chords, we cut two longitudinal grooves, into which the thin-walled pipes with an outer diameter $D_{out}=2$ mm were inserted. The first groove (lower) is in the plane of symmetry of the nacelle, groove No. 2 (upper) is located at distance $\gamma=7{,}5^o$ relative to the plane of symmetry. The nacelle is divided into 6 longitudinal bands with relative coordinates $\overline{x}=\dfrac{x}{b}$=0.2; 0.3254; 0.4734; 0.6213; 0.7692; 0.9172. At the points of intersection of longitudinal bands and collectors we made drainage openings with diameter $D_{\text{coll}}=2$ mm perpendicular to the plane, tangent at a given point. Thus, there are 6 drainage openings in the bottom part of the nacelle with 2 at the top. In order to simultaneously measure pressure at multiple points of the nacelle model, we applied a battery-powered micromanometer in the form of a series of glass tubes whose lower end is connected to a common reservoir. The upper end of each tube in the micromanometer is fed with pressure at the corresponding point. A magnitude that will characterize the pressure is accepted to be a pressure coefficient C_p, equal to the ratio of excess pressure at the examined point at the surface of body ΔP_i to the speed head of incident flow $C_{pi}=\dfrac{\Delta P_i}{q_\infty}$.

Prior to the experiment, we register the initial values for fluid levels l_{0i} in in reading tubes. By analogy with a cup micromanometer, an expression for a pressure difference at the i-th point will take the following form:

$$\Delta P_i=\frac{\rho_{fluid}}{\rho_{al}}g(l_i-l_{0i})k_{bat.manom},$$

where ρ_{fluid} is the density of the fluid, poured to micromanometer, g/cm^3; ρ_{al} is the density of a reference liquid (alcohol), g/cm^3; l_i is the height of a liquid level in the i-th reading tube, mm; $k_{bat.manom}$=0.2567 is the factor of a battery micromanometer, g/cm^3.

The chosen methods to study aerodynamic characteristics are the weight and drainage experiments. Maximum flow velocity in a working part of the wind tunnel, at which the study was conducted, amounted to 40 m/s, which corresponds to the Reynolds number $Re \approx 7{,}25 \cdot 10^5$, computed based on a diameter of the model. When processing experimental data, we employed a correction method with the introduction of corrections for different effects [32].

5. Results of processing data from the weight and drainage experiment to study aerodynamic characteristics

In order to give a quality representation of the aerodynamic effects, we show photographs of the detachment of an airflow in a trace following the nacelle model, which is defined by the characteristic "blur" of silk tufts at a special screen and at the surface of the model. There is no any flow detachment after the nacelle model with a passage; for the nacelle model with a closed outer contour, it is barely visible along the model's contour; and it is clearly seen after the nacelle model with a fully closed input. To study a flow pattern around the model of TJTE nacelle, we manufactured a longitudinal screen with silk tufts and installed it in a working section of the wind tunnel, to illustrate a detaching flow in the frontal part of TJTE model with a fully closed input. Thus, we have shown experimentally that closing the TJTE input gives rise, in the frontal part of nacelle, to a complex spatial detaching flow, which predetermines a gain in the frontal drag.

Fig. 3 shows dependences, derived by processing data from the weight experiment, of frontal drag in TJTE model on flow rate in the wind tunnel's working section, in the absence of influence from the underlying surface (RW) on the nacelle.

Fig. 4 shows dependences, derived by processing data from the weight experiment, of frontal drag in TJTE model on flow rate in the wind tunnel's working section. In this case, we took into consideration the existence of influence from the underlying surface on the nacelle at a relative height of the model above the screen of

$$\bar{h} = \frac{h}{l} = 0{,}15.$$

Estimation of an increase in the drag of the nacelle model at full and partial closing of air passage through the model is shown in Fig. 5, 6. The increase in the drag of the nacelle model when approaching a separating surface (RW) should be noted, which could possibly be explained by a tunnel effect between the bottom surface of the nacelle and RW.

