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*National Aerospace University «Kharkiv Aviation Institute», Ukraine***DESIGN OF CIRCULAR AIR INTAKES FOR SUBSONIC TURBOFANS**

The **subject matter** of this article is the process of subsonic air intake shaping for high-bypass ratio turbofan at the airplane preliminarily designing stage. The **goal** was to improve a mathematical model of V. I. Polikovskii method of subsonic air intake shaping for high-bypass ratio turbofan. The **tasks** are to consider the presence of cant of inlet cross-section, required to perform effective operation at airplane cruising angle-of-attacks; to increase the radius of curvature of the air intake lip to provide air flow near it without flow separation, which was definitely determined and could not be increased in the existing method; to improve constant length velocity gradient law (used in this method) so that too large duct expansion angles near the air intake outlet cross-section can be avoided; to consider the engine inlet spinner presence. The **methods** used are analytical and digital mathematical methods, implemented in MathCAD and Microsoft Visual Studio systems. The following **results** were obtained: based on the proposed method, new calculation module for the Power Unit software version 11.8 has been developed (C-language Win32 UNICODE application) with a friendly user interface. **Conclusions.** The scientific novelty of the results obtained is as follows: 1) mathematical model (algorithm and its program implementation) for circular turbofan air intake shaping has been improved considering cant of the inlet cross-section, air intake lip rounding with two radiuses, presence of engine inlet spinner, and zero expansion angles in the diffuser outlet cross-section; 2) adequacy of calculation results using the improved mathematical model is shown using comparison with shapes of circular turbofan air intakes, developed by the leading aviation companies.

Keywords: air intake; turbofan; air intake shaping; constant length velocity gradient; air flow; preliminarily designing.

Introduction

Air intake shaping is an important stage of power plant designing of almost any airplane. The shaping is done repeatedly: they vary flight mode and some designing parameters (including the power plant arrangement) with the goal to find the most effective version; when initial data are corrected in the process of the project development and additional experimental investigation performing. In addition, an air intake operation is analyzed at various flight modes, under various angles-of-attack and angles-of-sideslip, and also in emergency and off-normal situations. The iterations are extremely numerous at the preliminarily designing stage. Thus, development of simple, rather exact and quick-implemented calculation method for conditions of limited initial data, which allows to reduce expenses of time and intellectual assets to perform an air intake preliminarily design for a future airplane, is complicated and rather actual problem. The same method provides exactness enough to perform term and diploma projects.

Method of V. I. Polikovskii [1] for turbojet engine air intake shaping is widely known. With small improvements [2] it was used in the past [3, 4] and it has been used nowadays [5, 6] at least in education process. On the base of this method, the author has even developed algorithm of shaping of annular air intakes for turboprop engines [7].

But it is easy to notice, that modern turbofan air intakes considerably differ from ones designed according to this method [8]. Firstly, to perform effective operation at cruising angle-of-attack, the modern air intakes have a definite cant of inlet cross-section. Secondly, to provide air flow near the air intake lip without flow separation, they have considerable radius of its fillet, which is definitely determined and could not be increased in the existing method. Thirdly, constant length velocity gradient law (used in this method) frequently results in too big duct expansion angles near the air intake outlet cross-section. All this requires some changes in mathematical model and algorithm of shaping for these air intakes. So, the **goal** of the research work, which results are given in this publication, is to improve and test the method of circular air intake shaping for turbofans (taking into account all stated above).

1. Problem Statement

In subsonic airplanes with turbofans, having high by-pass ratio, engines are usually placed in separate engine nacelles, located under wings with pylons. Cruising flight Mach number of these airplanes makes 0.75..0.85. These engines distinguish by big air flow and thereby have considerable frontal sizes, that is explained by their low specific thrust. Air intake mass

decrease at their very big diameter (up to 2.0..2.5 m) is reached by decreasing in relative length, which in existing structures makes 0.6..0.9 of engine inlet diameter [9].

High sensitivity of turbofans to pressure losses at air inlet and short relative length of these air intakes require careful shaping of the latter. It is performed basing on application of digital methods for solving of gas-dynamic equations taking into account gas compressibility, its viscosity, and three-dimensional gas flow. External outlines and shape of inner duct are optimized from the condition of getting maximal effective thrust of power plant at specified degree of flow regularity at the engine inlet. These shaping should provide not only minimal external drag at Mach numbers less than critical one, but also high value of the critical Mach number; which corresponds to appearance of supersonic flow zones, closed by shocks, and leading to wave drag appearance on the outer surface of engine nacelle [9].

As zero approximation for the following digital simulation of these air intakes, it is possible to use V. I. Polikovskii method [1, 2], presented below with small changes.

Initial data for an air intake shaping are: the designing flight speed v_H and flight altitude H , the engine diameter by the compressor D_{en} and the air mass flow G_a at this flight mode.

During shaping of a turbofan subsonic air intake, four problems should be solved: the inlet area determination; the external outlines shaping; air intake lip shaping, and internal outlines shaping.

