# Effect of flight range on the dimension of the main aircraft

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***Abstract:*** *The purpose of the article is to analyze the characteristics of aircraft, including aircraft of the Boeing and Airbus families, as well as to highlight the factors affecting the flight range depending on the dimension of the main aircraft. The possibilities of competition with Boeing and Airbus were considered and options for solving this problem were proposed. Formulas were used to identify the economic excellence of the aircraft and an analysis was made of the distribution of flights and major airports around the globe. A graphical model for the search for the rational appearance of the aerodynamic balancing scheme of long-range aircraft was presented. Among them were Boeing 747-400, Airbus A380-800 and VHI-5, the characteristics of which correspond to three specific zones of flight range. Conclusions were drawn about the dependence of the mass of the aircraft on the flight range, a scheme was determined according to which the dimension is the smallest, and a relationship was established between the duration of the flight and the fatigue of passengers and their impact on the requirements for comfort and ergonomics of a passenger seat depending on the duration of the flight.*

***Key Words:*** *Boeing family, Airbus family, location of airports, mass balance*

## 1. INTRODUCTION

Aviation is one hundred years old. We learned to fly farther and faster than birds. The globe is finite.

For example, the equator has a length of 40.000 km, which means that the maximum range that can be implemented on Earth will be less than 20.000 km.

There is no point on the globe where we did not fly through the air (Fig. 1). The types of aircraft that have become widespread in aviation are diverse: airplanes, airships, helicopters, gyroplanes, etc.

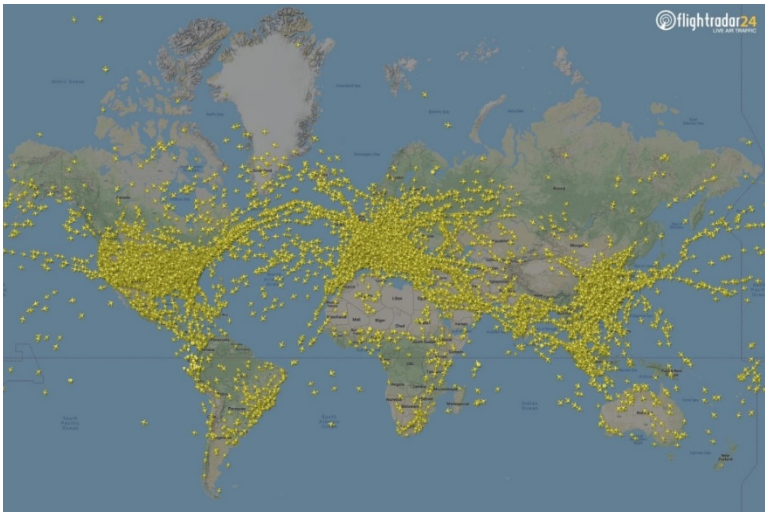


Fig. 1 – Data on the position of aircraft on the main routes according to Fligtradar [1]

A separate specific page of civil aviation opens the era of airship building. In 1909, the German joint-stock company DELAG based on seven airships completed 1582 scheduled flights and carried 34028 passengers before the First World War. On August 24, 1919, the company resumed regular flights on the LZ-120 airship between Berlin and Friedrichshafen. The LZ-127 airship has become the brightest page of civilian use for 10 years, serving transatlantic flights with a range of up to 11 thousand km. Airplanes for such tasks still could not swing. Great Britain used the R-100 and R-101 airships on the route England-India-Australia. The tragedy of the airship LZ-129 Hindenburg in 1937 called into question the feasibility of using airships.

Advances in aircraft and helicopter engineering exacerbated the situation. They will return to the airships in civil aviation, have tried many more times, but so far they are more likely transport and sightseeing tasks.

From the point of view of functional consumer efficiency, a main aircraft is characterized by a transport operation [2], [3], [4], [5], [6], [7], [8], [9]. The longer the flight, the greater the performance indicator. But the faster in time we complete this flight, the more efficient the transport system. Of the long-distance flights, one of the most popular is the London – Sydney flight (16.994 km). Now it is running with an intermediate landing. Since the days of Lord Sydney, the popularity of this route has only increased. A successful experiment in the development of European civilization on one separate mainland led to the flow of goods and passengers at a distance of 18.000 km. For three hundred years, the temporary distance on this route has been reduced to one day. The first successful non-stop flight from London to Sydney was made by the Australian company Qantas in 1989, flying a V747-400 flying 18.000 km in 20 hours, 9 minutes without passengers and baggage.

