



Specifics of the requirements for the interior layout of long-haul aircraft

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Abstract: The main idea of aviation in the 21st century is the safety of passengers and crew, but the human is always inclined towards comfort. The purpose of the article is to study the comfort requirements for the interior layout of long-haul aircraft. The concept of the fuselage layout with capsule accommodation of passengers was formed. It was stated that with a flight range of more than 8 hours, the flight is comfortable only in business or first classes. The proposed variant of capsule placement, designed for the Boeing 777-200LR cabin, can be installed in other passenger airliners with a ceiling height of at least 2.1 m. Also, it was indicated that the proposed two-story capsule placement allows to provide the layout with first-class seats in a given cabin. It was concluded that the installation of individual passenger cells in railway transport on the high-speed trains Strizh or Sobsan, in airport terminals as hotel accommodation also holds promises.

Keywords: moment of inertia, load-range diagram, capsule, fuselage

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1. Introduction

The slogan “to fly the fastest and farthest” has received an economic connotation in the 21st century. It is necessary to fly wherever it is necessary, and so it should be fast, cheap and most importantly comfortable (Boytsov et al., 2005; Bulychev et al., 2018; Dolgov & Kuprikov, 2008; Dolgov et al., 2010a; 2010b; Eger et al., 1986; Egorov & Nartova, 2012; Formalev et al., 2016a; Formalev et al., 2018; Formalev & Kuznetsova 2018; Formalev & Kolesnik, 2017a; 2017b; Shuldan & Shtendera, 2020).

This is the nature of today’s demands. Let us try to interpret these requirements into the language of numbers, depending on the flight range of an aircraft. The development of long-haul aircraft of the Boeing and Airbus families (Fig. 1), covers all the many park problems that exist in the World. An evolutionary attempt to overtake these manufacturers is possible only in a situation of using competencies that give a qualitative gain (Bondariev, 2021; Gorokhov et al., 2018; Kolesnik et al., 2015; Kuprikov & Maximov, 1997).



Figure 1. Development of long-haul aircraft of the Boeing and Airbus families.

The main idea of aviation in the 21st century is undoubtedly the safety of flight (Aftandiliants, 2021; Kuprikov, 2003; Kuprikov & Patrakov, 2004; Kuprikov & Rabinskiy, 2018; Kuprikov, 2018a; 2018b; Kuznetsova et al., 2015; Okonechnikov et al., 2016; Prokofiev et al., 2016; Zaikov, 2015). The economic design of aircraft will force the manufacturer to move away from the external appearance parameters of aviation systems to the internal redesign of already known and well-proven types of aircraft (Aftandiliants, 2020; Gorban et al., 2021; Polieshchuk et al., 2021). All other things being equal, the economic perfection of the aircraft can be identified on the Pareto-optimal set in the coordinates of the load-range diagram (Formalev et al., 2016b), where the cruising range is

determined by the Breguet formula, expressed through the relative fuel mass \bar{m}_T (Eq. 1):

$$L = K a M / C_p \ln (1 / (1 - \bar{m}_T)), \tag{1}$$

where: L – estimated cruising flight range; C_p – specific fuel consumption; K – aerodynamic quality; a – the speed of sound; M – flight speed.

By adding the third axis to the dimension of the aircraft, for example, expressed in take-off mass, we can clearly show the ultimate dimension of the aircraft, expressed by modern infrastructural constraints (Fig. 2). For example, at point A, the aircraft design as a transport system degenerates. Splicing of points of the estimated flight range P, which is due to the limitation of the target load in the volume of the passenger compartment, and T - the maximum flight range with the target load, due to the volume of fuel tanks.

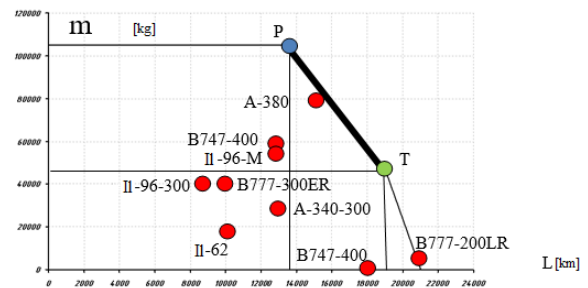
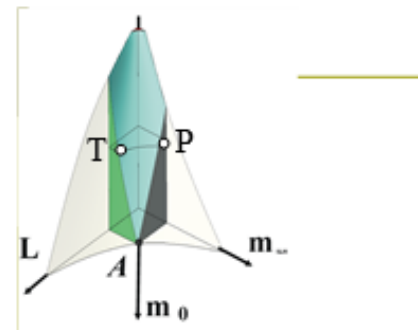


Figure 2. Long-haul aircraft cargo-range diagram.