2. Determining of Inlet Cross-Section Area of Turbofan Circular Air Intake

The inlet cross-section area, m^2 , and its diameter, m , are determined by the formulas

$$F_e = \frac{G_a}{v_e \rho_{com}}, \quad D_e = \sqrt{\frac{4F_e}{\pi}},$$

where v_e – is the air speed in the inlet cross-section, m/s; ρ_{com} – is the air density in the inlet cross-section taking into account compressibility, kg/m^3 :

$$\begin{aligned} \rho_{com} &= \rho_H \left[1 + \frac{k-1}{2} M_H^2 (1 - \bar{v}_e^2) \right]^{1/(k-1)} = \\ &= \rho_H \left[1 + 0.2 M_H^2 (1 - \bar{v}_e^2) \right]^{2.5}. \end{aligned}$$

Here ρ_H – is the air density at flight altitude, kg/m^3 (when there are no more exact data, it is taken

from GOST 4401-81 «Standard atmosphere. Parameters», ISO 2533:1975 “Standard Atmosphere”); $k=1.4$ – is the adiabatic exponent; $\bar{v}_e = v_e/v_H$ – is the relative speed in the inlet cross-section, $\bar{v}_e = 0.2..1$. For low Mach numbers $M_H \leq 0.4..0.5$, it is desirable to use external braking of incoming flow as mach as possible, thereby the relative speed at the inlet \bar{v}_e should be appointed low (0.4..0.8). At big subsonic Mach numbers, \bar{v}_e value is selected mainly basing on external flow considerations and air duct length. To decrease total pressure losses in long and curvilinear air ducts, it is necessary to appoint lower \bar{v}_e value, but for short air intakes – bigger one [1, 2].

3. Shaping of External Outlines

External outlines and lip are shaped by means of compromise satisfaction of two conditions simultaneously: low external drag and low internal pressure losses. Thus in addition to the outline smoothness, it is necessary to get as big as possible radius of curvature in mid-section and smooth increase in the radius of curvature along the shell length [1, 2].

There are a lot of analytical dependencies satisfying these conditions. Elliptical outlines are used in V. I. Polikovskii method, which practically proof their good performances for flight Mach number not exceeding 0.75..0.85. In this case, the design is started with the «skeletal» line in the form of ellipse. Further, an external outline is put aside normally from this «skeletal» line in the form of ellipse too (Fig. 1).

Affluence angle β defines the compromise position of the «skeletal» line satisfying the two conditions simultaneously (low external drag and low internal pressure losses):

$$\beta = k_\beta \sqrt{\frac{1}{\bar{v}_e} - 1},$$

where $k_\beta = 22$ for round air intake. Though due to rounded air intake lip, the β angle can be decreased in comparison to the designing one by the value $k_3 = 5..10^\circ$, that allows to get satisfactory outlines even under low \bar{v}_e and big D_e [1, 2].

In real conditions, considerable turn of incoming air flow can result in big air affluence angles to the shell lip and cause flow separation from its convex surface. The problem of its shaping consists in prevention of flow separation and formation of supersonic flow zones with shocks on the shell; in other words, prevention of the factors leading to decrease or complete disappear-