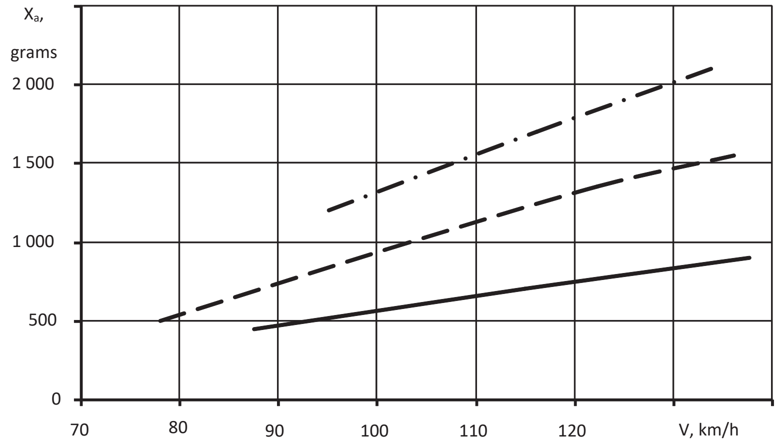

Fig. 3. Dependence of the model's frontal drag on speed in ADC working section; no influence from the underlying surface (——— – model with a passage; - - - - - – model with a closed external contour; — · — – model with a fully closed input)

The processed results from the drainage experiment involving a nacelle model with a closed input at maximum speed in the presence and absence of an underlying surface are given in Table 2.

Table 3 gives values for an increase in the frontal drag of TJTE nacelle at full and partially closed input to the engine. The values are converted to the actual dimensions and Reynolds numbers that correspond to an actual nacelle in line with the procedure presented in paper [33]. Here we also take into consideration the presence and absence of RW for a typical case of aircraft landing at a landing speed of 220 km/h.

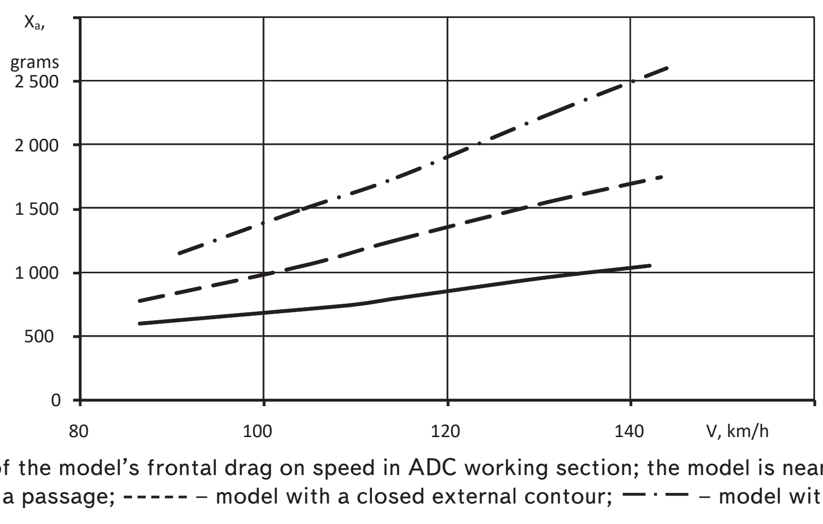

Fig. 4. Dependence of the model's frontal drag on speed in ADC working section; the model is near the screen's surface (——— – model with a passage; - - - - - – model with a closed external contour; — · — – model with a fully closed input)

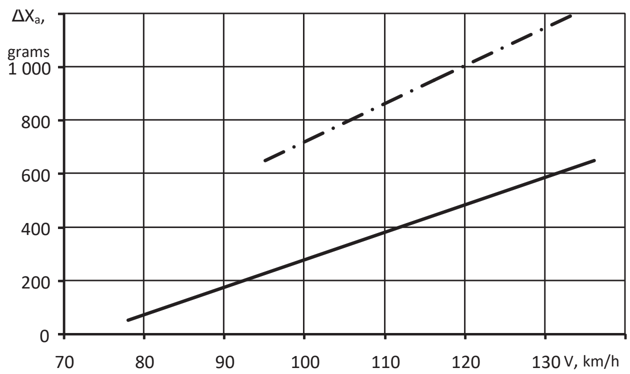

Fig. 5. Dependence of an increase in the model's frontal drag on speed in ADC working section; no influence from the underlying surface (——— – model with a closed external contour; — · — – model with a fully closed input)

