ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

UDC 621.452.3.032.3.01 **doi: 10.32620/aktt.2022.6.01**

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DESIGNING OF NON-CIRCULAR AIR INTAKES FOR SUBSONIC GAS-TURBINE ENGINES

*The **subject matter** of the article is the process of subsonic air intake shaping for gas-turbine engines at the airplane preliminarily design stage. The **goal** is to develop a mathematical model for non-circular air intake shaping for gas-turbine engines on the base of V. I. Polikovskii method of subsonic air intake shaping for high-bypass ratio turbofan. The **tasks** to be solved are: to consider the possibility of non-circular shape of the external outline of the engine nacelle; to take into account the possibility of non-circular shape of the internal air intake duct (in the first approximation, the shape of internal air intake duct cross-section is defined in the form of a rectangular with possible four different radiuses in its corners); 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: 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 a friendly user interface. **Conclusions**. The scientific novelty of the results obtained is as follows: 1) mathematical model (algorithm and its program implementation) for non-circular air intake shaping for gas-turbine engines has been developed considering non-circular shape of the external outline of the engine nacelle, non-circular shape of the air intake duct internal outline, presence of engine inlet spinner, and zero expansion angle in the diffuser outlet cross-section; 2) adequacy of calculation results by the developed mathematical model is shown by means of comparison with the shape of real air intake, developed by the Antonov Company. For the following improvement of the mathematical model, it is desirable to add the possibility of considering S-shape of the air intake duct, defining its length from designer's considerations, defining a bigger radius of curvature of the air intake lip, and considering the presence of boundary layer bleeding devices in front of the air intake.*

Keywords: *air intake; gas-turbine engine; 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 it was used in the past [2] and it has been used nowadays [3] 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 [4]. In publication [5], modern approach to optimization of air intake lips is shown; and in article [6], optimization of their interaction with engine nacelle and pylon on the base of flow digital 3D gas-dynamic analysis. But all these publications are devoted to subsonic air intakes of circular or close to circular cross-section.

In the same time, there are a lot of air intakes of non-circular or circular, but non-axisymmetric cross-section, which are arranged above, under or sideways to fuselage or engine nacelle. In publication [7], complication and contradictoriness of the requirements to these air intakes are shown.

Publication [8] contains interesting comparison of calculation for non-axisymmetric air intakes by one-dimensional and three-dimensional theory; but only small air intakes for environmental control system are considered in the article. In the publication [9], digital and experimental optimization of S-shaped air intake for unmanned air vehicle is given. Publication [10] considers defining of the center line for these air intakes in the form of a polynomial, and in the publication [11]

S-shaped air intakes are compared with axisymmetric ones.

Thus, known publications considering non-axisymmetric air intakes do not contain convenient engineering algorithm for these air intake designing, that requires definite changes in design model and algorithm of designing in comparison with the base one.

1. Problem Statement

We will understand the term «non-axisymmetric air intake» as: firstly, air intakes of non-circular cross-section; and secondly, air intakes with curvilinear axis (of both circular, and non-circular cross-section). These air intakes are rather often used as dorsal, side, and ventral ones. Of course, to analyze their flow in the exact statement, it is necessary to consider flow around fuselage or wing surface, located in front of the air intake, that is only possible by methods of digital simulation using heavy CAD/CAE systems.

In addition, real designing of air intakes 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.

But at the initial stages of designing, this approach is too labor-consuming. Thus, **the goal** of the publication is development of rather simple algorithm of non-circular air intake designing for gas-turbine engines on the base of known method V. I. Polikovskii, so that the flow around the designed air intake can be further simulated and its shape can be corrected.

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 the designing flight mode.

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

The inlet cross-section area, m^2, is determined by known formula

$$F_e = \frac{G_a}{v_e \rho_{com}},$$

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

$$\rho_{com} = \rho_H \left[1 + \frac{k-1}{2} M_H^2 \left(1 - \bar{v}_e^2\right)\right]^{1/(k-1)} =$$

$$= \rho_H \left[1 + 0.2 M_H^2 \left(1 - \bar{v}_e^2\right)\right]^{2.5}.$$

Here ρ_H – is the air density at flight altitude, kg/m^3 (when there are no more exact date, 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, $\bar{v}_e = 0.2 \ldots 1$ [1, 2].

2. 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 a little bit lower than the inlet area [1, 2];

$$F_2 = F_{min} = k_4 F_e, \qquad k_4 = 0.8 \ldots 0.9.$$

Let us assume in the first approximation, that the shape of the air intake duct cross-section is rectangular one with fillets in corners. It allows simulating of wide range of non-axisymmetric air intakes, shown in Fig. 1, a. Fig. 1, b shows shapes, which cannot be defined in this manner, that is a limitation of the model.