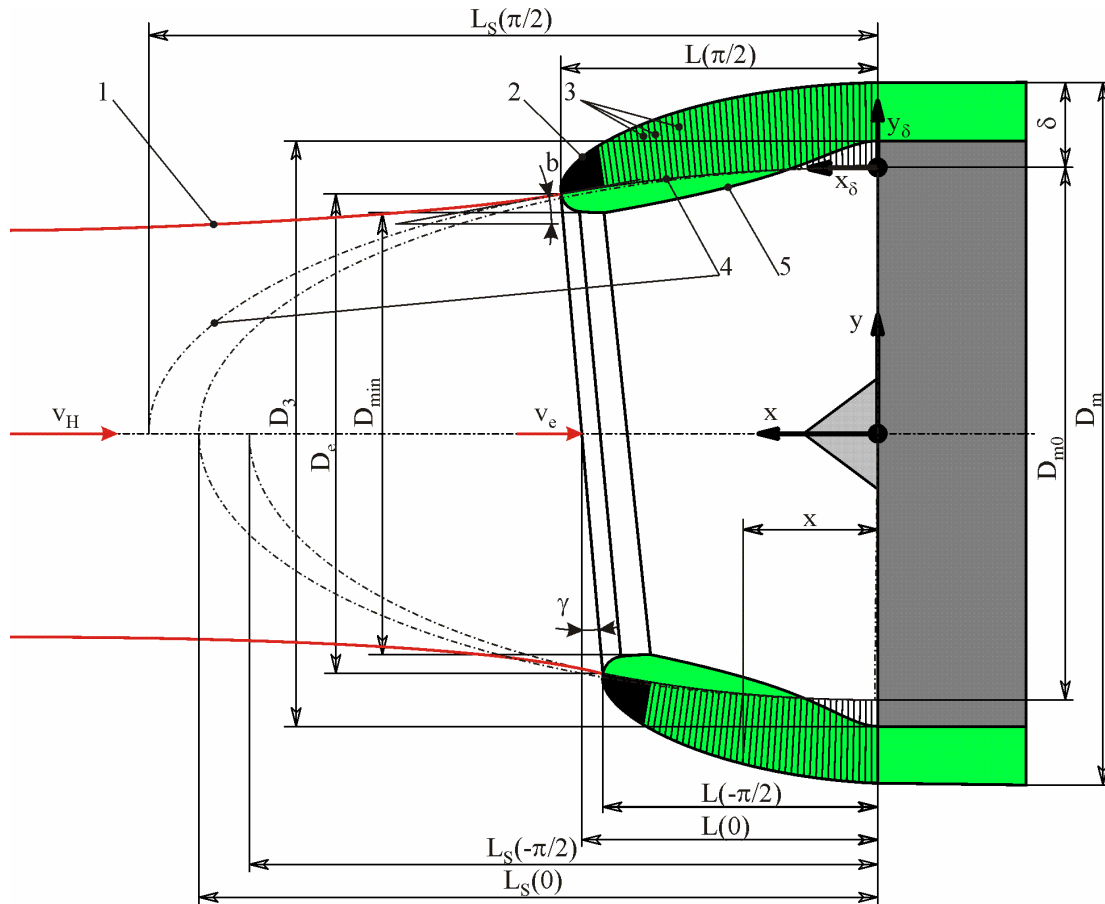


Fig. 1. Designing Model of Turbofan Subsonic Air Intake

ance of suction force [9]. Thereby, air intake length should be not less than

$$L \geq k_L M_H^2 D_m,$$

where L – is the physical length of air intake; $k_L = 0.5..3.0$ – is the experimental factor; $M_H = v_H/a_H$ – is the designing flight Mach number; a_H – is the sonic speed at the designing flight altitude H ; D_m – is the mid-section diameter of the engine nacelle, which is specified as follows [2]:

$$D_m = k_2 D_{en}, \quad k_2 = 1.2..1.3.$$

To plot the «skeletal» line, the ellipse equation is used, which major semiaxis is equal to L_s , but minor semiaxis is equal to $D_{m0}/2$:

$$\frac{x^2}{L_s^2} + \frac{y^2}{(D_{m0}/2)^2} = 1.$$

External outline is shaped by the ellipse with semiaxes L_δ and δ . The ordinates of the ellipse are put aside normally to the «skeletal» line

$$\frac{x_\delta^2}{L_\delta^2} + \frac{y_\delta^2}{\delta^2} = 1.$$

To avoid flow separation on the air intake lip at all operational modes, it is necessary to provide outlines of air intake inlet section smooth enough. Air intake with following radius of curvature of air intake lip meets this condition [1, 2]

$$\rho_{min} = k_1 \sqrt{F_e}, \quad k_1 \geq 0.04..0.05.$$

Semiaxes L_δ and δ are determined by the relations [1, 2]

$$\delta = \frac{\rho_{min}}{\delta}, \quad L_\delta = \frac{\delta}{\delta}, \quad \bar{\delta} = 0.10..0.25,$$

(lower values corresponds to bigger designing Mach numbers).

Semiaxes of «skeletal» line ellipse are calculated by the formulas

$$D_{m0} = D_m - 2\delta, \quad L = \frac{D_{m0}^2 - D_e^2}{2D_e \operatorname{tg}\beta},$$

$$L_s = \frac{L}{\sqrt{1 - (D_e/D_{m0})^2}}.$$

4. Agreement of Lengths of Major Semiaxes of «Skeletal» Line and External Outline Ellipses

When $L_\delta < L$, then further external outline is extended equidistant to the «skeletal» line ellipse [1, 2]. When it happens that $L_\delta > L$, then in mid-section, air intake shell has certain inclination to the axis, thus it expands behind the mid-section, that is inadmissible. To avoid this, it is possible to set the condition $L_\delta \leq L$, which reduces to the quadratic inequation in $\bar{\delta}$ [8]:

$$\frac{\sqrt{\pi k_1 D_e}}{2\bar{\delta}^2} \leq \frac{(k_2 D_{en} \bar{\delta} - \sqrt{\pi k_1 D_e})^2 - D_e^2 \bar{\delta}^2}{2D_e \bar{\delta}^2 \operatorname{tg}\beta}$$

Or

$$(k_2^2 D_{en}^2 - D_e^2) \bar{\delta}^2 - (2\sqrt{\pi k_1 k_2 D_{en} D_e}) \bar{\delta} + (\pi k_1^2 D_e^2 - \sqrt{\pi k_1 D_e^2 \operatorname{tg}\beta}) = 0,$$

which solution is obvious $\bar{\delta} \in (-\infty; \bar{\delta}_1] \cup [\bar{\delta}_2; +\infty)$,

where $\bar{\delta}_{1,2} = \frac{\sqrt{\pi k_1 k_2 D_{en} D_e}}{k_2^2 D_{en}^2 - D_e^2} \mp$

$$\mp \sqrt{\frac{\pi k_1^2 k_2^2 D_{en}^2 D_e^2 - \pi k_1^2 D_e^2 - \sqrt{\pi k_1 D_e^2 \operatorname{tg}\beta}}{(k_2^2 D_{en}^2 - D_e^2)^2 - k_2^2 D_{en}^2 - D_e^2}}.$$