That is, in fact, the plane begins to carry itself with zero payload weight return (Dyadin et al., 2021; Kyrylenko et al., 2020; Skryabinskiy et al., 2022). An interesting example is the New York – Singapore route of the Singapore Airlines SQ 21 with a length of 15.345 km. The Airbus 340-500 is in the air for 18 hours and 50 minutes. The layout of the cabin is noteworthy: only 98 business-class seats (250 seats in an economy class layout), that is, the minimum layout density for

a given volume of the passenger compartment. For many years, since June 29, 2004, this flight was the longest in the world. But it was cancelled in October 2012 for purely economic reasons. The Figure 3 shows a histogram of the distribution of flights between the largest airports in the world that can operate with long-haul aircraft (B747, A-380, B777, A-340). These airports are represented by red dots on the world map below (Fig. 3).

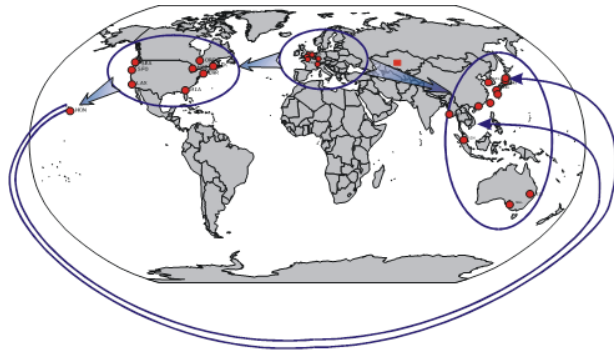


Figure 3. Map of regular flights between major airports in the world.

The distribution of large airports is characterised by the demographic factor. The European and North American regions are clearly expressed, but the countries of the Southeast Asia are of particular interest - these are countries from Japan to Australia. Figure 4 presents a map of regular flights of civil aviation for 2009, it can be seen that the zone of South America, Oceania and South Africa will begin to develop in the future.



Figure 4. Civil aviation regular flights map, 2009. Search for a rational aerodynamic balancing scheme of a long-range aircraft-

Flight range analysis shows three distinct flight distances. The first one, up to 3000 km, corresponds to inland flights. The second in the range from 8000 to 11000 is the transatlantic flight range. Historically, the B747 was designed for this range. The next frontier at 13.000 kilometres for the development of Asia-Pacific traffic from Europe and America. A-380 is a striking representative of this generation aircraft. The histogram has a

subject area in a zone of 17.000 kilometres. These are the tasks of future generations - the so-called "kangaroo flights" - flights from Australia to Europe and America, for example, London - Sydney (16.994 km), or Melbourne (16.903 km), or Auckland (18.338 km).

Figure 5 shows a graphical representation of the mathematical model of the search for the rational appearance of the aerodynamic balancing scheme of a long-range aircraft in the plane of infrastructure terminal constraints. If we take the ordinate axis as the target load, and the abscissa axis as the flight range, then in the resulting minimax problem the load-range diagram is limited by the limiting flight range. It is necessary to find the vector of design parameters $X^*(x_i)$ on the set of parameters X and restrictions U . If the range limitations are considered "hard", then it is enough to check the intersection points of the load-range diagram and the range restrictions for the feasibility of the project according to the aircraft existence equation.

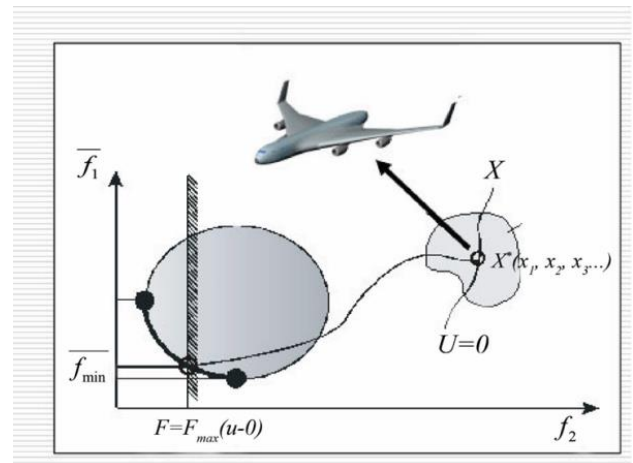


Figure 5. Graphic search model of the rational aerodynamic shape of the balancing scheme of a long-range aircraft in the plane of infrastructure terminal restrictions.