## 2. FEATURES OF THE DEVELOPMENT OF THE MAIN AIRCRAFT OF THE BOEING AND AIRBUS FAMILIES

Singapore Airlines flight SQ21 (Newark – Singapore) operates from New York Liberty Airport (EWR) to Changi Airport (SIN). The flight is carried out on aircraft of the Airbus A350-900 families (Fig. 2). The flight distance is 9696 miles/15601 km. The average flight time is 17 hours and 58 min.

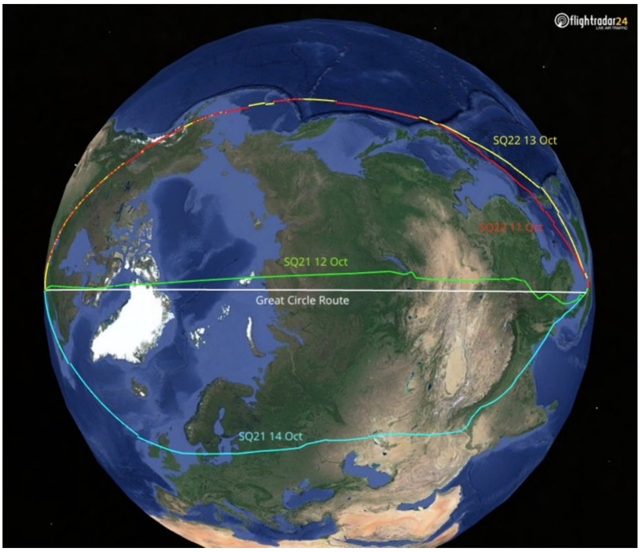


Fig. 2 – Singapore Airlines flight SQ21 according to Fligtradar [1]

The development of long-haul aircraft of the Boeing and Airbus families covers all the many park tasks that exist in the World. Trying to overtake these manufacturers is not possible. You can compete only in a situation of using competencies that provide high-quality gain in a similar transport operation.

Consider options for breakthrough solutions:

– Increase the speed to a comfortable stay on board for the passenger. This time is 3-5 hours. So, the speed of the aircraft must be increased to 3M-5M. These speeds are technically and theoretically achieved, but for safety reasons in civil aviation are not used.

– Improve flight comfort. For a daily flight, an ordinary economy class is no longer suitable. And it’s hard to fly in business. It begs the development of a business class to individual capsules or cabins.

– Increase the safety of passengers and crew through the use of collective rescue systems.

– Reduce the dimension of the aircraft or increase the flight range due to refueling in the air.

Yes, these decisions are unlikely to be allowed soon by ICAO in main aviation. But on the basis of serial main-line aircraft, presidential and business aircraft, transport and special-purpose aircraft are designed. These types of aircraft are a good basis for creative rethinking of well-known design solutions.

Figure 1 shows data on the position of aircraft on the main routes according to Fligtradar [1], this is a momentary section, but its assessment shows that there are areas (North America, Europe and the countries of the “tiger belt”) where there are so many planes that already “traffic jams” in the air. But there are zones (the Arctic and Antarctic, Siberia and Amazonia) where absolutely no one flies. There are several reasons. The climate is harsh, but at a flight level of 10-12 km, the characteristics of the flight environment are stable. Problems in the lack of infrastructure during an emergency landing.

At the same time, if you analyze the features of the Singapore Airlines SQ21 flight from New York Liberty Airport (EWR), to Changi Airport (SIN) via the Crosspolar route and the usual trajectory through Japan and Alaska in Figure 3. You will notice that changing the route reduces the flight range 744 km, which is 5%. This means that flight time, fuel supply, and emission emissions, etc. will also be reduced. Airbus 340-500 is in the air for 18 hours 50 minutes. The interior layout is noteworthy. Only business class – 98 seats (in a three-class layout of 250 seats). That is, the minimum layout density for a given passenger compartment volume. For many years since June 29, 2004 this flight was the farthest in the world. But it was canceled in October 2012 for purely economic reasons, and in 2018 it was again restored, but already on the basis of the A-350-900 [9], [10], [11], [12], [13].