It is clear from the previous expressions, that to decrease the air intake length L , it is desirable to select maximal value of $k_1 = 0.05$, minimal value of $k_2 = 1.2$ and minimal value of $\bar{\delta} \in [0.10..0.25]$:

$$\bar{\delta} = \begin{cases} 0.1; & (\bar{\delta}_2 < 0.1) \vee (0.1 < \bar{\delta}_1); \\ \bar{\delta}_2; & (\bar{\delta}_1 < 0.1) \wedge (0.1 \leq \bar{\delta}_2 \leq 0.25); \\ 0.25; & (\bar{\delta}_1 < 0.1) \wedge (0.25 < \bar{\delta}_2). \end{cases}$$

5. Air Intake Length Specifying from Structural Considerations

Air intake length L can also be specified from structural considerations. Analyzing real structures, it is possible to note, that the ratio of air intake length to the engine diameter makes

$$k_D = L/D_{en} = 0.5..1.0.$$

If to express the air intake length from the previous formulas and to assume air density taking into account compressibility by mean value of \bar{v}_e , then we get for round air intake

$$k_D D_{en} = L = \frac{D_{m0}^2 - D_e^2}{2D_e \operatorname{tg}\beta} = \frac{1}{2\operatorname{tg}\beta} \sqrt{\frac{\pi \rho_{com} v_H \bar{v}_e}{4G_a}} \left[D_{m0}^2 - \frac{4G_a}{\pi \rho_{com} v_H \bar{v}_e} \right].$$

As the affluence angle is considerably lower than 45° , it is possible (with exactness allowable for pilot project stage) to substitute tangent of affluence angle with the angle itself; then we get

$$k_D D_{en} = \frac{180}{2\pi k_\beta} \sqrt{\frac{\bar{v}_e}{1 - \bar{v}_e}} \frac{\pi \rho_{com} v_H \bar{v}_e}{4G_a} \times \left[D_{m0}^2 - \frac{4G_a}{\pi \rho_{com} v_H \bar{v}_e} \right].$$

Squaring both sides of the equation (to remove root), we come to quadratic equation in \bar{v}_e :

$$\bar{v}_e^2 + 2k\bar{v}_e + c = 0,$$

where $k = \frac{G_a (\pi^2 k_D^2 k_\beta^2 D_{en}^2 - 16200 D_{m0}^2)}{4050 \pi \rho_{com} v_H D_{m0}^4}$,

$$c = \frac{16G_a^2}{\pi^2 \rho_{com}^2 v_H^2 D_{m0}^4} - \frac{\pi k_D^2 k_\beta^2 G_a D_{en}^2}{2025 \rho_{com} v_H D_{m0}^4}.$$

Its positive root

$$\bar{v}_e = -k + \sqrt{k^2 - c}$$

gives the speed in the inlet cross-section, which provides the air intake length, with some approximation equal to the specified one $k_D D_{en}$ [8].

6. Taking into Account Cant of Inlet Cross-Section

Structural feature of modern subsonic air intakes of high by-pass ratio turbofans is presence of definite cant of inlet cross-section γ – to provide effective operation at cruising angles-of-attack [9]. Thus air intake length is proportionally extended or compressed:

$$L(\varphi) = L(0) + \frac{D_e \operatorname{tg} \gamma}{2} \sin \varphi,$$

where $L(0)$ – is the air intake length in horizontal plane; φ – is the polar angle in front view, counting from the horizontal axis.

Presence of the cant also changes length of the major semiaxis of «skeletal» line ellipse $L_s(\varphi)$ and the affluence angle $\beta(\varphi)$. As a result plotting of the «skeletal» line, external outline ellipse, a also internal outline should be performed for some values of the polar angle φ .

7. Air Intake Lip Shaping

To avoid flow separation at air intake lip streamlining under angle-of-attack or angle-of-sideslip, flow acceleration is performed in the inlet section. For this purpose, the area of minimal cross-section is assumed equal to [1, 2]

$$F_2 = F_{\min} = k_4 F_e,$$

$$k_4 = 0.8 \dots 0.9,$$

that definitely defined radius of curvature of the air intake lip (Fig. 2, a)

$$R_1 = \frac{D_e - D_{\min}}{2(1 - \sin \beta)}.$$

After that, the greater value of air intake lip radius of curvature was assumed: $R = \max\{\rho_{\min}, R_1\}$ [1, 2].

Thus, radius of curvature was rather low, and flow speed could reach sound one. To avoid this, in modern air intakes, rounding with two radiuses is used. Radius of curvature of air intake lip within the interval $[L - x_\rho; L]$ remains equal to ρ_{\min} ; but further in the interval $(L - x_R; L - x_\rho)$, it is assumed equal to $R = k_R R_1$ (where $k_R = 1 \dots 10$), that allows to accelerate air flow more smoothly.