In this case, the solution of the mass balance equation is defined by determining the mass of the aircraft and identifying groups of elements, the mass of which is known, as well as control over the mass ratio of individual units and systems of the aircraft according to the equation of mass balance of the aircraft (Eq. 2):

$$1 = \sum_j \bar{m}_j, \tag{2}$$

where: \bar{m}_j – relative weight of the j-the element of the aircraft; m_{as} – weight of the airframe structure; m_{eu} – weight of the engine unit; m_{ec} – weight of equipment and control; m_f – weight of the fuel; m_{tl} – weight of a given target load; m_{sl} – weight of service load and equipment.

Figure 6 shows the aircraft properties corresponding to these three characteristic flight ranges. It is noteworthy that all three aircraft were designed for operation in the same aviation infrastructure, fly at the same speed with the same type of thrust systems in a four-engine scheme and use kerosene as fuel.

Among the long-haul flights, the most popular and massive flight is London - Sydney (16.994 km). Now it is performed with an intermediate landing. Since the days of Lord Sydney, this route has only grown in popularity. A successful experiment in the development of European civilization on one separate continent led to the flow of goods and passengers at a distance of 18.000 km. After three hundred years, the travel length on this route was reduced to one day. The first successful attempt of a non-stop flight from London to Sydney was made by the Australian company Qantas in 1989, flying B747-400 18.000 km in 20 hours 9 minutes without passengers and luggage. This is an example of point A on the load-range diagram.

These projects make it possible to perform the maximum possible flight ranges that, purely theoretically, can be carried out in the equatorial zone. For example, when flying from Buenos Aires to Shanghai, the range is 19.602 km, from Auckland to Madrid - 19.628 km, and between Taipei and Asuncion in the great circle - 19.918 km. But so far there are no such tasks on the main lines. There are experiments and marketing exercises. On December 10, 2005, the Boeing 777-200LR completed the longest flight from Hong Kong to London on a 21.602 km west-to-east flight in 22 hours 40 minutes. With a passenger capacity of 301 people, there were 27 people on board. This is a typical point A on the load-range diagram. Boeing 777-200LR (Fig. 7) and take as a basis for the analysis of alternative ways to improve fatigue, comfort, and ergonomics.

The fatigue of passengers directly depends on the duration of the flight, which determines the presence of increased requirements for the comfort and ergonomics of the passenger seat with the increasing duration of the flight. Figures 8 and 9 show the graphs of the dependence of the step between the rows on the flight time in economy and business classes, respectively. Figure 10 shows the graph of the dependence of the aisle width on the flight time in economy and business classes. It can be noted that a qualitative leap in indicators occurs at around 7 hours 45 minutes.

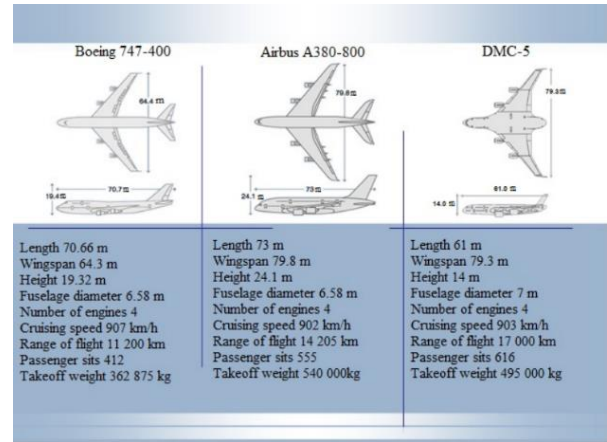


Figure 6. Long-haul passenger aircraft.



Figure 7. Boeing 777-200LR.