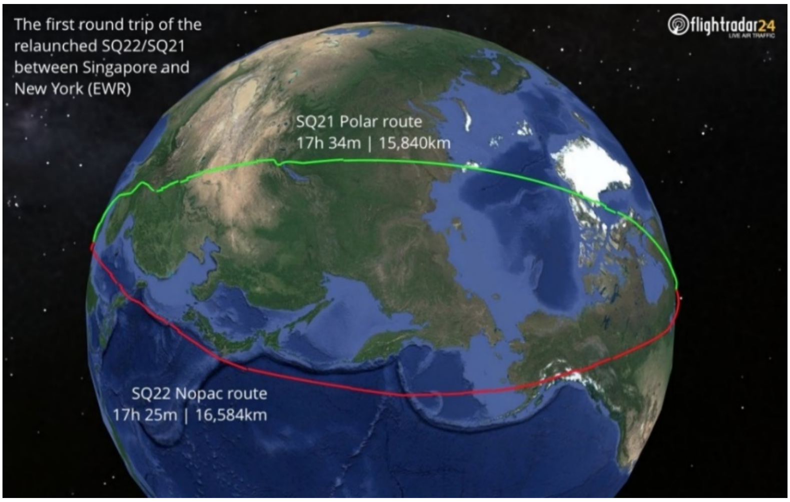


Fig. 3 – Singapore Airlines flight SQ21 according to Flightradar via the Crosspolar route and the usual trajectory through Japan and Alaska [1]

The Airbus A350-900 is a long-range aircraft capable of taking on board up to 380 passengers and transporting them at a distance of up to 16.100 km. The aircraft was put into operation in 2014 and became the basic version in the A350 family, designed to replace the previous generation of long-range airliners A330 and A340. According to Airbus, the A350-900 is 30% more cost-effective per seat and has a 25% lower operating cost compared to the Boeing 777-200ER.

In addition to the basic model A350-900, the manufacturer offers modifications: A350-900R – an airplane with an increased flight range of 1.500 km due to more powerful engines, and A350ULR (Ultra Long Range) – an ultra-long-range version of the Airbus A350 with a flight duration of up to 20 hours per due to the installation of additional fuel tanks (the liner can accommodate only 170 passengers).

Airbus A350 family of aircraft: Airbus A350-900 is designed to carry from 325 to 380 passengers over a distance of 16.100 km; Airbus A350-1000 is designed to carry from 366 to 440 passengers over a distance of 14.800 km.

Its competitor in the Boeing 777-200 LR market (Longer Range – long range) is able to take on board from 314 to 440 passengers and transport them to a distance of 17370 km. December 10, 2005, the plane set a world record (in the Guinness Book of Records), flying 21.602 km without landing, from Hong Kong to London in 22 hours 42 minutes. The route was laid from west to east, in contrast to the generally accepted in this direction from east to west, whose length is 9647 kilometers.

Due to the aircraft’s ability to connect virtually any two continents, Boeing called this model “Wordliner”. If we consider that these are the limiting values of the range of modern mainline aircraft, then reducing the route on routes from North America to Asia can give an undeniable advantage.

## 3. ANALYSIS OF FACTORS AFFECTING THE FLIGHT RANGE

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 chart [14], [15], [16], [17], [18], [19] where the cruising range is determined by the Breguet formula, expressed in terms of the relative mass of fuel $\overline{\mathrm{m}}_{\mathrm{T}}$ (Eq. 1):

$$L = \frac{KaM}{C_f}, \ln \frac{1}{1 - \overline{\mathrm{m}}_{\mathrm{T}}} \tag{1}$$

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

Figure 4 shows a histogram of the distribution of $N$ flights between the largest airports in the world that can operate long-haul aircraft (B747, A-380, B777, A-340).