For round air intake, diameters of inlet and minimal cross-sections, and also affluence angle β uniquely determine the radius of inner fillet of air intake lip (R_1). But for air intake of rectangular shape with specified radiuses of fillets in its inlet cross-section corners (R_{ei}), it can happen so, that the radiuses of fillets in minimal cross-section corners (R_{mini}) (which are equal to radiuses of fillets in the inlet cross-section corners minus the radius of inner fillet of the air intake lip $R_{mini} = R_{ei} - R_1$) are negative. Thus, the problem should be solved in a reverse order: initially we define parameters of the minimal cross-section (height H_{min}, width B_{min} and radiuses of fillets in corners R_{mini}), and only further we can calculate parameters of the inlet cross-section (height H_e, width B_e and radiuses of fillets in corners R_{ei}).

ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

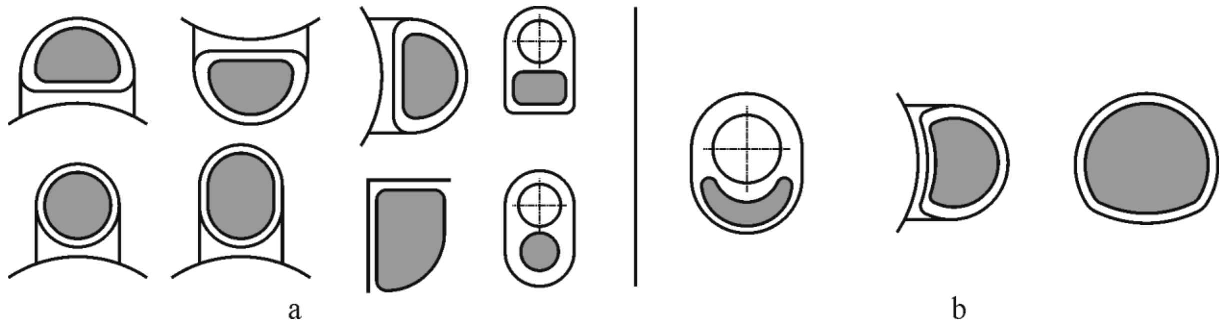

Fig. 1. Possible air intake shapes in front view

Depending on the utilization of boundary layer bleeding from the surface adjacent to a fuselage, we will consider the following versions of air intakes (Fig. 2). Let us assume the following designations: n_i – is a flag of the fillet presence ($R_{min\,i}$ and $R_{e\,i}$) in the specific corner (which is equal to unit when there is a fillet or is equal to zero then there is no fillet); $n_H = n_1 + n_2$ – is the number of fillets (R_1) by height; $n_B = \max\{(n_0 + n_1);(n_2 + n_3)\}$ – is the number of fillets (R_1) by width.

From the elementary geometry, area of a rectangle with fillets in corners is equal to:

$$F_{min} = H_{min} B_{min} - \left(1 - \frac{\pi}{4}\right) \sum_{i=0}^{3} R_{min\,i}^2 .$$

Nor, parameters of the minimal cross-section can be calculated (assuming all $R_{min\,i}$ are defined). As at this step of the algorithm, we know only the area of minimal cross-section, it is reasonable to specify the ratio $k_{B\,min} = B_{min}/H_{min}$, by which sought height (H_{min}) and width (B_{min}) can be calculated:

$$H_{min} = \sqrt{\frac{F_{min} + \left(1 - \frac{\pi}{4}\right) \sum_{i=0}^{3} R_{min\,i}^2}{k_{B\,min}}} ,$$

