https://doi.org/10.26552/ pas.Z.2022.1.02

PROPOSAL FOR MODIFICATION OF THE L-13 "BLANIK" SAILPLANE'S WING HINGE STRUCTURAL DESIGN

Dominik Michael Mrakvia
Air Transport Department
University of Žilina
Univerzitná 8215/1
010 26 Žilina

Libor Trško
Research Centre UNIZA
University of Žilina
Univerzitná 8215/1
010 26 Žilina

Abstract

As a result of a tragic accident in Southern Austria, all L-13 "Blanik" sailplanes were grounded. During this accident, the factory structural design failed, even though the plane underwent all mandatory inspections and repairs. The intention of this article is to introduce the possibilities of structural modification of this aircraft, specifically its wing beam and hinge. Already existing modifications are described, as well as new ones with the aim to strengthen its critical parts. Structural modification of the wing hinge and beam, replacement of rivet joints with stronger Hi-Loks and use of different hole angles to ensure a firmer joint and better stress distribution around these holes are covered. Last two beforementioned modifications are described in more detail, a tensile test is carried out and its results are compared to the results of the control samples. In the end, viability and practicability of these modifications are discussed

Keywords

Strengthening, Wing hinge, Structural modification, Hi-Lok, Tensile test, Blanik, L-13

1. INTRODUCTION

The L-13 "Blanik" is a two-seater high wing sailplane which was produced in the former Eastern Bloc country – Czechoslovakia. The development of this aircraft began in 1954 at the National Center for Research, Development and Testing in Aerospace (VZLÚ) in Prague. First two prototypes were built and tested in 1956. After these successful tests, the production of L-13 was moved to Let Kunovice national company. 2616 planes were made until the end of production of the original model in 1978, from which many are still flying all over the world. Modernized versions of this sailplane are still produced in the Czech Republic by the company Blanik Aircraft, namely the L-13AC and L-13 SW equipped with Rotax 912 ULS engine [1][2].

Sadly, the success of this famous aircraft was stained by a tragic accident. On the 12th of June 2010, an aircraft with registration OE-0935, crashed near the airfield Ferlach-Glainach (ICAO code: LOKG), roughly 10 km south from the city of Klagenfurt am Wörthersee in Austria. While on final, after a routine aerobatic flight, the right wing broke from the plane, the plane then spun out of control and crashed into the ground killing both pilots on board. As a result of this accident, all L-13s around the world were grounded until a solution of this, at that time unknown, problem was provided. Today a handful of companies, including the manufacturer, provide structural modification of the wing hinge, which, according to the investigators, broke off because of fatigue cracks in riveted joints used to connect the wing hinge with the wing spar [3][4].

The factory wing hinge was never structurally modified, as there was no reason to do so. It was a proven structure which served its purpose for many years without any flaws. The wing hinge and spar are joint together using conventional steel rivets in three rows. In every row the are seven rivets, which comes up to 21 in total. By the wing root, two more rivets in rivets are installed to counter the longitudinal and transversal strengths [3][4].

2. EXISTING STRUCTURAL MODIFICATIONS

Individuals as well as companies came up with solutions to this issue. The most important ones are covered in this paper. The first man who came up with a proposal for modification is a Brazilian engineer Glavão. His proposal counted on the introduction of a few new components into the already existing structure of the plane. The most significant being the wing struts, which are usually used on general aviation aircraft, such as the Cessna 172. These should relieve the stress of the wings, mainly its spar and the joints joining them to the wing hinge and prevent another failure of this critical part of the plane's structure. These would be connected to the wing spar and to a metal strip, which would be connected to the fuselage of the plane using rivets. These struts would reduce the bending moments inboards of the strut attachment point and reduce the tensile stress in the same area. For the possibility of these struts to be installed, additional reinforcement of the components connecting the struts to the plane is needed. This is solved by doubling the wing spar and the thickening of the wing cover in the affected areas [5].

These modifications were analyzed mathematically with promising results, but not a single "Blanik" was rebuilt using this proposal. The technological implementation is just too difficult and not viable [5].

Other modifications were presented by a private company named Aircraft Design and Certification (AD&C), based in Germany. This company specializes in aircraft modifications. Their proposal suggests the implementation of a L profile near the wing root, connecting both the wing hinge and spar to the fuselage. The lower wing spar is strengthened around the area of the original fatigue crack. The most stressed rivets are replaced for ones with bigger diameter, which makes them stronger and able to withstand greater tensile and shear stress. These modifications were tested with promising results. A plan of maintenance inspection before the rebuild was prepared. It consisted of the visual check of the fuselage and wing covers for cracks and tears. The wings are then detached, and the wing spar is examined and checked for fatigue damage using the eddy current testing method. This method is a non-destructive test, which determines whether any material defects are present inside the material. If the spar does not pass the test, the wing cannot be modified and the whole wing needs to be replaced. The same goes for the holes drilled in the wing hinge and spar. If the holes are too elliptical, either the wing hinge or the whole wing needs to be replaced for a new one [6].

