Formation of requirement for an aircraft with increased payload and flight range

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Abstract. The constant growth of cargo and passenger air transportation, their trends, as well as laws on noise and harmful emissions requirements make it possible to create a modern cargo aircraft of increased range and carrying capacity. In this paper, the analysis of the volume of the existing air fleet and the forecast of its development is carried out, it is proposed to consider the features of the formation of requirements for an aircraft of increased payload and flight range. The formation of such requirements will speed up the design process of such an aircraft, in case of a decision to start its creation. The research method will consist in analyzing the air cargo transportation market by GDP, current and future laws, the size and type of fleet, as well as current market leaders. As a result of the study, a general description of the aircraft and requirements for its characteristics were formed, as well as the size of the market for a potential aircraft of increased payload and range. The conclusion was the statement that such an aircraft of the above type is possible.

1 Introduction

Currently, almost all types of air vehicles are used to cargo transportation [1-5]. Cargo aircraft is a type of civil aircraft designed for air cargo transportation, namely for the transportation of goods and mail. Cargo can be loose (mail), dense and bulky. All modern cargo aircraft projects are modifications of passenger projects. These aircraft can perform the role of transporting mail and cargo, combine cargo and passenger transportation, and quickly convert from passenger to cargo. When changing the configuration of a cargo aircraft from a passenger one, the passenger cabin is converted into a cargo one. Modern cargo modifications of passenger aircraft with their fuselage, designed primarily for passenger transportation, limit air cargo transportation both in volume and in cargo density. Their disadvantages include insufficient strength of the floor, the section of the fuselage, which does not allow maximum use of the internal volume, the lack of a sufficient number of cargo doors of the required size.
2 Problem definition

In this paper, the task is to develop requirements for a cargo aircraft of increased payload and range. This is an aircraft capable of carrying over 100 tons of payload over a distance of over 8000 km. In this paper, it is proposed to consider the project of a long-haul cargo aircraft, taking into account the principles of weight design. Such a project can have a number of advantages in the face of technical superiority over its existing converted counterpart. Another way of development is the further use of cargo aircraft created on the basis of passenger ones. They have a number of economic advantages, in the face of already designed, manufactured and certified systems and units [6, 7]. This reduces monetary, human, time and resource costs.

3 Solution methods

The analysis will consist of three parts: an assessment of trends in global air cargo transportation, an assessment of the global fleet of cargo aircraft and the development of requirements for a cargo aircraft of increased range and payload capacity of the next generation.

3.1 Analysis of results for 2021 and trends in freight transport

To date, the global CTK (increased by 7.9%) and ACTK are steadily growing, but in the first half of the year, ACTK was still 12.4% lower than in 2019 [8]. According to IATA, over $6 trillion worth of goods were transported by air in 2021. This is 35% of the total value of all goods transported in 2021, and the load factor was 53.8% (231342 million ton-kilometers out of 430016). 53% of these shipments occur in the form of additional baggage from passenger aircraft (belly cargo). At the same time, airlines have learned to use their passenger planes without any conversion in the form of cargo aircraft (fig. 1).

![Graph showing cargo transportation and GDP 2019-2021.](image)

Fig. 1. Cargo transportation and GDP 2019-2021.

So, only in the first half of 2021, the number of cargo aircraft increased by 12% compared to 2019, mainly due to this use of passenger aircraft, and the growth of cargo
traffic was 13%. The growth of air cargo transportation began in 2021, increasing by 7.9% compared to 2019, by 5% compared to 2018. If in 2021 air cargo transportation overtook GDP in terms of decline, then in 2021 in terms of growth, which is typical for economic recovery (fig. 2).

Fig. 2. Comparison of ACTK over time since 2019, divided into main and additional cargoes.

There was a sharp increase, which by the end of the year led to an increase in air freight rates in 2020 as a whole increased by 55.9% (compared to 2019), amounting to $2.79/kg. Against the background of a decrease in traffic, revenues from air cargo increased by 27.2% in 2020 to the level of $128.8 in hard monetary terms (Fig. 3). This is a new record on a large scale, which helped airlines a lot. The lack of free space on wide-body passenger aircraft meant that the combined load capacity was insufficient to meet the rapidly growing demand.