$$B_{min} = k_{B\,min} H_{min} .$$

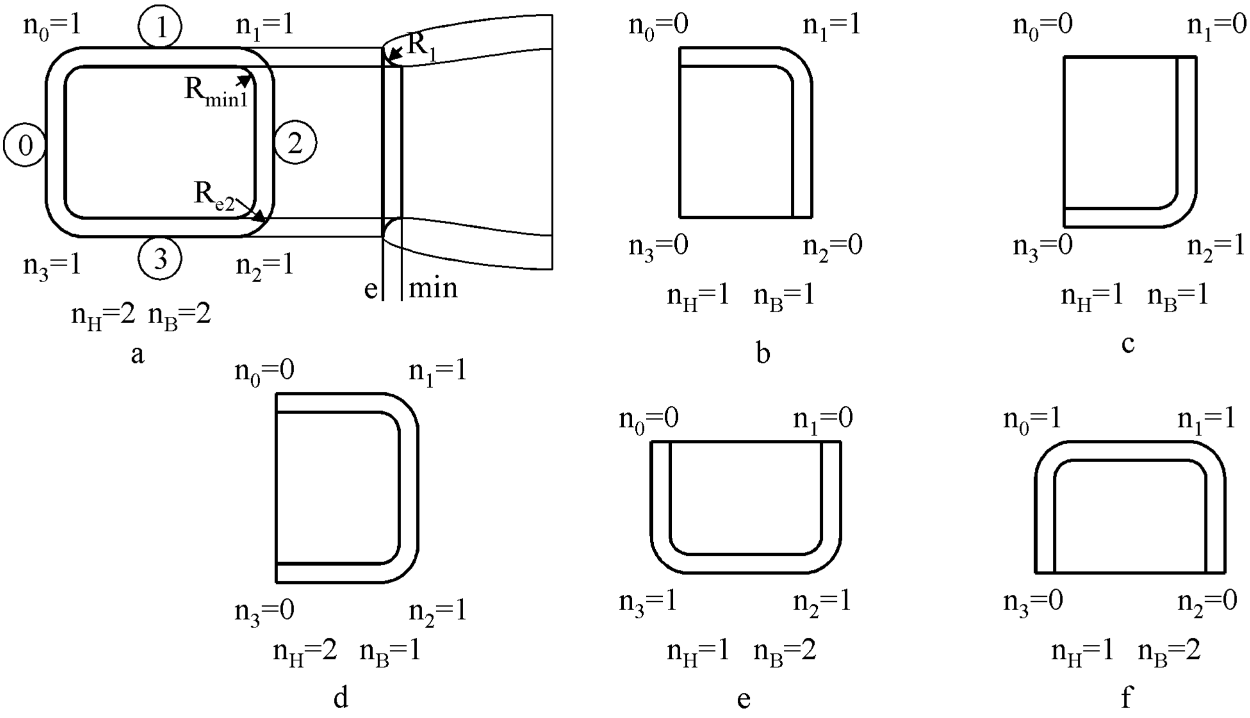

Fig. 2. Determining parameters of minimal and inlet cross-sections

In the same time, the height or width of minimal cross-section can be limited by designer's considerations, therefore it is necessary to foresee a possibility of direct defining of the height (H_{min}) or width (B_{min}) of the minimal cross-section:

$$B_{min} = \frac{F_{min} + \left(1 - \frac{\pi}{4}\right)\sum_{i=0}^{3} R_{mini}^2}{H_{min}};$$

$$H_{min} = \frac{F_{min} + \left(1 - \frac{\pi}{4}\right)\sum_{i=0}^{3} R_{mini}^2}{B_{min}}.$$

In case of round cross-section, all its radiuses of fillets are equal to:

$$R_{mini} = \sqrt{\frac{F_{min}}{\pi}}.$$

At this stage, it is necessary to take into account limitations of the design model:

$$R_{min0} + R_{min1} \le B_{min}; \quad R_{min0} + R_{min3} \le H_{min};$$

$$R_{min2} + R_{min3} \le B_{min}; \quad R_{min1} + R_{min2} \le H_{min}.$$

Now, to calculate radius of the inner fillet of the air intake lip (R_1), we get the following quadratic equation:

$$F_e = H_e B_e + \left(\frac{\pi}{4} - 1\right)\sum_{i=0}^{3} n_i R_{ei}^2 = \left(H_{min} + n_H R_1\right) \times$$

$$\times \left(B_{min} + n_B R_1\right) + \left(\frac{\pi}{4} - 1\right)\sum_{i=0}^{3} n_i \left(R_{mini} + R_1\right)^2$$

or

$$aR_1^2 + bR_1 + c = 0; \; D = b^2 - 4ac; \; \left(R_1\right)_{1,2} = \frac{-b \pm \sqrt{D}}{2a},$$

where $$a = n_H n_B - \left(1 - \frac{\pi}{4}\right)\sum_{i=0}^{3} n_i;$$

$$b = n_B H_{min} + n_H B_{min} - \left(2 - \frac{\pi}{2}\right)\sum_{i=0}^{3} n_i R_{mini};$$

$$c = H_{min} B_{min} - F_e - \left(1 - \frac{\pi}{4}\right)\sum_{i=0}^{3} n_i R_{mini}^2.$$

Practically, it is necessary to use the second (positive) root $R_1 = \left(R_1\right)_2$.