EASA then issued a directive EASA AD 2011-0135, by which they approved the use of this modification. After a rebuild is done, the airplane gets its airworthiness back for 3750 flight hours with maximum 2 % aerobatic use. EASA later issued another directive further approving the modification and granting 5000 flight hours, but without aerobatic use. The operator of the plane must decide. Either he can use the plane longer without further structural modifications, or he can keep the aerobatic use, but sacrifice 1250 flight hours [6].

Structural modifications are also carried out by today's manufacturer – Blanik Aircraft. They do similar pre-rebuild inspections as the AD&C company. The difference being that Blanik dismantles the fuselage as well and they do inspect the insides of it, specifically the sixth partition. They also check the symmetry of the fuselage. Again, the spar is tested using the eddy current method, the roundness of the holes used for rivets is checked as well. The next step is to change the wing hinge for a longer one, factory holes for rivets are redrilled from 6 to 6.36 millimeters and the rivets are changed for stronger Hi-Loks. The number of these Hi-Loks grew from 23 original pieces to 33 [7][8].

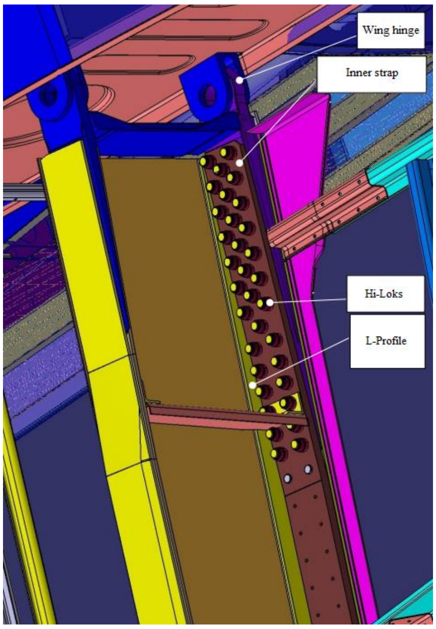

Figure 1: Modifications proposed and made by Blanik Aircraft. [7]

Using these modifications, the critical point of the wing spar gets shifted by 100 millimeters further away from the wing root and the resulting forces decrease by 60 %. Calculations confirmed that a wing hinge modified this way withstands twice as much force as the factory one. EASA approved this modification and the planes using it are airworthy for additional 6000 flight hours [7][8].

3. THEORETICAL WING HINGE MODIFICATIONS

While suggesting modifications, it is not needed to think overly complex. It is possible to draw inspiration from the aforementioned modifications. That goes both for the pre-rebuild inspection and the modifications themselves.

To determine whether the plane can be modified, its structure needs to be examined. The examination of the wing spar and the sixth partition is very important and would be carried out the same way, as described by Blanik Aircraft. The visual inspection and eddy current testing method would be used. The same goes for the hole roundness check. The results of the inspection would be then evaluated, and the following steps would be determined. If the wing spar, hinge assembly or sixth partition would not pass the previously mentioned tests, the corresponding part must be replaced for a new and reinforced one. The fuselage is checked as well for any surface damage on the cover, the symmetry is checked, and the structure of the fuselage is inspected as well. Any fatigue cracks or damage found must be repaired to prevent any further harm. The wing hinge itself does not need to be inspected, as it will be changed for a new and improved part [6][7][8].

3.1. Extension of the Wing Hinge

To strengthen the wing hinge assembly, the wing hinge itself needs to be reworked and changed. The easiest thing to do is to install a longer and stronger wing hinge. This would shift the critical point further away from the wing root, making it stronger and able to withstand greater stress. This adjustment has a countereffect. The implementation of an extended wing hinge will result in the creation of a longer lever according to (1), which expresses the equilibrium of the forces on a lever [7][8][9].

$$F_1 \times L_1 = F_2 \times L_2 \tag{1}$$

Equation (1) says that the force F1 acting on the longer arm with length L1 must be equal to the force F2 acting on the shorter arm with length L2. This means that if the wing hinge is extended, but force acting on it does not change, the force being transferred to the shorter unchanged arm has to be greater. To counter this, the sixth partition must be reinforced to withstand such loads [9].

3.2. Reinforcing of the Wing Spar and Wing Cover

Another important structural modification is the strengthening of the wing spar in the most exposed areas. These are located near the wing root, as the biggest loads are being transferred through there. Inspiration can be drawn from the work of engineer Galvão. He mentioned the reinforcement of the wing spar by doubling it in the most stressed areas. This would help to achieve better stress distribution over the spar. To be sure, strengthening of the wing cover in the same areas is needed for the same reasons. The factory wing cover is made of duralumin.

