The dependence of the appearance of the aircraft on the conditions of the Arctic basing

Mikhail Yu. KUPRIKOV*[,1], Nikita M. KUPRIKOV[1,2], Lev N. RABINSKIY[3]

*Corresponding author
*[,1]Department of Engineering Graphics,
Moscow Aviation Institute (National Research University),
4 Volokolamskoe shosse, 125993, Moscow, Russian Federation,
kuprikov@mai.ru*, nkuprikov@mai.ru
[2]Scientific and Information Center "Polar Initiative",
1 Volokolamskoe shosse, 125993, Moscow, Russian Federation
[3]Department of Perspective Materials and Technologies of Aerospace Designation,
Moscow Aviation Institute (National Research University),
4 Volokolamskoe shosse, 125993, Moscow, Russian Federation,
rabinskiy@mail.ru

DOI: 10.13111/2066-8201.2019.11.S.11

Received: 23 April 2019/ Accepted: 04 June 2019/ Published: August 2019

Abstract: *Positioning on the global political arena of the Arctic Territory as the exclusive economic zone of the Russian Federation requires, first of all, the development of a regional transport network, including cargo and passenger traffic for the sustainable development of the region. The solution of such a transportation problem is a compromise of the aircraft performance. The purpose of the article is to analyze and find out how dependent is the appearance of the aircraft on the conditions of stationing in the Arctic. An analysis of the scientific and methodological support and well-known design solutions was carried out, which showed that to create a successful sample of the automatic part of the safety system, it is necessary to solve the FOS problem based on the solution of the inverse design problem from the inner layout of the aircraft .Mathematical dependences of the landing mass on the ice thickness were identified. The main stages of the transport operation in the Arctic were pointed. On the basis of the developed formal heuristic models, a subsystem of moment-inertial analysis has been created. The analysis of the research results showed that by 2050 the flight range will increase with a decrease in the landing mass.*

Key Words: *North Pole, construction, moment of inertia, target load, diagram, load-distance*

1. INTRODUCTION

The growth of the activity in the polar regions of the Russian Federation depends on the availability of specialized aircraft for polar exploitation in the fleet of domestic aviation [1], [2], [3], [4]. The geographical location of the Russian Federation highlights the pronounced regional isolation of the Arctic zone of the Russian Federation (AZRF). In Russia, more than 40% of the territories are inaccessible and remote polar areas – the Arctic, which requires the use of aviation technology (airplanes and helicopters) to ensure uninterrupted aviation and transport accessibility of the Russian Arctic. In these regions, as nowhere else, the issues of increasing the volume of passenger and freight traffic [5], [6], [7], [8], [9], increasing the efficiency and reliability of operation under severe infrastructure and climatic constraints (ICC) are important.

The solution to the problem of continuous aviation and the transport accessibility of the Far North and Far East regions is a compromise of the aircraft technical and operational characteristics [4], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30]. Today, the transportation task in the Arctic region is achieved through the use of an obsolete aircraft fleet, as well as through the development of new promising aircraft for polar exploitation (Fig. 1). The climate in the Arctic and the components of the natural environment of archipelagoes are sensitive to climate changes of different time scales. The most striking indicator of past and current changes is the temperature regime of the surface layer of air, the circulation of the atmosphere and the state of ice cover [31], [32], [33]. This led to a change in requirements for transport operations in the Arctic, which, in turn, leads to a change in transport aviation [5].

Ice thickness and ice cover area are dynamically changing values, and analysis of changes in the ice situation in the Arctic since 1950 allows us to make an estimate about the reduction or almost complete melting of the ice cap of the Russian Arctic sector by 2090.These processes are related to the fact that along the NSR (northwest passage) sea and ocean currents lead to ice drift from the Barents Sea to the Bering Strait, while in the northwestern passage off the coast of Greenland, Canada and the USA, ice forms static ice fields or drift within a limited closed area. The difference in climatic zones is a prerequisite for the appearance of “ice islands” (icebergs) [10].

The operation of various kinds of vehicles in the Arctic depends on the infrastructural and climatic constraints, requirements for transportation (over 2400 km) and overall mass characteristics (target load of more than 15 tons). The scientific and methodological support developed in the period 1950-1970 is outdated, the boundary conditions of exploitation in the region and the geopolitical situation have changed. The development of aviation technology (IL-14, An-12 and An-74) in the years 1950-1980 took into account the requirements of the universality of medium-term operation in the Arctic. The modern experience of research and design work and aircraft operation in the Arctic creates a scientific base and confirms the relevance of solving the problems of shaping the aircraft's appearance, taking into account the satisfaction of the “hard” infrastructural and climatic limitations of polar exploitation.