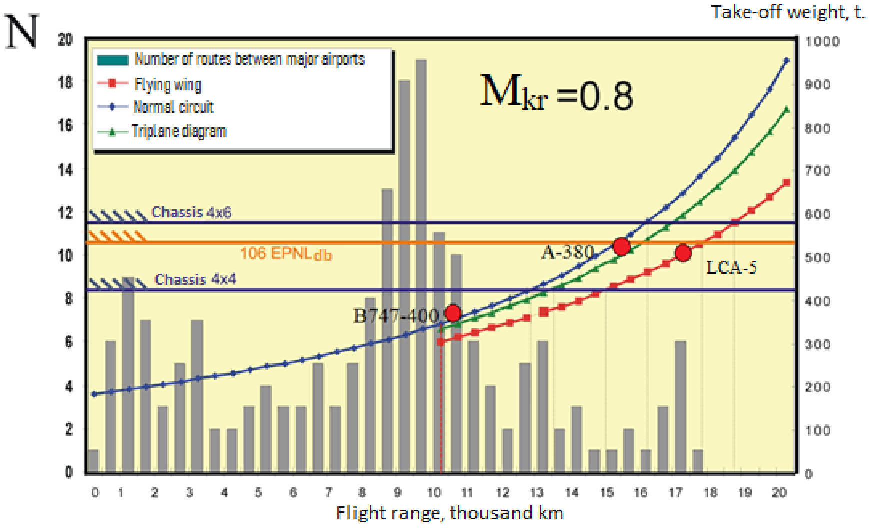


Fig. 4 – Dependence of the take-off mass of the aircraft on the flight range

The location of major airports around the globe is characterized by a demographic factor. The European and North American regions are so pronounced, but the countries of the “tiger belt” are of particular interest – these are countries from Japan to Australia. The horizontal boundary lines (Fig. 4) show the restrictions on the dimension of the take-off mass of the aircraft in the chassis layout options according to the scheme of four trolleys of four wheels and the scheme of four trolleys of six wheels.

Self-limitation is shown by noise on the ground based on the dimension of the take-off mass recalculated from the washed surface area of the aircraft. On the right is the take-off mass scale and the dependence of the take-off mass of the aircraft in tons on the flight range in thousands of kilometers.

An analysis of this distribution allows us to identify three distinct zones. The first zone corresponds to inland flights with a range of up to 3.000 km. These are intracontinental routes, flight safety on which is well established.

The second zone is characterized by a flight range of 6.000 to 11.000 km. These are transatlantic flights and the Asia-Pacific routes, a significant part of the route of which passes above the water surface, which requires 3-4 engines. It was on these routes that the designers focused on the creation of aircraft in operation.

These zones are in good agreement with the distribution spectra of B-747 flights operating with Air France and Lufthansa. However, a significant number of routes, and these are Euro-Asian, American-Australian routes, account for the third zone with a flight range of more than 11.000 km with a pronounced predominance of routes with a length of 13.000-17.000 km. This peak coincides well with the upper boundary of the second zone of various takeoff mass gradients. A striking representative of the aircraft of this generation is the A-380.

The resulting restriction on the dimension of the aircraft must be coordinated with the characteristics of the landing gear (ACN, which is normalized). The analysis of the largest airports shows that for guaranteed operation in them the permissible ACN numbers should not exceed 60-65 (B-747).

The determining factor that affects the maximum permissible level of ACN is the layout of the supporting elements of the main landing gear. In Figure 4, the horizontal boundary lines show the results obtained by Airbus Industries during the creation of the European VHI and recalculated to the maximum allowable take-off weight of the aircraft for the following wheel configurations on the main landing gear struts: 4 struts of 4 wheels – lower border, 4 struts of 6 wheels – the upper boundary, and between them combinations 6-4-4-6 are located depending on the layout of the external struts on the wing or on the fuselage.

Restrictions on the configuration of the chassis layout demonstrate the limiting values of take-off masses, and, consequently, the fact that there are many restrictions that contribute to the degeneration of the three-dimensional region (in coordinates: maximum take-off mass – flight range – target load) of the transport capabilities of the LCA. The histogram has a subject area in the area of 17.000 kilometers.

And then there were planes (Boeing 777-200LR, A350ULR), which under certain conditions can carry out long-haul flights corresponding to the third range zone – more than 17.000 km (Eq. 2):

$$1 = \sum_i \frac{m_i}{m_0} = \sum_{\mathrm{i}} \bar{\mathrm{m}}_{\mathrm{i}} \tag{2}$$

where: $\bar{\mathrm{m}}_{\mathrm{j}}$ is the relative mass of the $j$-th element of the aircraft; $m_{ap}$ is the mass of the airframe; $m_{pp}$ is mass of the power plant; $m_{eq.con}$ is weight of equipment and control; $m_f$ is the mass of fuel; $m_{tl}$ is mass of a given target load; $m_{sl}$ is the mass of service load and equipment.