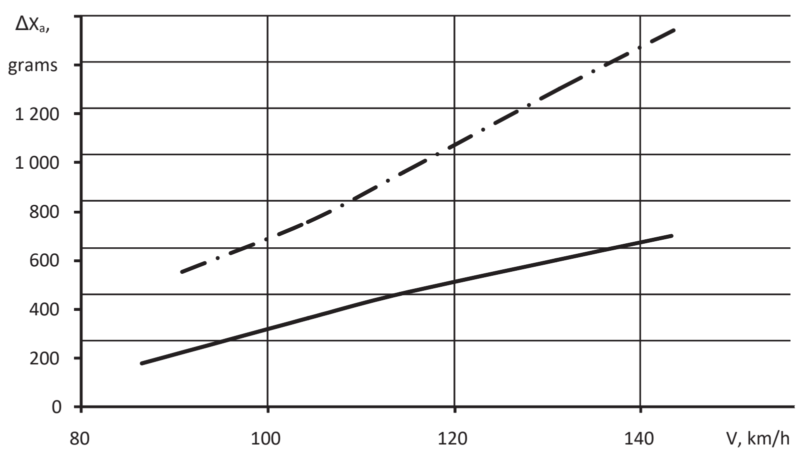

Fig. 6. Dependence of an increase in the model's frontal drag on speed in ADC working section; the model is near the screen's surface (——— – model with a closed external contour; — · — – model with a fully closed input)

Table 2

Distribution of C_p on the surfaces of the nacelle model with a fully closed input

No screen surface								
No. of opening	1	2	3	4	5	6	7	8
Surface	Lower surface						Upper surface	
Value for C_p	0.097	0.0712	0.0248	0.0152	0.0133	0.0152	0.0733	0.0833
Model near screen surface								
Surface	Lower surface						Upper surface	
Value for C_p	0.0582	0.0538	0.0459	0.0467	0.0315	0.027	0.074	0.0813

Table 3

Values for an increase in the frontal drag of nacelle for TJTE engine

Characteristic	In free flow	With respect to RW
ΔX_a, kg (at a fully closed input to engine)	190	220
ΔX_a, kg (at a closed engine's outer contour)	90	110

The obtained values for an increase in the frontal drag of engine nacelle were applied when evaluating the length of a run by an aircraft of the An-148 type. The study was conducted using the developed modular software package "Integration-2.1" based on the procedure outlined in paper [34].

6. Discussion of results: calculation of a typical case of aircraft landing with the neutralization of engine thrust at different by-pass ratios

To quantify the influence of a by-pass ratio on the characteristics of AC, we shall extrapolate the obtained results on TJTE with different by-pass ratios. Table 4 gives values for an increase in the frontal drag of a TJTE at a fully closed inlet to engine ΔX_a, with or without RW, for a typical case of landing an aircraft of the An-148 type with a landing speed of 220 km/h.

Table 4

Values for an increase in the frontal drag of a TJTE engine's nacelle

Characteristic	In free flow	With respect to RW
ΔX_a, kg (m=12)	137	159
ΔX_a, kg (m=20)	239	277

Table 5 gives results of the calculation of a typical case of landing an aircraft of the An-148 type with engines with varying by-pass ratios at a landing speed of 220 km/h onto a dry concrete RW, which is at sea level. It should be noted that the considered case of landing upon a dry concrete RW yields the smallest gain in the run length when closing input to engines, as, in this case, a proportion of the total kinetic energy of an aircraft, absorbed by the wheels' brakes, is the largest.

Table 5

Results of calculating a typical case of aircraft landing

Characteristic	Without reverse	When closing input to engines	With the maximal reverse
L_{run}, m (m=15)	790	771	637
L_{run}, m (m=20)	777	759	628

Calculation of AC run distance at m=15 allows us to make the following conclusions:

– closing an input to engines insignificantly (by about 2.5 %) reduces the length of aircraft run, which could be possibly explained by a significantly greater contribution to the absorption of aircraft kinetic energy by the brakes and aerodynamic drag of the aircraft itself with the wing mechanization released;

– small dimensionality of the model of an engine nacelle and a wind tunnel impede reliable conversion of the results obtained during blowing into full-scale Reynolds numbers, which is why the results derived are preliminary.