Fig. 3. Tariffs of the air cargo transportation and profit from them by years.
This led to the fact that the load factor of cargo transportation increased by 7.1% to 53.9% (fig. 4). Global cargo transportation and the Russian market. It is noticeable that the Russian air cargo market has increased actual transportation and congestion, but the total cargo capacity has fallen along with passenger transportation.

![Chart 8: Industry-wide passenger and cargo load factors](source)

**Fig. 4.** Load factors achieved by carriers.

Despite the fact that airlines were able to reduce costs somewhat in 2020, the unit costs of airlines only increased due to the extremely high rates of reduction in traffic. Because of this, the global break-even ratio of freight traffic congestion in 2020 reached 76.3% ACTK, while the same figure was from 66.4% in 2019 (Fig. 5). Therefore, for the first time since 2008, airlines did not earn a profit. In 2004, the entire world civil aviation, according to IATA, transported a little more than 40 million villages, while Federal Express alone transported 19.656 million in 2021. All this indicates a rapid growth in air cargo transportation.

![Fig. 5. Airlines profits by years.](source)
3.2 Analysis of the volume of the existing air fleet and forecast of development in 10 years

In 2021, the number of aircraft designed strictly for cargo transportation increased by 3%, and the conversion of passenger aircraft for cargo transportation broke records. Since almost half of the cargo is transported in the form of belly cargo in passenger wide-body aircraft, it is necessary to fix their growth. The total number of large and extra-large wide-body aircraft (both passenger and cargo) will increase from 4839 to 7347 by the beginning of 2032. That is, the ten-year growth will be 51.8%. It is assumed that the cumulative annual growth rate (CAGR) will fall by 4.3% per year (from 2015 to 2020) to 2.1% per year (from 2022 to 2032) due to losses as a result of restrictions. At the same time, it is necessary to take into account the increase in the share of cargo wide-body aircraft from 10% to 30%. Thus, we can say that the market volume of such aircraft can reach 1000 aircraft (Airbus adheres to a similar assessment). During the period 2020-2032, the cumulative annual growth rate of the cargo fleet was 3.3% (3,100 sides by 2032), and passenger fleet was 2.6% (35,000 sides by the beginning of 2032). Let's take a closer look at the “super-large" A350 and Boeing 777/777X (both meet the ICAO aerodrome reference code E). In total, at the beginning of 2022, 2,155 aircraft are in operation (45% of the total number), of which 220 are cargo (all 777F). Total orders and deliveries are 3,026 aircraft (including 777X and A350F), of which 327 are cargo, i.e., about 10% of all super-large. Airbus and Boeing expect this share to triple to 30% due to a number of factors. Consider the Boeing and Airbus cargo aircraft families now and in the future: Boeing: 777-8F (2028), 747-8F, 777F, 767-300F, 767-300BCF, 737-800BCF. Airbus: A350F (2025), A330-200F, A330P2F, A321P2F. Of these aircraft, the BCF and P2F programs are programs for the complete conversion of aircraft from passenger to cargo, and the “F" aircraft are cargo aircraft originally built according to modified passenger designs. There are both Combi and Quick-Change, for the joint transportation of passengers with cargo and a quick change in the configuration of the aircraft, respectively. In addition to the above factory programs, there are also private conversion programs. In 2027, new ICAO laws will come into force, the purpose of which is to reduce noise and harmful emissions into the atmosphere. As a result of the entry into force of these laws in the future, the construction of new aircraft units of older generations will be prohibited, including cargo. Financial barriers will also be introduced for the use of cargo aircraft based on old platforms. It is also necessary to note the disappearing jumbo and super-jumbo segments. Both Boeing 747-8 and A380.