2. METHODOLOGY

Analysis of the scientific and methodological support and well-known design solutions displayed that to create a successful sample of the automatic part of the safety system, it is necessary to solve the FOS problem based on solving the inverse design problem from the aircraft’s inner layout [14]. The disposition of the fuel reserves and the mass of the target load affects the control system and leads to a significant change in the moment-inertia appearance both during the flight and during the performance of the transport tasks cycle. It can be concluded that when shaping the look of the automated safety system it is necessary to pay attention to the transformation tensor of the infrastructure and climatic constraints and operating conditions, since they are decisive in the formation of the look of the aircraft. Restrictions make adjustments to the structure and composition of tasks solved in the framework of the formation of the aircraft's appearance (FOS). The FOS in this work is the description of the values of the main design parameters, which unambiguously determine the shape, size, characteristics of the aircraft, corresponding to the preliminary design stage and ensuring operation in the Arctic. We will decompose the FOS procedures. Under ICC conditions, it is necessary to determine the masses of the aircraft during the FOS, identify the groups of elements whose mass is known, as well as the control over the mass ratio of individual units and systems of the aircraft according to the equation for the weight balance of the aircraft:

$$1 = \bar{m}_{aifr.} + \bar{m}_{eng} + \bar{m}_{t.l.} + \bar{m}_{eq.} + \bar{m}_{f.} + \bar{m}_{p.e.}(\bar{m}_{e.e.}; \bar{m}_{i.r.e.}) \quad (1)$$

where $\bar{m}_{aifr.}$- relative weight of the airframe; $\bar{m}_{eng.}$- relative mass of engines; $\bar{m}_{eq.}$- relative mass of equipment; $\bar{m}_{f.}$- relative mass of fuel; $\bar{m}_{t.l.} = F(\text{T3})$- relative mass of target load; $\bar{m}_{p.e.}$- relative weight of equipment for polar exploitation, $\bar{m}_{e.e.}$- relative mass of emergency equipment for polar operation; $\bar{m}_{i.r.e.}$- relative mass of equipment for ice reconnaissance, including locators, echo-sounders, UAVs, etc.

$$\bar{m}_{f.} = \bar{m}_{f.}^{one\ way\ flight} + \bar{m}_{f}^{return\ flight} + \bar{m}_{t}^{park.m.} + \bar{m}_{f}^{new\ m.} \quad (2)$$

$$\bar{m}_{t.l.} = \bar{m}_{t.l.}^{insertion} + \bar{m}_{t.l.}^{unloading} + \bar{m}_{t.l.}^{platform} \quad (3)$$

$$\bar{m}_{p.e.} = \bar{m}_{e.e.} + \bar{m}_{i.r.e.}; \quad (4)$$

In the formation of the layout scheme SAB, which consists in the implementation of mutual spatial coordination of the main compassable elements of the aircraft $\bar{m}_{p.e.}$; $\bar{m}_{T}$; $\bar{m}_{p.e.}$, it is necessary to proceed from the tasks for which the SAB is being developed. The main task of the SAB is the implementation of infrastructure, scientific and strategic tasks in the Arctic, logistics and prompt delivery with the help of the SAB of specific cargo and fuel to the areas of operation of the drifting polar stations “North Pole” of the Arctic and Antarctic Research Institute in the basing areas of the operational units of the Arctic Military District of the Armed Forces The Russian Federation and the Border Troops of the Federal Security Service of Russia, the Ministry of Emergency Situations of the Russian Federation, ice-guided areas for ship caravans along the NSR (Fig. 1).