Calculation of the parameters is clear from Fig. 2, b:

$$y_R = D_{\min}/2 + R; \quad y_{\rho c} = D_e/2 + \rho_{\min} \sin \beta;$$

$$x_{\rho c} = \rho_{\min} \cos \beta; \quad x_R = x_{\rho c} + (y_R - y_{\rho c}) \tan \varepsilon;$$

$$y_\rho = y_{\rho c} - \rho_{\min} \cos \varepsilon; \quad x_\rho = x_{\rho c} - \rho_{\min} \sin \varepsilon;$$

$$\varepsilon = \arccos\left(\frac{y_R - y_{\rho c}}{R - \rho_{\min}}\right),$$

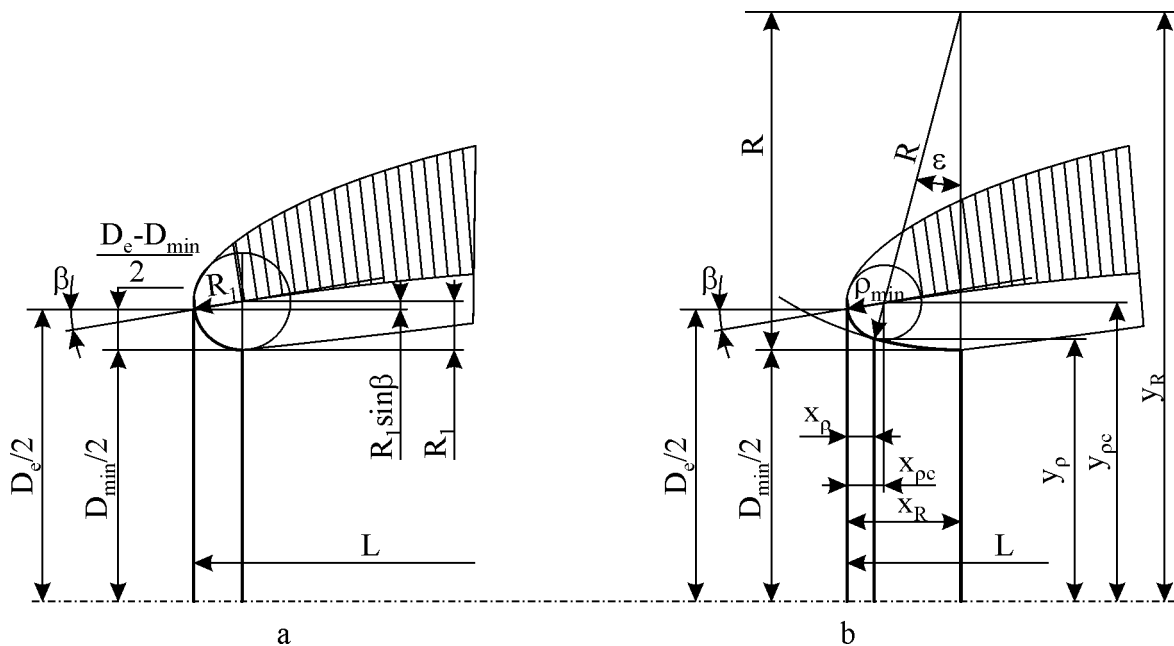


Fig. 2. Determining of air intake lip parameters

where x_R, y_R – are the center coordinates of radius R circle; $x_{\rho c}, y_{\rho c}$ – are the center coordinates of radius ρ_{min} circle (it is the radius of curvature of external outline ellipse in the major semiaxis); x_ρ, y_ρ – are the intersection pint coordinates of the circles.

Now, all the parameters are specified, and it is possible to plot the «skeletal» line by the ellipse equation

$$y = \frac{D_{m0}}{2} \sqrt{1 - \frac{x^2}{L_s^2}}$$

Then the ordinates of the ellipse of external outline are put aside normally to the «skeletal» line

$$y_\delta = \delta \sqrt{1 - \frac{x_\delta^2}{L_\delta^2}}$$

As the «skeletal» line is not manifested in the air intake structure, the case when $D_{m0} < D_3 = D_{en}$ is quite acceptable (see Fig. 1).

8. Shaping of internal outlines

Shaping of internal outlines. As it is known, the main designing idea of short diffusers consists in the following. As the main pressure gain and the main losses in diffuser are concentrated in their front section (where speed is high), then it is necessary to provide diffuser good operation just in this section, even if thus operation of the tail section with low speed becomes worse [1, 2].

The main way of the idea implementation is application of diffusers with curvilinear generatrix, which have small expansion angles in the high-speed section and big ones in the low-speed section. In addition, the curvature of the walls determines a positive pressure gradient from the wall to the axis, which reduces danger of the flow separation. The most successful are curvilinear diffusers with a constant length pressure gradient ($dp/dx = const$) and with a constant length velocity gradient ($dv/dx = const$) [1, 2].

The following formulas are used for their plotting

$$F_p(x) = \frac{F_3}{\sqrt{1 + \left(\frac{F_3^2}{F_{min}^2} - 1\right)\bar{x}}}, \quad F_v(x) = \frac{F_3}{1 + \left(\frac{F_3}{F_{min}} - 1\right)\bar{x}}$$

where $F_i(x)$ – is the current diffuser cross-section area; F_{min} – is the area of the diffuser minimal cross-section, corresponding to the diameter D_{min} ; $F_3 = \pi D_{en}^2/4$ – is the duct cross-section area in the outlet cross-section of the diffuser (taking into account compressor spinner); $\bar{x} = x/(L - x_R)$ – is the coordinate, counting upstream from the diffuser outlet cross-section ratio to its length [4].

Fig. 3 above shows three considered diffusers of the same length. It is clear, that the curve $dv/dx = const$ lies between the line $\alpha = const$ and the curve $dp/dx = const$.