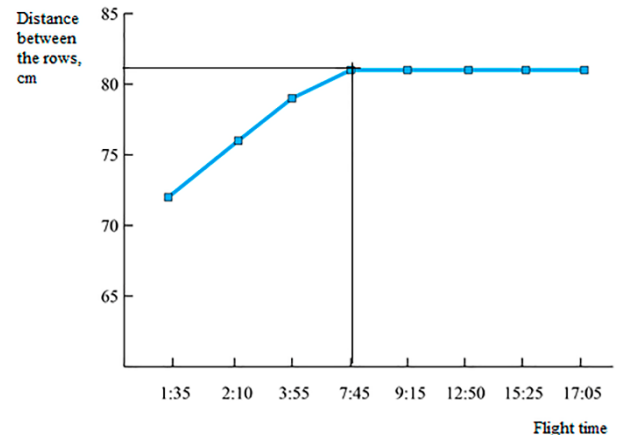


Figure 8. Graph of the dependence of the distance between the rows on the flight time in economy class.

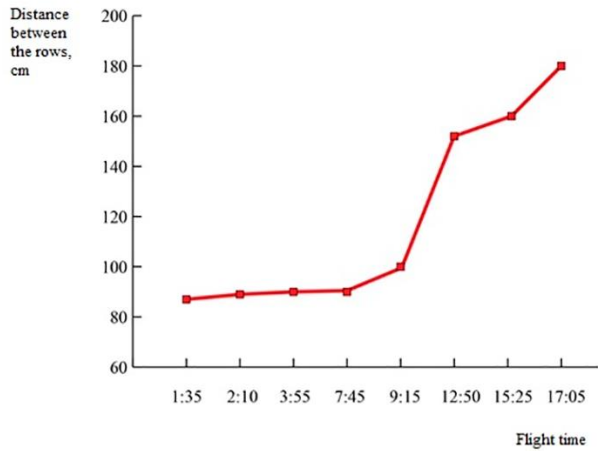


Figure 9. Graph of the dependence of the distance between the rows on the flight time in business class.

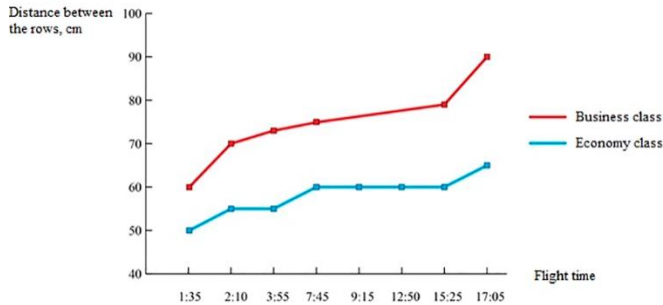


Figure 10. Graph of aisle width versus flight time in economy and business class.

2. Methods of increasing the comfort levels in an aircraft

Many of the world's airlines offer alternatives to standard business or first-class seating to improve comfort. Such places are either wide folding chair-beds hidden by partitions, or separate compartment rooms with a full berth and other furniture. Also, these places are equipped with entertainment systems. Figure 11 shows a first-class compartment, Figure 12 shows the first-class seat equipped with a folding chair and partitions.

Compartments for resting the aircraft crew are of particular interest. Rooms equipped with berths or comfortable armchairs are usually located in the voids below or above the main salon. In aviation, capsule accommodation is a promising alternative to traditional passenger accommodation. Not so long ago, the Air Lair capsule placement project by the British design agency Factory design was presented to the public. The capsule (Fig. 13) is a module with a folding chair, table, and entertainment system. The modules are installed one above the other in two rows (Fig. 14), which allows increasing the passenger capacity in the area by up to 30%.



Figure 11. First class compartment.



Figure 12. First class seat.



Figure 13. Air Lair capsule.



Figure 14. Air Lair two-story capsule layout.

Table 1 shows the values of the area per person in the cabin with non-standard placement.

Table 1. Values of floor space.

	Area, m ²
Fenced-off first class seat	1.55
First class compartment	3
Crew lounge	1.08
Capsule	0.9

Among the alternative types of arrangement, individual capsules in a two-story layout have the highest density of passengers. As a capsule placement on board the Boeing 777-200LR, a cell was proposed, shown in Fig. 15. The chairs installed in the capsule fold out into a full-fledged berth. This cell provides the passenger with first-class convenience with the density of the business class layout.

To assess the change in passenger capacity, the authors introduce the occupancy rate K, which is calculated as (Eq. 3):

$$K = N/n, \tag{3}$$

where N – the number of passenger seats installed in a typical layout, n – the number of passengers accommodated in cells on an equal area. This coefficient shows how many times the cost of a ticket should be increased in comparison with the cost of a ticket of the corresponding class to recoup the flight.

Table 2 shows the values of the K rate for business classes of Delta, Singapore Airlines and Emirates operated by Boeing 777-200LR. Table 3 shows the values of the occupancy rate K for the first class of the Emirates airlines.