Fixing the mass of an empty equipped aircraft as variable parameters, we take the mass of the target load and the relative mass of fuel, which through the Breguet formula, ceteris paribus, is uniquely determined by the flight range (Eq. 3):

$$\bar{m}_T = f\ (L) \tag{3}$$

Figure 5 presents a graphical model for finding the rational appearance of the aerodynamic balancing scheme of a long-haul aircraft in the plane of infrastructure terminal restrictions on a set of two conflicting criteria.

The task of forming the appearance of a long-range aircraft of high passenger capacity is reduced to finding the vector $X$ on the set of restrictions $U$.

In this case, the solution of the equation of mass balance is characterized by determining the mass of the aircraft and identifying groups of elements whose mass 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.

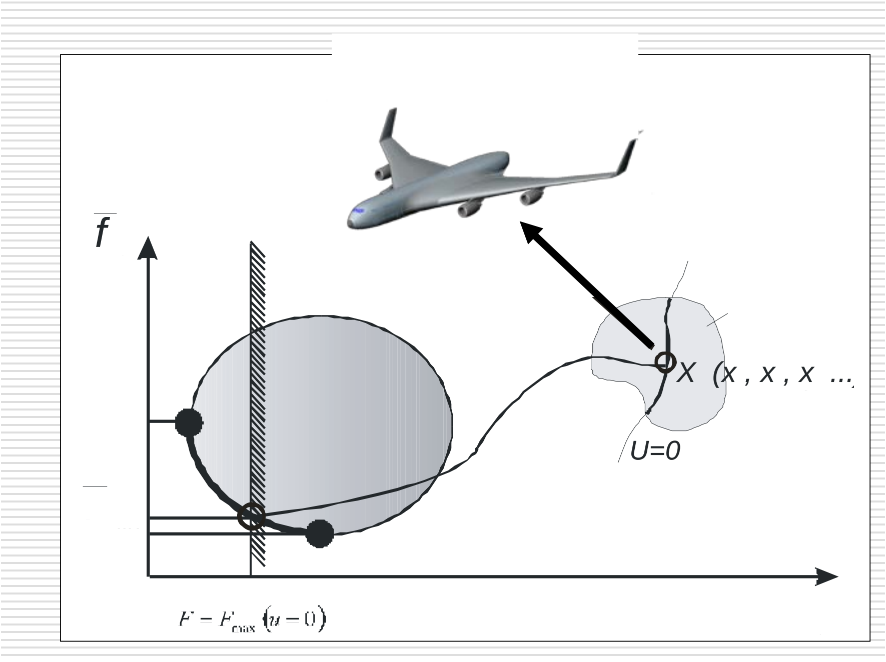
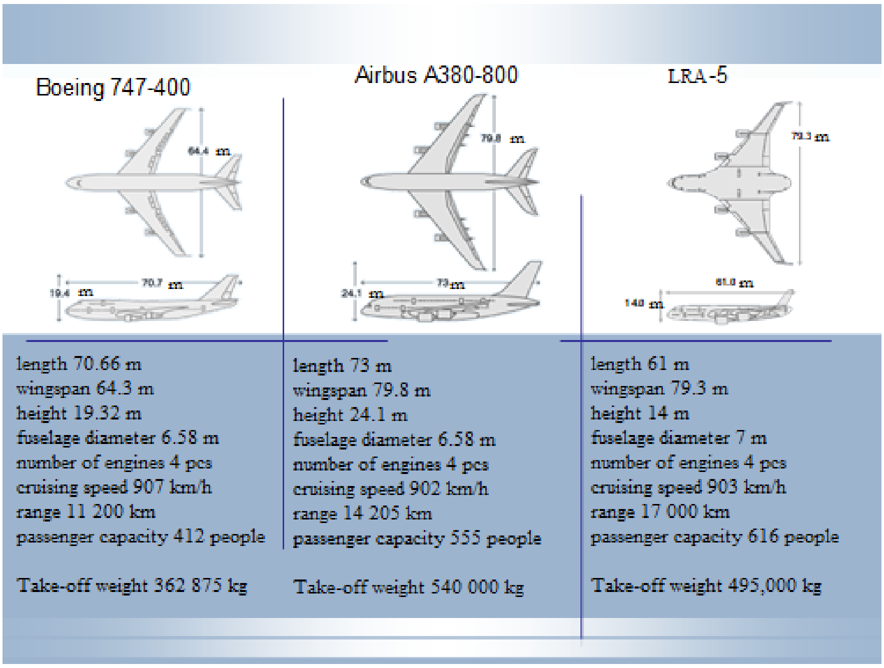