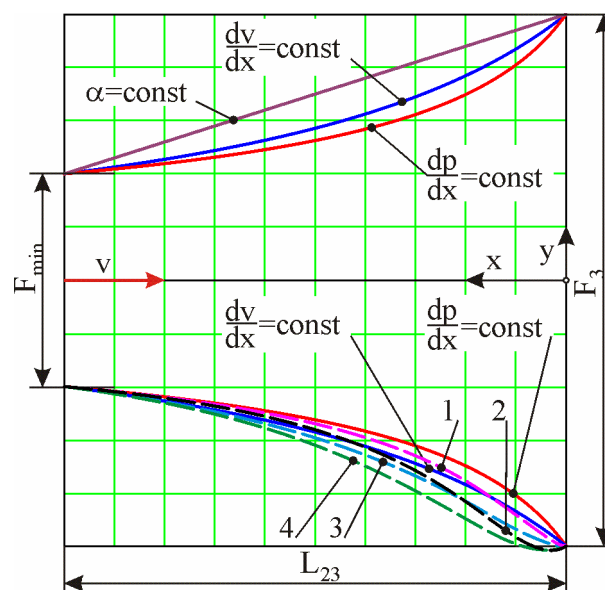


Fig. 3. Diffuser Shapes

Diffusers with a constant length pressure gradient are the best for designing of short ducts with the high rate of braking. They are usually used for inlet ducts of heat-exchangers and cowlings of reciprocating engines [1, 2].

Diffusers with a constant length velocity gradient are widely used for jet engines air intakes. As they have smoother outlines and provide more uniform field of speed at the jet engine inlet. But, they are usually longer [1, 2].

In pure state diffusers, designed according to the law $dp/dx = const$ or $dv/dx = const$ from inlet till outlet cross-section, are sometimes unpractical. Initial section near the inlet cross-section can give long zone having too low angles, which causes increase in friction losses. Outlet section sometimes can get expansion angles, reaching 150° and more, that also unpractical and results in appearance of a zone, in which losses in diffuser exceeds losses at impact [1, 2].

Thereby, it is possible to propose functions (modified by author) to plot curvilinear diffusers. The modification consists in specifying zero expansion angle in the diffuser outlet cross-section at minimal difference of the modified functions from the base ones at the diffuser initial section. Thus, engine inlet spinner (of conical shape) is also taken into account:

$$F_{pm}(\bar{x}) = \frac{F_3}{\sqrt{1 + \left(\frac{F_3^2}{F_{min}^2} - 1\right) \bar{z}(\bar{x})}} - \frac{\pi d^2(\bar{x})}{4F_3};$$

$$F_{vm}(\bar{x}) = \frac{F_3}{1 + \left(\frac{F_3}{F_{min}} - 1\right) \bar{z}(\bar{x})} - \frac{\pi d^2(\bar{x})}{4F_3};$$

$$\bar{z}(\bar{x}) = (n-1)(p-1)\bar{x}^n + (n-1)(1-p)\bar{x}^{n-1} + p\bar{x};$$

$$p = \begin{cases} \frac{\pi D_{con}^2(L-x_R)F_{min}^2}{F_3 L_{con}(F_{min}^2 - F_3^2)}, & \text{for } F_{pm}(\bar{x}) \\ \frac{\pi D_{con}^2(L-x_R)F_{min}}{2F_3 L_{con}(F_{min} - F_3)}, & \text{for } F_{vm}(\bar{x}) \end{cases};$$

$$d(\bar{x}) = \begin{cases} D_{con} \left[1 - \frac{\bar{x}(L-x_R)}{L_{con}} \right], & \text{for } \bar{x} < \frac{L_{con}}{L-x_R} \\ 0, & \text{for } \bar{x} \geq \frac{L_{con}}{L-x_R} \end{cases},$$

where $n=2..4$ – is the power exponent, determining approximation measure of the modified functions to the base ones (when $n=2$, we get the base functions); p – is the parameter, characterizing tangent inclination angle to the internal outline generatrix near the duct outlet cross-section, taking into account engine inlet spinner; D_{con} – is the engine inlet spinner diameter in the engine inlet; L_{con} – is the length of the engine inlet spinner; $d(\bar{x})$ – is the current diameter of the engine inlet spinner.

These curves are shown in Fig. 3 below:

$$1 - F_{pm}(x), n = 2.2;$$

$$2 - F_{pm}(x), n = 2.5;$$

$$3 - F_{vm}(x), n = 2.2;$$

$$4 - F_{vm}(x), n = 2.5.$$

It is clear from the Fig. 3, that presence of the inlet engine spinner provides flow cross-section decreasing and, consequently, small flow acceleration directly in front of engine.

9. Examples of Calculation Results

The considered method is implemented by Ruslan Yu. Tsukanov in calculation module of the Power Unit 11.8 software. The air intake shape is delivered as a set of arrays of meridional cross-sections, which is convenient to plot 3D-model. Calculation results according to this method are well conform to shapes of circular air intakes of turbofans, developed by the leading aviation companies (Figs 4, 5).