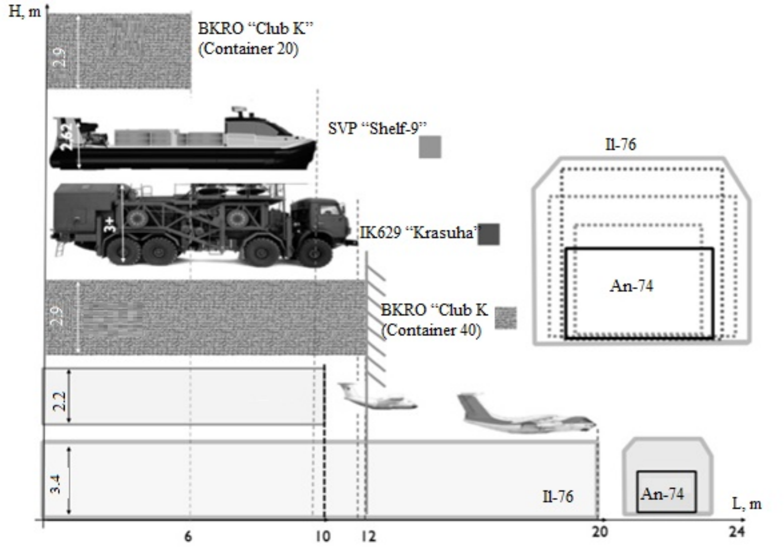

Fig. 1 – Nomenclature of freights and SAB restrictions

In the nomenclature of goods transported during transport operations, there are both special cargo and scientific equipment, and oil drills, and construction equipment intended for the carriage of goods in bulk, or fixed on containers or platforms.

Due to the use of new information technologies and modern materials, there is a decrease in the mass fraction of the design and aggregates of the aircraft in the weight structure in favor of increasing the mass of the target load ($\bar{m}_{p.e.}$) and fuel mass ($\bar{m}_T$):

$$\sum \bar{m} = 1 = \bar{m}_{l.} \downarrow + m_T, \tag{5}$$

where $\bar{m}_{l.} \downarrow = \bar{m}_{pos} \downarrow = \bar{m}_{p.s.} \downarrow + \bar{m}_{t.l.} \uparrow + \bar{m}_{T.balance}$

To meet dimensional requirements for the carriage of goods ($\bar{m}_{t.l.}$)in the chosen plane to the work areas (L_{TO}). The drift polar stations "North Pole" will be presented in the following form:

$$\begin{gathered} \bar{m}_{p.s.} \rightarrow \bar{m}_T \uparrow \min \bar{m}_{p.s.} \downarrow \rightarrow \max \bar{m}_{t.l.} \uparrow \rightarrow V_f \uparrow = \\ f\,(S_{sec}(r)_f; L_f) \rightarrow L_f \leftarrow \min J_{ozy} = const. \end{gathered} \tag{6}$$

Reducing the mass fraction of the design and assembly of aircraft ($\bar{m}_{t.l.}$)in the structure of the weight of the aircraft is necessary in favor of increasing the mass of fuel ($\bar{m}_T$)and target load masses which ($\bar{m}_{t.l.}$), in turn, are limited by the size of the fuel tanks and the size of the fuselage(V_f).

3. RESULTS AND DISCUSSIONS

When choosing an aircraft (AC) for the transportation of goods in the polar regions, it is necessary to take into account certain requirements and FTC of mixed polar flights, including the technical feasibility of transportation to the areas of operation (L_{TO}) of Polar Drifting Polar Stations Required Target Mass ($\bar{m}_{t.l.}$) and technical dimensions of the cargo compartment, because at($\bar{m}_{t.l.}$) $= const$ and $\left(V_{fl.}\right) = const$ cargo dimensions may not satisfy $V_f \rightarrow (S_{sec}(r)_f;\ L_f)$ selected AC.

Taking into account the infrastructural limitations of basing on ice runways and on continental aerodromes, it is necessary to consider the size of the fuselage (L_f). Fuselage size and layout density (ρ_k) on the OZ axis, in turn, require the application of the moment-inertia approach to minimizing the moments of inertia (I_{oz}) when designing a promising SAB. On the basis of (6) and the chosen scheme, the main parameters are determined and the layout of the SAB. In the process of assembling (1.4), external and internal forms are determined, the location of the payload, equipment, equipment, engine units, etc.

$$\uparrow (\bar{m}_{t.l.}) \rightarrow \uparrow \Delta \bar{J}_{oz} \tag{7}$$

$$\begin{cases} m_0 = \sum_j m_j \\ I_{00x} = \sum_j I_{j0x} int. + \sum_j I_{jox} ext. \\ I_{00z} = \sum_j I_{0z} int. + \sum_j I_{joz} ext. \\ I_{00y} = \sum_j I_{0y} int. + \sum_j I_{joy} ext. \end{cases} \tag{8}$$