Calculating a distance of AC run at m=20 allows us to argue about the following:

– when increasing a by-pass ratio up to 20 units, the length of an aircraft run somewhat decreases in all cases, owing to an increase in the total aerodynamic drag of the aircraft with an increased diameter of engine nacelles;

– closing an input to engines at m=20 reduces the length of an aircraft run by approximately 4 % (calculated based on the length of an aircraft run with engines with a by-pass ratio of m=15 without reversing);

– the greatest gain in reducing the length of an aircraft run could probably be obtained at the expense of the earlier triggering of a reverse device. An increase in the landing speed increases frontal drag of TJTE nacelle at a fully closed input to the engine in proportion to the square of speed (Fig. 7).

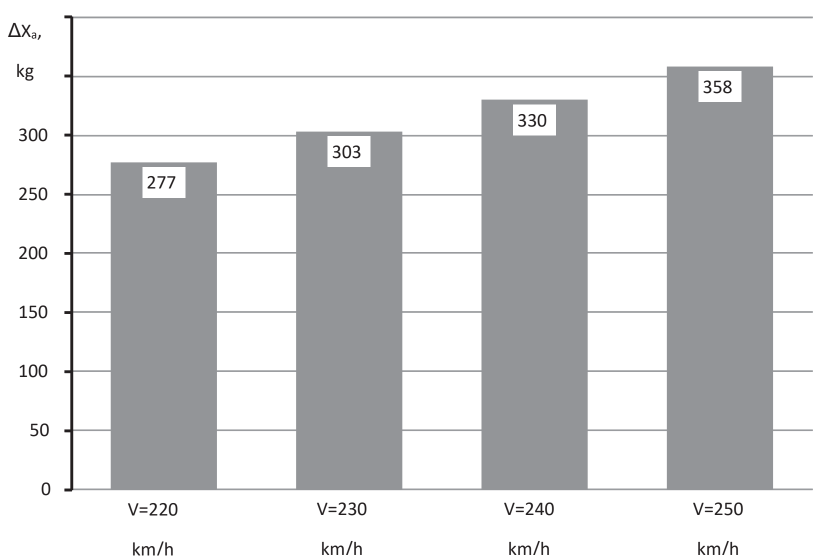

Fig. 7. Magnitudes of increase in TJTE nacelle's frontal drag at a fully closed input to the engine with a by-pass ratio m=20 and different aircraft landing speeds

Thus, the results of research presented here make it possible to build a projected dependence of the magnitude of AC run length on engine's by-pass ratio (Fig. 8). We present dependences of aircraft run length, when landing onto a dry concrete RW, which is at sea level, on the by-pass ratio of TJTE. Dash-dotted line – without using the reverse, dashed line – when closing an input to engines, solid line – maximum reverse.

An analysis of the provided dependence allows us to draw a general conclusion about reducing the length of an aircraft run in all cases when increasing a by-pass ratio. However, the quantification of the magnitude of decrease in an airplane run length requires further detailed research, since the procedures represented in this work do not fully take into consideration the impact of a scale effect on the magnitude of aerodynamic forces. To ensure the required broad range of change in the operation modes of a powerplant with a by-pass ratio exceeding 10 units, it is necessary to apply control over a flow-through part of the engine. It is implied to use rotary blades of the fan's impeller, rotating blades of the fan's guiding device, an adjustable output device of external contour. It is known that high values for a by-pass ratio are the source of enhancing a phenomena of throwing particles in connection with large masses of air sent into space, confined by the wing of an aircraft, RW, the fuselage, and outer engines. In this case, the flaps set into a landing position form a more closed volume, exacerbating the problem of throwing foreign objects to aircraft engines.

The results, obtained in this work, are preliminary in nature, due to the constraints for equipment applied in a wind-tunnel experiment, to the application of semi-empirical procedures for calculating the take-off-landing characteristics of an aircraft. The prospects for the further study are as follows:

– to establish the impact of closing an input to engines, located under the wing, on the aerodynamic characteristics of the wing;

– to establish a character of the spatial flow around a nacelle of the engine with a closed input;

– to develop specialized software to calculate the length of AC run in order to account for operational factors;

– to refine results of the weight and drainage experiments.