Only now, parameters of the inlet cross-section can be calculated:

$$R_{ei} = \left(R_{mini} + R_1\right) n_i;$$

$$B_e = B_{min} + n_B R_1; \quad H_e = H_{min} + n_H R_1.$$

Thus, in case of boundary layer bleeding presence the center of the inlet cross-section is shifted relatively the center of the minimal cross-section vertically and horizontally as follows:

$$\Delta y = \begin{cases} 0, & n_H = 2; \\ R_1/2, & n_2 = 0; \\ -R_1/2, & n_2 = 1; \end{cases} \quad \Delta z = \begin{cases} 0, & n_B = 2; \\ R_1/2, & n_0 + n_3 > 0; \\ -R_1/2, & n_0 + n_3 = 0. \end{cases}$$

3. Shaping of External Outlines

External outlines 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. 3).

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 $k_\beta = 26$ for flat air intake. Though due to rounded air intake lip, the β angle can be decreased in comparison to the designing one by the value $k_3 = 5...10°$, that allows to get satisfactory outlines even under low $\bar{v}_e$ and big B_e or H_e [1, 2].

Dimensions of the engine nacelle mid-section B_m and H_m are defined analogously to the diameter of the base method [2]:

$$B_m = k_{2B}\, D_{en}, \qquad k_{2B} = 1.2...1.3;$$

$$H_m = k_{2H}\, D_{en}, \qquad k_{2H} = 1.2...1.3.$$

ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

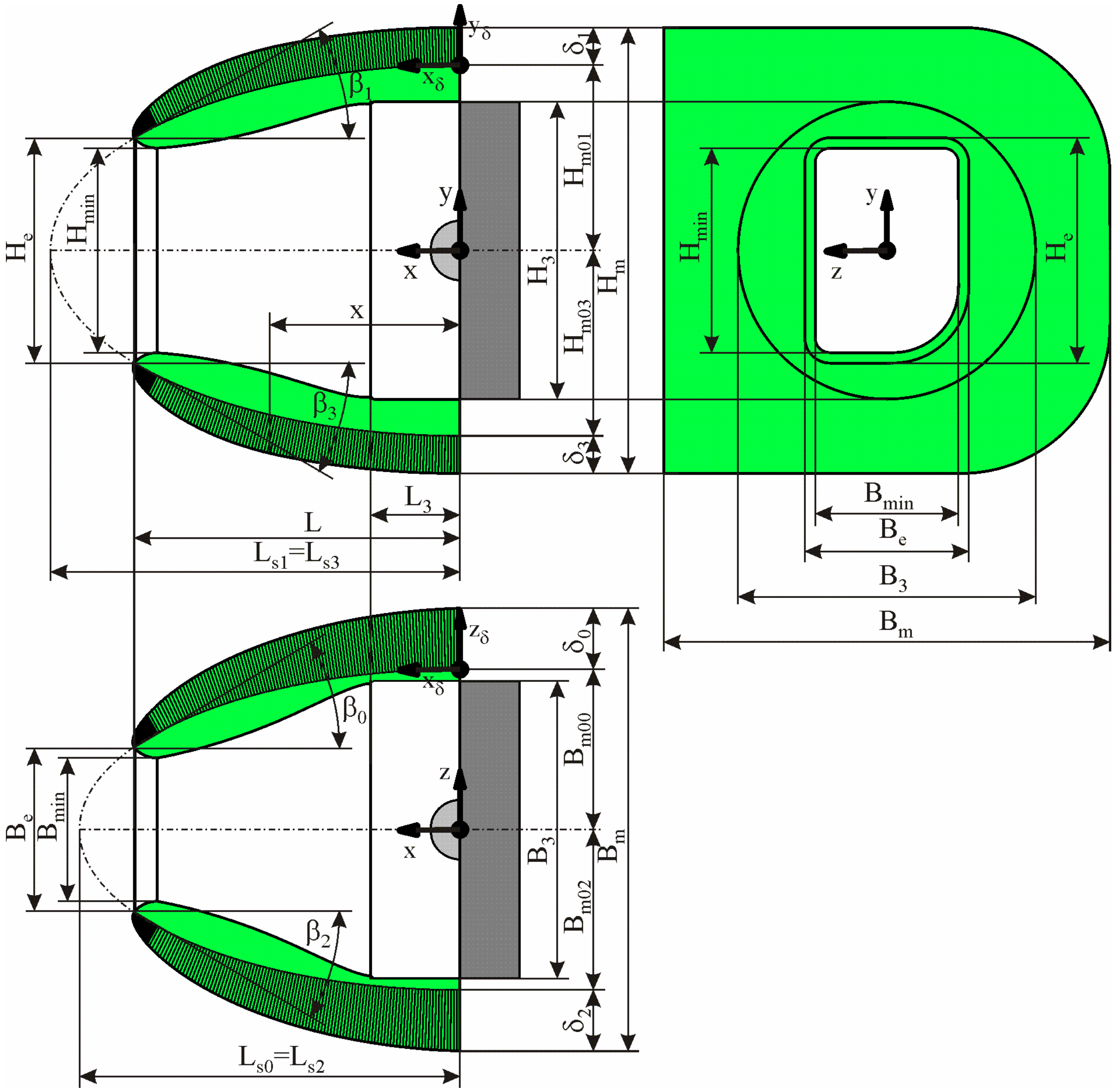

Fig. 3. Design model of non-circular air intake

To plot the «skeletal» line, the ellipse equations are used, which major semiaxes are equal to L_{si}, but minor semiaxes are equal to B_{m0i} or H_{m0i}:

$$\frac{x^2}{L_{si}^2}+\frac{y^2}{(B_{m0i}/2)^2}=1, \quad (i=0;2);$$

$$\frac{x^2}{L_{si}^2}+\frac{y^2}{(H_{m0i}/2)^2}=1, \quad (i=1;3).$$

External outlines are shaped by the ellipses with semiaxes $L_{\delta i}$ and δ_i. The ordinates of the ellipses are put aside normally to the «skeletal» lines

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

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]

$$\rho_{min}=k_1\sqrt{F_e}, \qquad k_1 \ge 0.04...0.05.$$

Semiaxes $L_{\delta i}$ and δ_i are determined by known relations [1, 2]

$$\delta_i = \frac{\rho_{min}}{\overline{\delta}_i}, \qquad L_{\delta i} = \frac{\delta_i}{\overline{\delta}_i}, \qquad \overline{\delta}_i = 0.10...0.25,$$

(lower values corresponds to bigger designing Mach numbers).

Minor semiaxes of «skeletal» line ellipse are calculated by the formulas

$$B_{m0i} = \frac{B_m}{2} - \delta_i > \frac{B_e}{2}, \quad H_{m0i} = \frac{H_m}{2} - \delta_i > \frac{H_e}{2},$$

thus, it is necessary to make sure, that the obtained semiaxes are not less than the halves of corresponding sizes of the inlet cross-section, otherwise it is necessary to increase k_{2B}, k_{2H} or $\overline{\delta}_i$.

We assume the lengths of all walls of the air intake are the same and equal to the length of the right wall (which we assume external wall of the engine nacelle):

$$L_i = L_2 = \frac{4B_{m02}^2 - B_e^2}{2B_e \operatorname{tg}\beta}.$$

The major semiaxes of the «skeletal» line ellipses are determined by the known formulas:

$$L_{si} = \frac{L_i}{\sqrt{1 - (B_e/2B_{m0i})^2}}, \; (i = 0; 2);$$

$$L_{si} = \frac{L_i}{\sqrt{1 - (H_e/2H_{m0i})^2}}, \; (i = 1; 3).$$

When the boundary layer bleeding is used, the adjacent surfaces of the engine nacelle can be assumed of flat shape (for which $\delta_i = L_{\delta i} = B_{m0i} = H_{m0i} = L_i = L_{si} = 0$).

Thus, the affluence angles for different walls become different:

$$\beta_i = \operatorname{arctg}\left(\frac{4B_{m0i}^2 - B_e^2}{2B_e L_i}\right), \; (i = 0; 2);$$

$$\beta_i = \operatorname{arctg}\left(\frac{4H_{m0i}^2 - H_e^2}{2H_e L_i}\right), \; (i = 1; 3).$$

4. Shaping of Internal Outlines

Variation of cross-section area of the internal outlines can be assumed in accordance with one of laws considered before [3]:

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

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

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

$$\overline{z}(\overline{x}) = (n-2)(p-1)\overline{x}^n + (n-1)(1-p)\overline{x}^{n-1} + p\overline{x};$$

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

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

where $\overline{x} = x/(L - x_R)$ – is the coordinate, counting upstream from the diffuser outlet cross-section ratio to its length;

$F_i(\overline{x})$ – is the current diffuser cross-section area;

F_{min} – is the area of the diffuser minimal cross-section;

$F_3 = k_5 \pi D_{en}^2/4$ – is the duct cross-section area in the outlet cross-section of the diffuser (taking into account compressor spinner);

$k_5 \ge 1$ – is the confuser factor, which is equal to unit, when the air intake duct is absent or short, and it is greater than unit, when it is desirable to decrease friction losses in long air intake duct;

$n = 2..4$ – 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 generatix 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;

$d(\overline{x})$ – is the current diameter of the engine inlet spinner.

ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

Dimensions of the air intake inlet cross-section are determined by formulas, analogous to ones for dimensions of the minimal cross-section. Firstly, we specify the ratio $k_{B3} = B_3/H_3$, by which sought height (H_3) and width (B_3) can be calculated:

$$H_3 = \sqrt{\frac{F_3 + \left(1 - \frac{\pi}{4}\right)\sum_{i=0}^{3} R_{3i}^2}{k_{B3}}}, \quad B_3 = k_{B3} H_3,$$

where R_{3i} – are the radiuses of fillets in corners of the outlet cross-section.

In the same time, the height or the width of the outlet cross-section can be limited by designer's considerations, therefore it is necessary to foresee a possibility of their direct defining:

$$B_3 = \frac{F_3 + \left(1 - \frac{\pi}{4}\right)\sum_{i=0}^{3} R_{3i}^2}{H_3}; \quad H_3 = \frac{F_3 + \left(1 - \frac{\pi}{4}\right)\sum_{i=0}^{3} R_{3i}^2}{B_3}.$$

In case of round cross-section, all the radiuses of fillets are equal to:

$$R_{3i} = \sqrt{\frac{F_3}{\pi}}.$$

At this stage, it is also necessary to take into account limitations of the design model:

$$R_{30} + R_{31} \le B_3; \quad R_{30} + R_{33} \le H_3;$$
$$R_{32} + R_{33} \le B_3; \quad R_{31} + R_{32} \le H_3.$$

It is also necessary, to foresee a possibility of defining the section of constant cross-section of length $L_3 < L$ at the air intake duct outlet.

Let us assume in the first approximation, that the air intake duct cross-section parameters: the side ratio – $k_B(x)$, the radiuses of fillets – $R_i(x)$, the width – $B(x)$, and the height – $H(x)$, are varied by linear dependencies:

$$k_B(x) = k_{B3} + \frac{k_{B\min} - k_{B3}}{L - L_3 - x_R}(x - L_3),$$

$$R_i(x) = R_{3i} + \frac{R_{\min i} - R_{3i}}{L - L_3 - x_R}(x - L_3),$$

$$H(x) = \sqrt{\frac{F(x) + \left(1 - \frac{\pi}{4}\right)\sum_{i=0}^{3} R_i^2(x)}{k_B(x)}}, \quad B(x) = k_B(x) H(x),$$

where $x_R = R$ – is the length of the air intake inlet section with a single fillet.

Now, the air intake shape can be plotted

$$y_1 = \frac{H(x)}{2} + \Delta y(x); \quad y_3 = \frac{-H(x)}{2} + \Delta y(x);$$
$$z_0 = \frac{B(x)}{2} + \Delta z(x); \quad z_2 = \frac{-B(x)}{2} + \Delta z(x),$$

where $\Delta y(x)$ and $\Delta z(x)$ – are the shifts of the air intake cross-section center relatively the minimal cross-section.

5. 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 satisfactory conform to shapes of real air intakes of gas-turbine engines, developed by Antonov Company (Figs 4, 5).

For example, Fig. 4, a shows calculation result for air intake of ТВ3-117ВМА-СБМ1 engine ($H = 6$ km, $M = 0.5$, $G_a = 7.8$ kg/s) with circular duct and non-circular external outline, and air intake shape of the Ан-140 airplane (Fig. 4, b). Fig. 5, a shows result of shaping of air intake for the same engine with the duct gradually transferring from flat cross-section into circular one and the same air intake shape of the Ан-140 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. On the base of known method of axisymmetric air intake shaping for turbofans, the method of non-circular air intake shaping for gas-turbine engines (directed toward application in practice of multiple calculations at an airplane preliminarily designing stage in conditions of incomplete information) is developed.

2. Comparison of the calculation results according to this method and real air intake shape demonstrated satisfactory 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.