It is important to note that I_{00z} can be formed by L_f and changes in cross-sectional area of the fuselage (S_{sec}) at $V_f = const$ and layout density in cross section due to target load distribution ($\bar{m}_{t.l.}$) along the length of the fuselage (L_f) for the delivery of special equipment and cargoes using the SAB, taking into account the ICC polar operation (ice thickness, etc.) on the shape and required cross-sectional area of the fuselage (S_{sec}) and overall dimensions of equipment, chairs and containers (pallets). In accordance with this, it can be concluded that the length of the fuselage and its radius will be a parameter of the characteristics of the volume-weight and moment-inertial layout of the fuselage:

$$V_f = f\left(S_{sec};\ L_f\right) = f\left((r_f^2\ \times\ \pi;\ L_f;\ m_{t.l.})\right) \tag{9}$$

Components that affect such characteristics as the volume of the fuselage (V_F) and the area of the air-swept surface (ASP) are the commercial load, equipment and gear, emergency equipment and equipment for conducting ice aerial reconnaissance. These components of the weight balance equation should be considered as parameters defining the length of the aircraft fuselage (Fig. 2):

$$L_f = f\ \left(L_1\left(L_{ramp}\right)\right) +\ L_2(V_{t.l.}) +\ L_3\ \left(\overline{m}_{eq.}\right) +\ L_4\ (m_{p.e.}(m_{e.e.};\ m_{i.r.e.})) \tag{10}$$

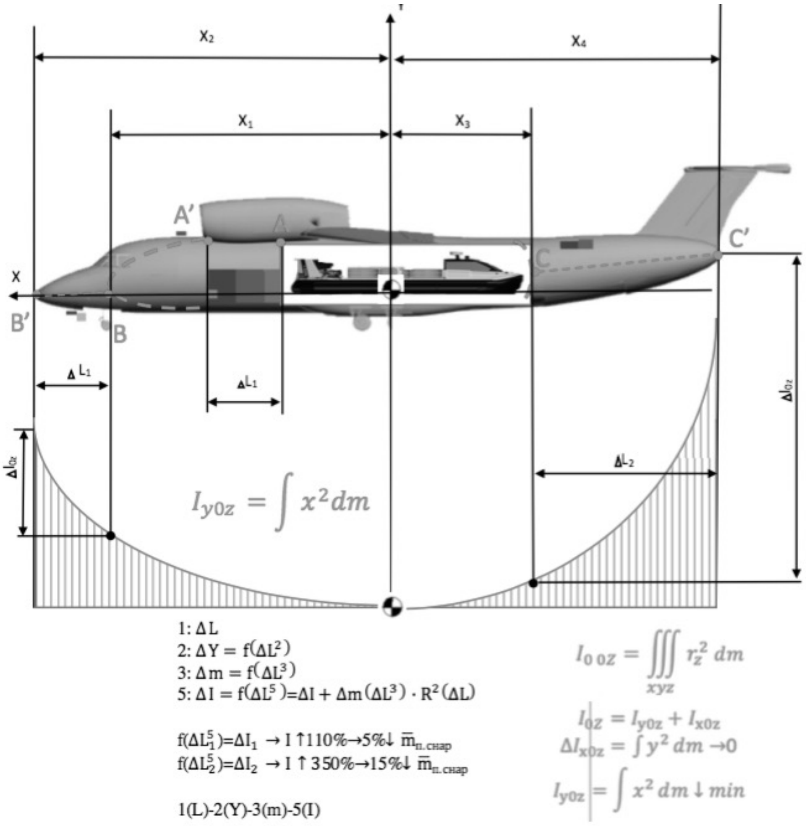

Fig. 2 – Option Analysis I_{0z} moment-inertial layout target load in the fuselage for the X1

It can be concluded that the characteristics of equations (9) – (10) together with the perimeter of the cross section (P) are parameters for the characteristics $S_{sec} = f\ (L_f; P)$ and $V_f = f\ (S_{sec};\ L_f)$ it allows us to create the dependence of the fuselage section on the mass of the target load

$$S_{sec} = f\ (m_{t.l.};\ J_{oz}) \tag{11}$$

The analysis of the influence of the application of the moment-inertia model on the aircraft performance characteristics, expressed as a series of circuit solutions, is presented in Fig. 3.