For example, Fig. 4, a shows calculation result for circular air intake of Д-18Т engine ($H=11$ km, $M=0.75$, $G_a=427$ kg/s) and air intake shape of the АН-124 airplane (Fig. 4, b). Fig. 5, a shows result of shaping of circular air intake for CFM 56-5A1 engine ($H=11$ km, $M=0.8$, $G_b=426$ kg/s) and air intake shape of the А-320 airplane (Fig. 5, b).

Apparently, a number of additional (manufacturing, operational and other) requirements, and also results of wind tunnel and full-scale test at various modes have been taken into account in real air intake designing.

Conclusion

1. The method of circular turbofan air intake shaping (directed toward application in practice of multiple calculations at an airplane preliminarily designing stage in conditions of incomplete information) is improved. The improved method takes into account: cant of inlet cross-section, air intake lip rounding with two radiuses, engine inlet spinner, and provides zero expansion angle in the diffuser outlet cross-section.

2. Comparison of the calculation results according to this method and real air intake shapes, developed by the leading aviation companies, demonstrated good conformation, that is getting the air intake parameters, which are capable hereafter to meet all set of requirements, made to them. Some difference is explained by the fact, that far extensive set of requirements, and also results of wind tunnel and full-scale tests have been taken into account in real air intakes.

3. On the base of the proposed method, new calculation module for the Power Unit software version 11.8 has been developed (C-language Win32 UNICODE application) having friendly user interface.

4. For the following improvement of the air intake designing method, it is necessary to take into account results of typical air intake wind tunnel tests or digital flow simulation, to analyze an air intake operation under the skew streamlining, and also to consider the unit operation in the off-normal and emergency situations, after that to update the software.

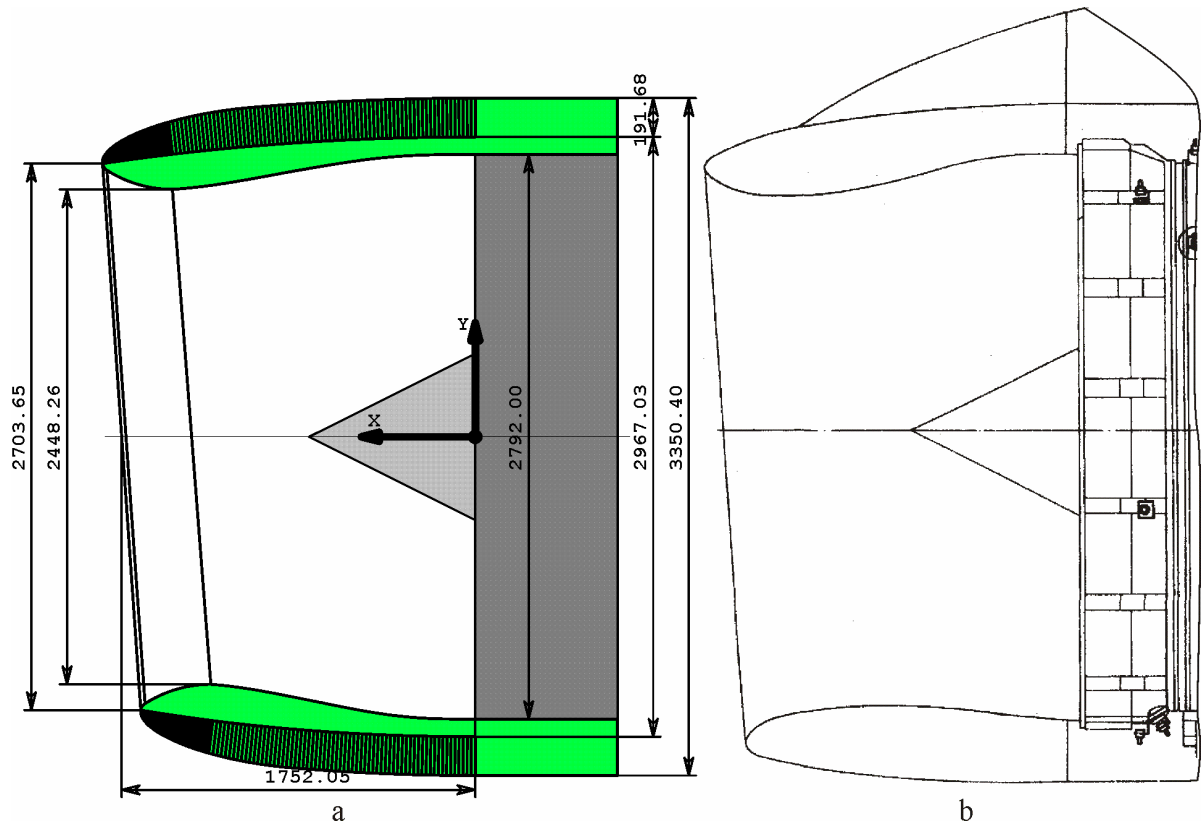


Fig. 4. Air intake of Д-18Т engine:
a – calculation (Power Unit 11.8); b – shape (АН-124) [10]