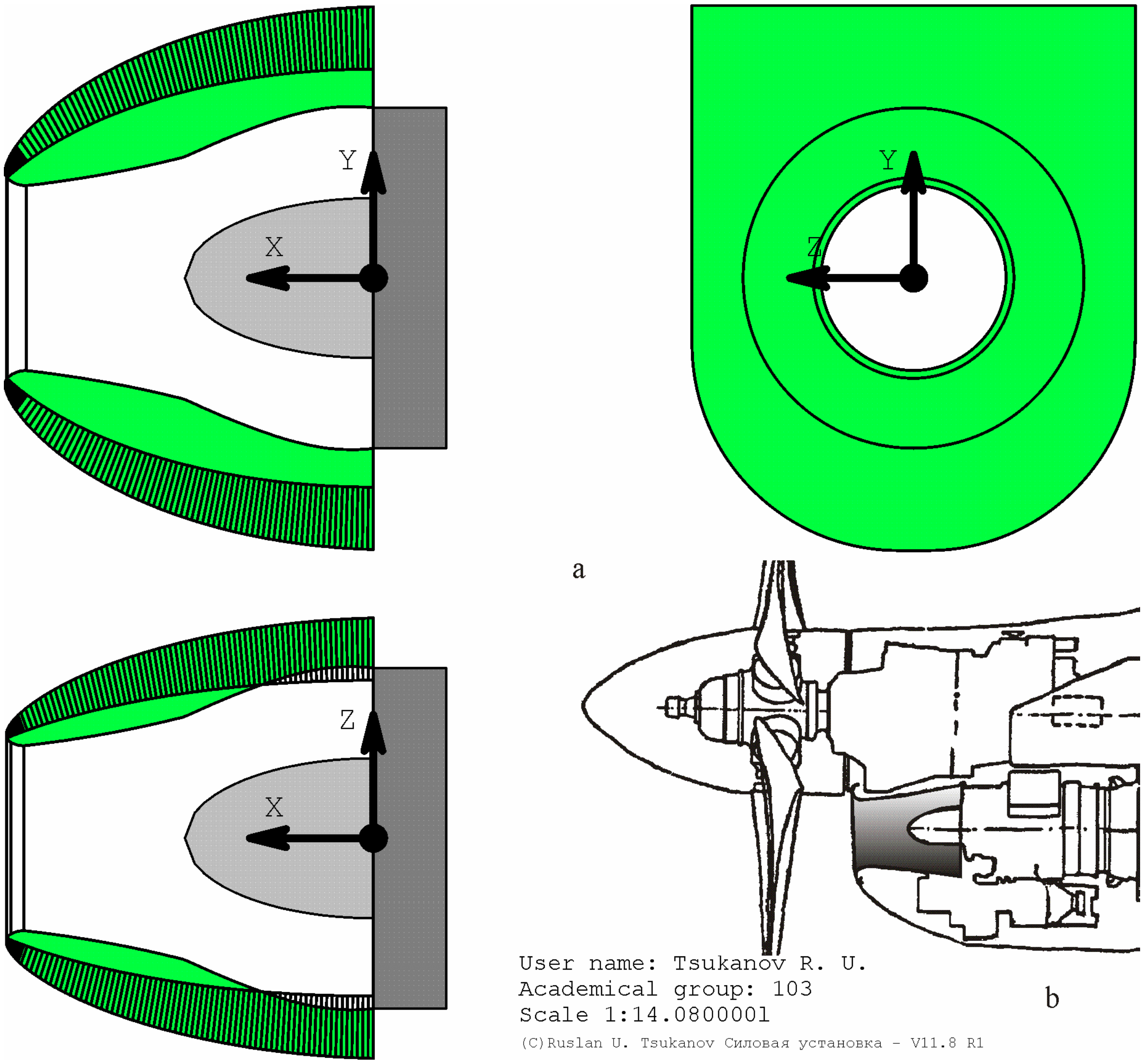

Fig. 4. Air intake of ТВ3-117ВМА-СБМ1 engine:
a – with circular inlet (calculation by Power Unit 11.8); b – shape (Ан-140) [12]

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 mathematical model, it is desirable to add possibility to take into account S-shape of the air intake duct, defining of its length from designer's considerations, defining bigger radius of curvature of the air intake lip, and also take into account presence of boundary layer bleeding devices in front of the air intake.

5. 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.

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ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