Based on the given occupancy rates, it can be concluded that the most advantageous option is the layout with four rows of cells in the cross section. Figure 17 shows a side view of the passenger compartment, Figure 18 - a cross-section of the Boeing 777-200LR cabin and the layout of personal passenger cells.

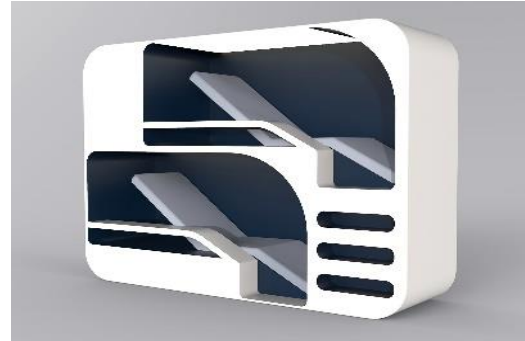


Figure 15. Individual passenger cell.

Figure 16 shows options for the layout of individual passenger cells on board of the Boeing 777-200LR.

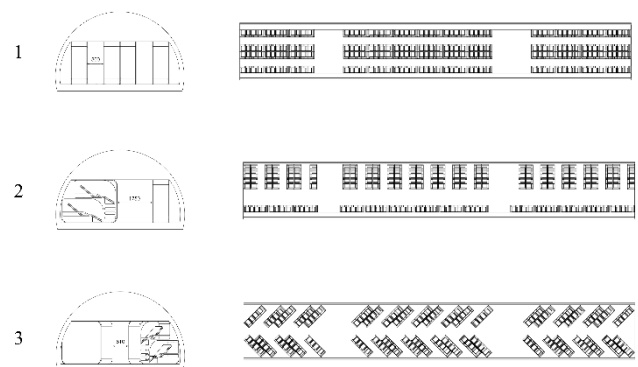


Figure 16. Layout options for passenger cells.

Table 2. Values of the occupancy rate K for business classes of Delta, Singapore Airlines and Emirates.

Layout type	Number of cells	Number of passengers	Coefficient K		
			Delta	Singapore Airlines	Emirates
1	52	104	1.16	1.08	1.31
2	46	92	1.32	1.3	1.5
3	42	84	1.42	1.3	2.1

Table 3. Values of the occupancy rate K for the first-class of the Emirates airlines.

Layout type	Coefficient K
	Emirates
1	0.5
2	0.67
3	0.67

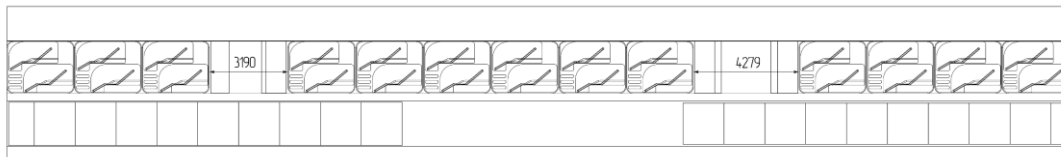


Figure 17. Side view of the passenger compartment.

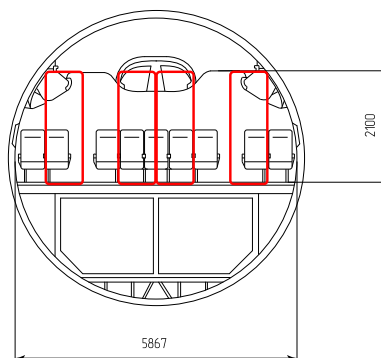


Figure 18. The cross section of Boeing 777-200LR and layout of individual passenger cells.

3. Conclusions

1. The aircraft has become a convenient method of transportation, which allows conducting transport operations to any part of the world.
2. The structural-parametric analysis of the development of long-haul aircraft made it possible to form the concept of the fuselage layout with capsule accommodation of passengers.
3. The proposed variant of the capsule arrangement, designed for the Boeing 777-200LR cabin, can be installed in other passenger airliners with a ceiling height of at least 2.1 m.
4. Analysis of alternative options for the passenger compartment arrangements allows us to state:
 - with a flight length of more than 8 hours, the flight is comfortable only in business or first classes.
 - the proposed two-story capsule placement allows in a given cabin to provide the layout with first-class seats with the occupancy rate of 1.08.

Conflict of interest

The authors confirm that they have no conflicts of interest to disclose.

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