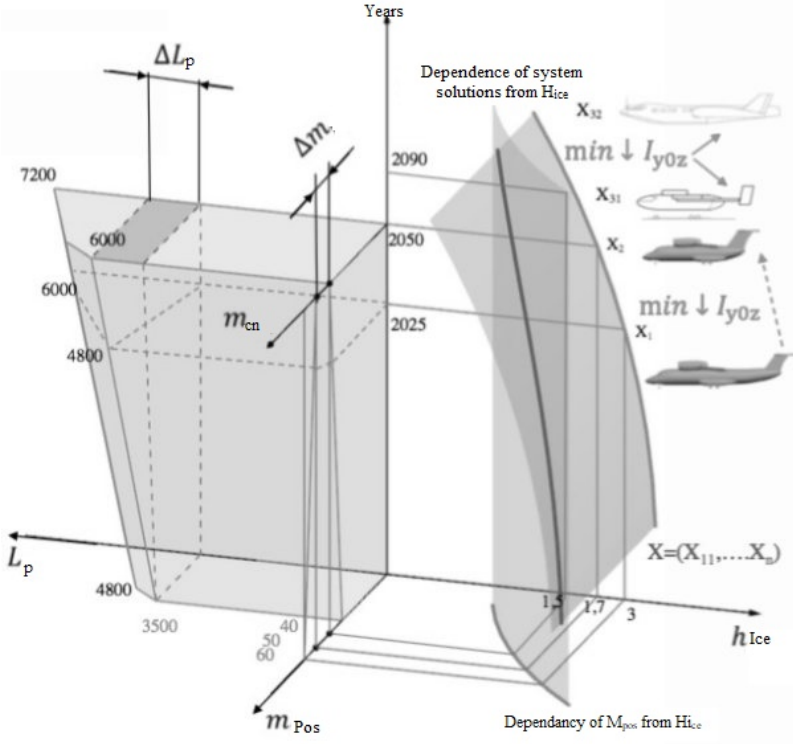

Fig. 3 – Analysis of the impact of the application of the moment-inertia model on the aircraft's characteristics

The alternate variants of the moment-inertial layout of the target load and scientific equipment (posts) in the fuselage and their influence on the change of the mass of the fuselage are considered. Taken together, these data allowed an analysis of the mutual influence of the relative mass of the fuselage and the parameters of the moment-inertial layout of target load zones and scientific equipment (posts).

The offered new method for the formation of the layout scheme of the aircraft in the conditions of infrastructural and climatic constraints of the Arctic based while minimizing the plane moment of inertia with respect to I_{y0z} (along the *OX* axis) based on the solution of the "inverse" design problem by combining three methods: moment-inertial analysis, matrix-topological and control points method, it is the basis of scientific and methodological support for the formation of the SAB image [10], [11], [12].

4. CONCLUSIONS

1. The identified mathematical dependences of the landing mass on the thickness of the ice made it possible to apply them to analyze the flight performance of an arctic-based aircraft. The reliability of the models is ± 7%.It is established that the ice thickness 1.7 m when flying at R_{potrb} = 1600 ÷ 2000 km transporting operation can be realized with aircraft landing weight from 37 tons to 59 tons, the normal aerodynamic scheme chassis ski, with two engines located on the wing.

2. The identified rational flight directions and usual routes for performing the polar transport operation made it possible to formulate requirements for SAB characteristics. The main stages of the transport operation in the Arctic were identified. The need to perform a transport operation in R_{potrb} = 1600 ÷2000 km requires consideration of change of ice thickness from 3 m to 1.7 m, which leads to a reduction in the allowable landing weight from 59 tons to 37 tons.
3. The established procedures for assembling the SAB decks based on the choice of a rational moment-inertia appearance made it possible to adapt: the method of control points to determine the external contour, the matrix-topological method for the longitudinal layout, the formation of a rational moment-inertia appearance.
4. On the basis of the advanced formal heuristic models, a subsystem of moment-inertial analysis has been formed. The program complex "Moment-Inertia Factor" was registered on January 11, 2011 as a computer program, assigned the State registration number No. 2011610197.
5. Identified rational ranges for the location of goods at a distance of 0.2-0.4 $\bar{l}$ from the center of mass, providing a rational moment-inertial appearance of the aircraft, which reduced the differential increase in take-off mass due to a decrease in the mass fraction located in the zone of large portable inertia moments.
6. The analysis of the results of design studies have demonstrated that by 2050 the flight range will increase to R_{potrb} = 2400 km with a decrease in landing weight to 50 tons, this would require additional measures to reduce the empty weight of the equipped aircraft, at the expense of stopping using the cargo ramp.

ACKNOWLEDGMENTS

The work was supported by grants from the President of the Russian Federation for state support of young Russian scientists – doctors of science (MD-6177.2016.8) and scholarships of the President of the Russian Federation for young scientists and graduate students who carry out promising research and development in priority areas for the modernization of the Russian economy – СП-1424.2018.1).

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