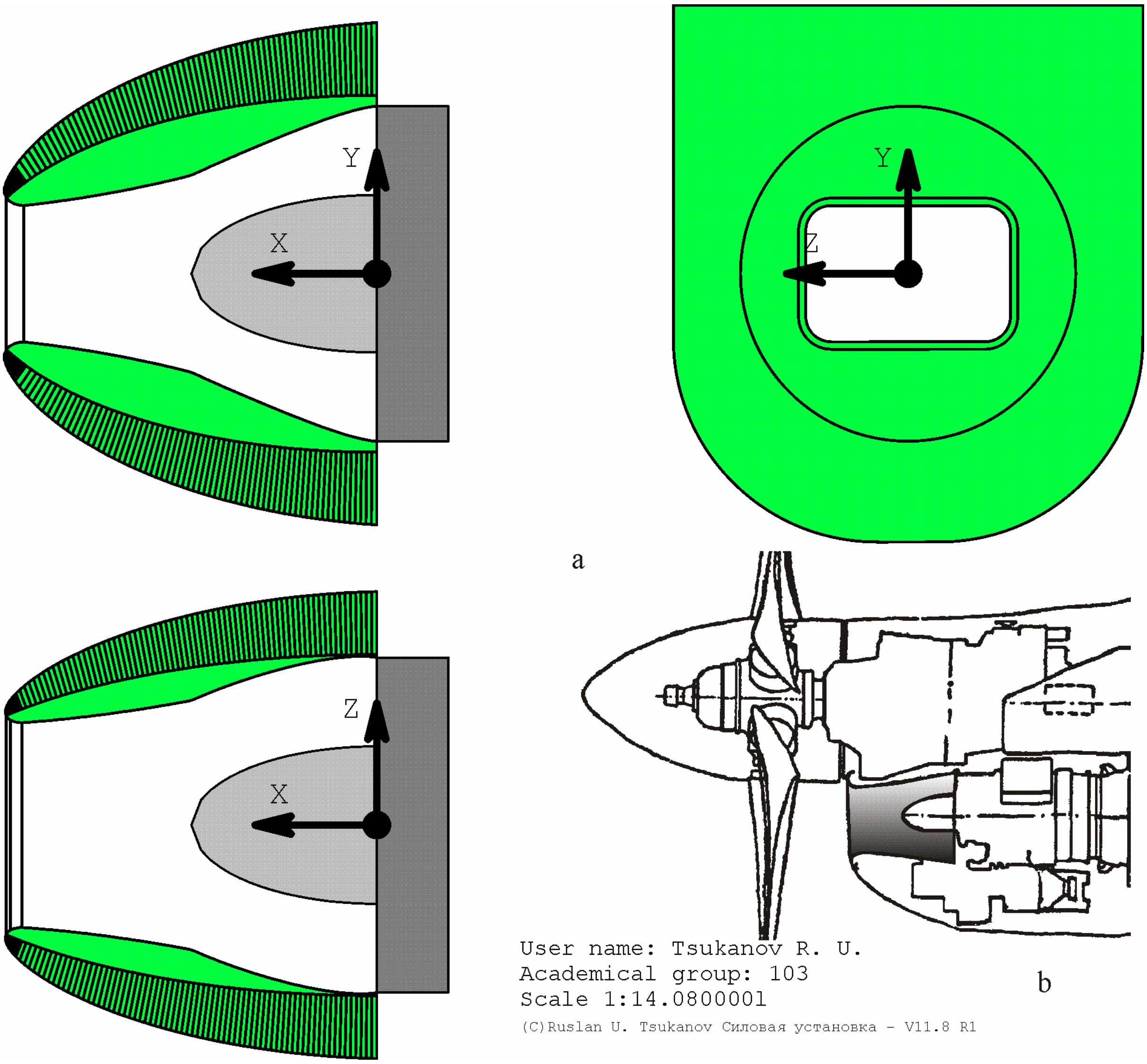

Fig. 5. Air intake of ТВ3-117ВМА-СБМ1 engine:
a – with flat inlet (calculation by Power Unit 11.8); b – shape (Ан-140) [12]

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Надійшла до редакції 20.10.2022, розглянута на редколегії 20.11.2022

ПРОФІЛЮВАННЯ НЕКРУГЛИХ ДОЗВУКОВИХ ПОВІТРОЗАБІРНИКІВ ГАЗОТУРБІННИХ ДВИГУНІВ

Р. Ю. Цуканов

Предметом вивчення в статті є процеси профілювання дозвукових повтрозабірників газотурбінних двигунів на етапі ескізного проектування літаків. **Ціллю** є розробка математичної моделі профілювання круглих повітрозабірників газотурбінних двигунів на основі метода В. І. Поліковського для профілювання до-

ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

звукових повітрозабірників двоконтурних турбореактивних двигунів. **Задачі:** врахувати можливість некруглої форми зовнішньої поверхні мотогондоли; врахувати можливість некруглої форми каналу повітрозабірника (в першому наближені форма поперечного перерізу каналу задається у вигляді прямокутника з можливими чотирма різними закругленнями у кутах); врахувати можливість наявності 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: на основі математичної моделі профілювання вісесиметричних повітрозабірників турбореактивних двигунів розроблено математичну модель (алгоритм і його програмну реалізацію) для профілювання некруглих повітрозабірників газотурбінних двигунів з урахуванням некруглої форми зовнішньої поверхні мотогондоли, некруглої форми каналу повітрозабірника, наявності вхідного кока компресора двигуна та нульового кута розкриття у вихідному перерізі дифузору. Шляхом порівняння з профілем повітрозабірника, розробленого ДП «Антонов», показано адекватність результатів розрахунку за розробленою математичною моделлю. Для подальшого вдосконалення математичної моделі бажано додати можливість врахування S-подібності каналу повітрозабірника, завдання його довжини з конструктивних міркувань, завдання більшого радіуса кривизни вхідної крайки, а також врахувати наявність пристроїв зливання примежового шару перед повітрозабірником.

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

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