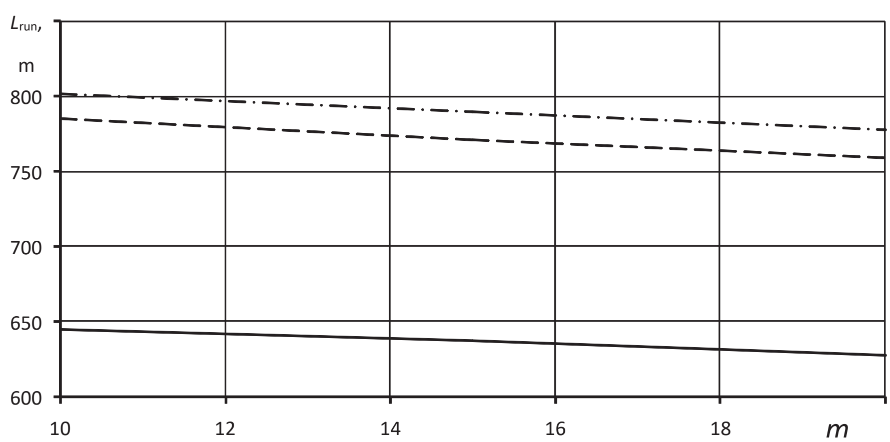

Fig. 8. Dependences of aircraft run length on engine's by-pass ratio

7. Conclusions

The result of our work is the constructed model "wing – nacelle" with a high by-pass ratio of the engine, and the devised procedure for conducting the weight and drainage experiment.

1. It was established that engine's thrust reverse using a new technique is one of the most effective ways of aircraft braking along the runway. Application of the engine's thrust reverse helps reduce the load on the primary braking system of an aircraft and shorten a braking distance, especially at a low coefficient of adhesion between wheels and RW, as well as at the beginning of the run. However, the main problem that remains is the throw of solid foreign objects from the surface of an airfield by reverse jets. When reverse jets hit the input devices of engines, this causes the distortion of velocity fields and temperatures at the inlet to engines, which is a prerequisite for the emergence of a surge mode in the operation of compressor and for engine shutdown. The interaction between these jets and the fuselage, wing and RW can affect a change in the aerodynamic characteristics of an aircraft when landing and distort readings of the sensors from instrument equipment located on the fuselage.

2. We have experimentally investigated the physical essence of the method for neutralization of engine thrust by rotating the fan's working blades at the time of aircraft landing. It was established that increasing a by-pass ratio of engines predetermines the relevance of research into feasibility of creating a fan with rotating blades (covered by the input to the engine) to shorten the length of the run. In addition to reducing the length of the run, such a structural solution could potentially provide for an engine thrust, which is close to optimal, at all flight modes, and significantly reduce noise level of the engine.

The drainage experiment and a silk tuft visualization technique have identified the detachment of a flow at the outer surface of a nacelle model with a fully closed input. The presence of the flow detachment predetermined an increase, revealed by the weight experiment, in the frontal drag of a nacelle model (by approximately 2.5 times). The weight experiment has also found that the existence of a screening surface (when engine nacelle approaches RW) increases frontal drag of a nacelle model by approximately 14 %. We established in the drainage experiment that this increase in frontal drag is due to a substantial redistribution of pressure on the surface of a nacelle model.

3. Calculation of a typical case of aircraft landing with the engine's thrust neutralization at different by-pass ratios has demonstrated that closing an input to engines insignificantly reduces the length of run of an aircraft of the An-148 type (approximately by 2.5...4 %). That could be possibly explained by a significantly greater contribution to the absorption of aircraft kinetic energy from the brakes and aerodynamic drag of the aircraft itself with the wing mechanization released. However, an insignificant decrease in the run length does not mean the lack of promise for an idea about closing an input to the engine, since the present study did not take into consideration:

– a decrease in powerplant weight when refusing from reversers;

– an improvement in the flight efficiency of a lightweight aircraft;

– an improvement in the efficiency of engines themselves without reversers in the presence of an additional local controlling factor;

– a reduction of the likelihood that foreign objects enter the engine during landing, which opens the possibility of using other layout decisions when arranging powerplant's engines on the plane;

– a significant simplification of piloting at the stage of aircraft landing.

Taking the above factors into consideration would make it possible to fully assess the application of the idea about closing an input to engine in order to shorten the length of aircraft run.

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