Fig. 5 – Graphical model for searching for the rational appearance of the aerodynamic balancing scheme of a long-range aircraft in the plane of infrastructure terminal restrictions

The table in Figure 6 shows the characteristics of the aircraft corresponding to these three characteristic flight range zones. It is noteworthy that all three aircraft are designed to operate in the same aviation infrastructure, flying at the same speed, with the same power plants in four propulsion systems and using kerosene as fuel.



| Boeing 747-400 | Airbus A380-800 | LRA-5 |
|---|---|---|
| length 70.66 m | length 73 m | length 61 m |
| wingspan 64.3 m | wingspan 79.8 m | wingspan 79.3 m |
| height 19.32 m | height 24.1 m | height 14 m |
| fuselage diameter 6.58 m | fuselage diameter 6.58 m | fuselage diameter 7 m |
| number of engines 4 pcs | number of engines 4 pcs | number of engines 4 pcs |
| cruising speed 907 km/h | cruising speed 902 km/h | cruising speed 903 km/h |
| range 11 200 km | range 14 205 km | range 17 000 km |
| passenger capacity 412 people | passenger capacity 555 people | passenger capacity 616 people |
| Take-off weight 362 875 kg | Take-off weight 540 000 kg | Take-off weight 495,000 kg |

Fig. 6 – Long-range passenger aircraft

If, as a limitation (Figure 4), we take a chassis with four trolleys of four wheels, the use of aircraft according to the “flying wing” scheme allows increasing the flight range of 15.000 km, in contrast to 13.000 km for a normal aerodynamic balancing scheme. At the same time, the use of a tricycle landing gear with a nose wheel with four trolleys of six wheels allows the flying wing to fly away at 19.000 km with a take-off mass of about 600 tons, that is, realize the maximum possible flight ranges that theoretically can occur on Earth in the equatorial zone.

## 4. CONCLUSIONS

From the point of view of functional consumer efficiency, a main aircraft is characterized by a transport operation. The longer the flight, the greater the performance indicator. But the faster in time we complete this flight, the more efficient the transport system. An analysis of the distribution of flight ranges between the main central airports allows us to identify three distinct zones. The first zone corresponds to inland flights with a range of up to 3.000 km. These are intracontinental routes, flight safety on which is well established. The second zone is characterized by a flight range of 6.000 to 11.000 km. These are transatlantic flights and the Asia-Pacific routes, a significant part of the route of which passes above the water surface, which requires 3-4 engines. However, a significant number of routes, and these are Euro-Asian, American-Australian routes, account for the third zone with a flight range of more than 11.000 km with a pronounced predominance of routes with a length of 13.000-17.000 km. This peak coincides well with the upper boundary of the second zone of various takeoff mass gradients.

Aircraft appeared on the market that, under certain conditions, can carry out long-haul flights corresponding to the range zone – more than 17.000 km. With increasing flight range, the take-off mass of the aircraft grows exponentially. The smallest dimension is the main aircraft, made according to the “flying wing”. Its take-off weight is 10-15% less than that of aircraft with a normal aerodynamic design. The nomenclature of long-range aircraft allows you to implement any Earth resource in the presence of infrastructure. It is possible to fly wherever you want. The fork is that it is fast and cheap. The use of aircraft according to the “flying wing” scheme equipped with a chassis with four trolleys of four wheels allows you to increase the flight range of 15.000 km in contrast to 13.000 km for a normal aerodynamic balancing scheme. At the same time, the use of a tricycle landing gear with a nose wheel with four trolleys of six wheels allows the flying wing to fly away at 19.000 km with a take-off weight of about 600 tons. Passenger fatigue directly depends on the duration of the flight, which leads to increased requirements for the comfort and ergonomics of the passenger seat with increasing flight duration. The slogan to fly faster than anyone and farthest in the 21st century has acquired an economic connotation.

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