Production of all jumbos ends in 2022, and most of the passenger jumbos have either already been written off or will be soon. When considering demand, cargo capacity and the growth of the cargo fleet, it is necessary to note the importance of conversions such as P2F/BCF, Quick-Change and Combi. The reason is the growth of goods from online commerce, which are mostly “loose" goods. In 2018, 1800 aircraft were delivered, in 2020 804 aircraft, in 2021 1014 aircraft (of which almost a quarter were previously produced 737MAX), and in 2022 about 1650 aircraft. At the same time, the full restoration of production is expected no earlier than 2025. All this leads to the fact that out of 2506 (according to IATA) new and modified cargo planes, only 598 aircraft will be completely new, and the remaining 1908 will be conversions. Boeing provides a close value of 2,430 aircraft, of which only 830 (25%) will be old upgraded aircraft (fig. 6).
In 2020, about 1300 aircraft were written off, which is a record figure (of which 25% are wide-body), but in 2021 it returned to the 2019 figure of about 650 aircraft (of which 20% are wide-body). In the next decade, 41.1% of new aircraft will replace the old ones due to the above reasons, which will lead to a drop in the age of aircraft from 24.9 to 22.9 years. It is expected that within a decade the duration of flights on long-distance highways will increase, which is due to the high range of modern wide-body aircraft and the availability of cheap money for lessors. As a result, low capacity–long range flights appear. Therefore, the number of cycles before decommissioning will be slightly reduced, but flight hours will increase by 20% compared to 2019. As new laws on noise and emissions come into force, the age of cargo planes will only grow due to the availability of old passenger planes for conversion, and the share of 25+ year-olds will grow from 5 to 10% or 4,000 aircraft.

4 Research results

From the materials above, it can be seen that twin-engine aircraft will dominate the market due to fewer engines at the same actual range and not much less load. Requirements: a high-wing plane of a normal aerodynamic scheme with a normal tail, two underwing turbojet engines of a high degree of double-circuit and a tricycle landing gear with a front support; a flight range with a maximum load of 9000 km (maximum load weight of 130 tons); the weight of an empty equipped aircraft is 140 tons, and the maximum take-off weight is 350 tons; overall dimensions are limited by the ICAO aerodrome reference code E, and the wingspan is 65 meters; the outer track of the chassis is 9-14m; the cross-section should be able to accommodate 2 pallet/containers of 96x125x118 inches (average weight up to 2.8 tons) and 1 pallet/container of 96x125x64 inches (average weight up to 2 tons) on the lower deck. At the same time, the percentage of the volume occupied by the cargo should be the maximum. The forward part of the fuselage should have a cabin and a crew rest area on the second deck. The design of the fuselage should have cargo doors on the sides, at the level of the power floor, the dimensions and opening angle of which were suitable not only for the transportation of standard pallets, but also for the transportation of oversized cargo. On the main deck, the aircraft should accommodate 30-34 pallets, on the lower deck 10-17 pallets, depending on the location of the wing. Particular requirements for cargo decks are:

- Distributed systems of air conditioning and life support on both decks to prevent heating of goods in pallets,
• System for both smoke detection and fire detection, pallet heating, powerful fire extinguishing system,
• An advanced audio/video surveillance system for the inspection of a potential fire, a system of roller movement on decks and fixing oversized and standard cargo.

5 Conclusions

After analyzing the trends of cargo transportation and the market of cargo aircraft of increased range and carrying capacity, the results of the study were: an economic justification was made for the possibility of creating a cargo aircraft of this dimension according to a specialized project; an assessment was made of the volume of the market for such aircraft; it was estimated at a thousand units; a set of requirements for the design of such an aircraft was developed.

As a result of the study, the volume of the air cargo transportation market was determined by analyzing the relationship of transportation with GDP, the dynamics of cargo tonne-kilometers and their ratio to transportation tariffs, regional demand, freight congestion coefficient, transportation volumes and airline revenues. The size of the cargo fleet is predicted, the dynamics of its development for the next 10 years according to its total size.

The requirements for the future cargo aircraft of increased payload and range were formed and a conclusion was made about the possibility of creating such an aircraft according to a specialized project.

References