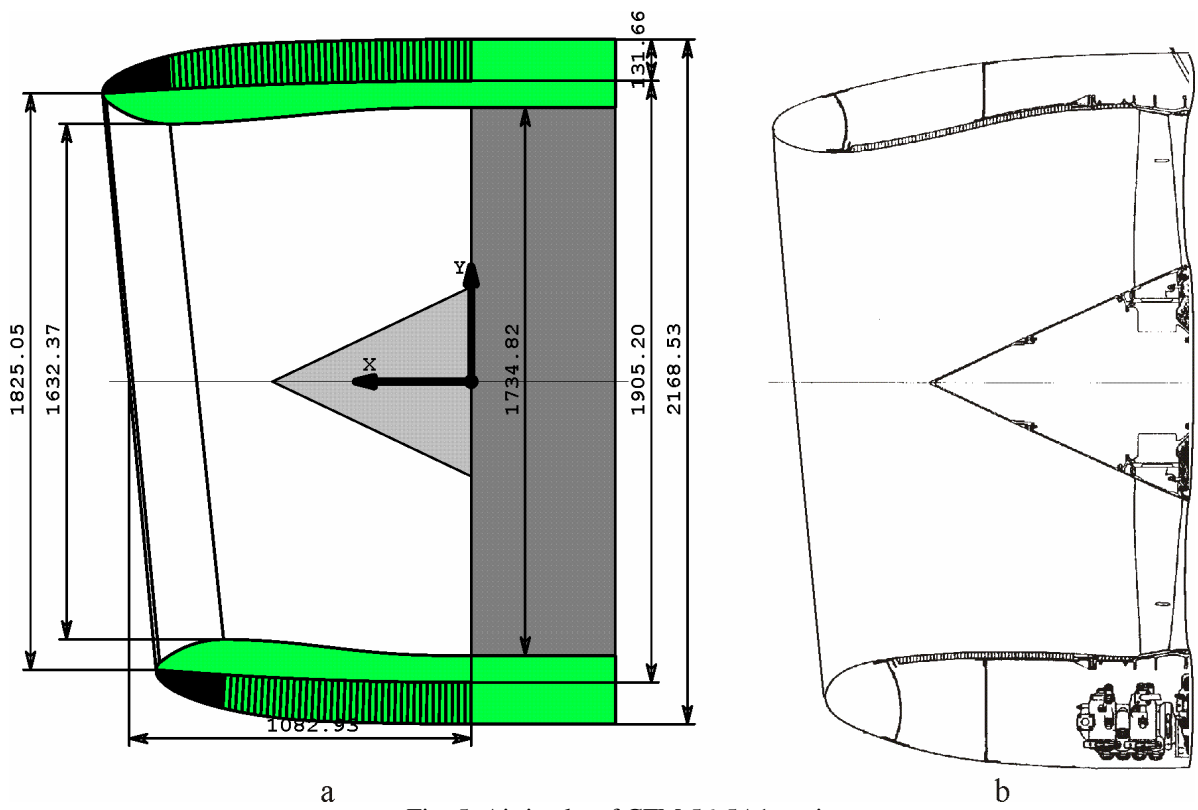


Fig. 5. Air intake of CFM 56-5A1 engine:
a – calculation (Power Unit 11.8); b – shape (A-320) [11]

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**ПРОФІЛЮВАННЯ КРУГОВИХ ДОЗВУКОВИХ ПОВІТРОЗАБІРНИКІВ
ДВОКОНТУРНИХ ТУРБОРЕАКТИВНИХ ДВИГУНІВ****Р. Ю. Цуканов**

Предметом вивчення в статті є процеси профілювання дозвуків повітрозабірників двоконтурних турбореактивних двигунів на етапі ескізного проектування літака. **Ціллю** є вдосконалення математичної моделі метода В. І. Поліковського для профілювання повітрозабірників двоконтурних турбореактивних двигунів. **Задачі:** врахувати наявність скосу площини входу, що є необхідним для забезпечення ефективної роботи повітрозабірника на крейсерських кутах атаки літака; збільшити радіус кривизни передньої кромки для забезпечення безвідривного її обтікання, який в існуючому методі визначався однозначно і не міг бути зміненим; доробити закон постійного градієнта швидкості по довжині повітрозабірника для виключення недопустимо великих значень кутів розкриття каналу поблизу вихідного перерізу; врахувати наявність вхідного кока компресора. Використовуваними **методами** є: аналітичні та численні математичні методи, що реалізовано в системах MathCAD і Microsoft Visual Studio. Отримано наступні **результати**. На основі запропонованого методу розроблено новий розрахунковий модуль програмного забезпечення Power Unit версії 11.8 (Win32 UNICODE застосунок, написаний на мові C) з дружнім інтерфейсом користувача. **Виводи.** Наукова новизна отриманих результатів складається в наступному: вдосконалено математичну модель (алгоритм і його програмна реалізація) для профілювання кругового повітрозабірника двоконтурних турбореактивних двигунів з урахуванням скосу площини входу, подвійного радіуса закруглення вхідної кромки, наявності вхідного кока компресора двигуна та нульового кута розкриття у вихідному перерізі дифузору. Шляхом порівняння з профілями повітрозабірників, розроблених провідними авіаційними фірмами, показано адекватність результатів розрахунку за вдосконаленою математичною моделлю.

Ключові слова: повітрозабірник; двоконтурний турбореактивний двигун; профілювання повітрозабірника; постійний градієнт швидкості по довжині; витрата повітря; ескізне проектування.

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