For it to be stronger, higher thickness cover or a cover from stronger materials must be used. Both modifications would provide better tensile and shear stress distribution over these critical parts of the plane’s structure [5].

3.3. Replacing Rivets with Hi-Loks

While using conventional steel rivets, it is important to pay close attention to the quality of the rivet joint. Not only for aesthetic purposes, but for premature fatigue reasons. With tensile tests, it was proven that displacement of a rivet by only one degree changes the stress distribution in and around it, which has a negative effect on fatigue of this joint. As it is hard to manually make a rivet with a one-degree accuracy, it is better to replace rivets with another type of joint [7][8][10].

For aeronautical use, rivets can be substituted by Hi-Loks. This joint was developed in 1943 in the United States by the Hi-Shear Corporation. They were used for the first time in the P51C Mustang fighter aircraft. The Hi-Loks are made from strong metals such as titanium or Inconel and can withstand greater forces and stress than conventional rivets. They are made of two parts – pin and collar. These get screwed together clamping the materials. These joints are then able to withstand high tension, high temperatures, friction, and vibrations. The substitution of rivets with Hi-Loks would ensure a stronger and reliable joint between the wing hinge and spar [11][12][13].

3.4. Extension of the Hi-Loks Service Life

Currently, while disassembling Hi-Lok joints, it is common practice to throw out both parts of the Hi-Lok. However, one of these components can be kept and used repeatedly. This could cut maintenance costs and lower the impact on the environment.

The Royal Military College of Canada did research on this topic. They carried out tensile tests to prove the possibility of this modification. The results proved that only the collar needs to be changed to preserve the limits prescribed by the manufacturer. The results even proved that the clamp force is higher than the limits with the collar change. Further research needs to be done, but the results are promising. If this modification is applied in practice, these joints could achieve higher static and shear strength values and this should result in a reliable and stronger joint, which will be cheaper to maintain and has a smaller impact on the environment [14].

3.5. Change of the Hole Angles for the Hi-Lok Joints

The most important change is to change the hole angles for the Hi-Lok joints. This means that the holes will not be drilled perpendicular to the material, but under an angle. This should provide better stress distribution around these holes and a greater contact surface for the joint to lean on. That should result in a stronger joint. The stress distribution was already discussed at the International Conference on Challenges and Opportunities in Mechanical Engineering (ICCOMIM) in 2012. There was an article published regarding this topic. Simulations and tensile tests were performed. Stress distribution around holes with different hole angles, namely 0°, 30° and 60°, is shown in figure one [15][16].

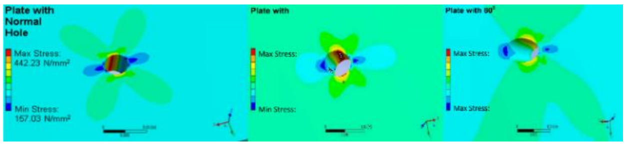

Figure 2: Stress distribution around holes with different hole angles. [15]

Better stress distribution is seen in the figure, as it is more distributed into the surrounding areas. But the tensile test results, which are shown in table one, proved that the tensile load decreased by 30°, but grew significantly by 60°. Maximum stress decreased with growing oblique angle [15][16].

Table 1: Tensile load and max. stress comparison. [15]

Oblique Angle (°)	Uniaxial Tensile Load (kN)	Maximum Stress (N/mm²)
0	160.30	438.25
30	158.20	396.50
60	162.50	387.06

Inserting a joint into these holes ensures a bigger contact surface. If a material with 8-millimetre thickness is considered, hole drilled under an angle of 30° ensures a 15.5 % increase in contact surface. The same goes for the 45° tilt – contact surface is increased by 41.25 %. These numbers promise that stronger joint can be achieved using these structural modifications. But with relation to the material taken out while drilling holes under an angle, it cannot be said for certain. Further research needs to be done, combining both oblique hole angles and Hi-Lok joints. As no other paper describes such an experiment, it will be described in this article [15][16].

4. EXPERIMENTAL VERIFICATION

As stated, the results and hypothesis from the previous chapter need to be examined further using a tensile test. For a tensile test to be carried out, a sample of sort is needed. A sample proposal was done in the CAD software Autodesk Inventor 2021. It consisted of two metal strips, one from steel and the other from aluminium. These strips were then joined together using a Hi-Lok under various angles. After simulations were carried out, the angles of 0°, 30° and 45° were determined to be the most viable. 0° representing the control sample to compare the other results to. In this design, the implementation of Hi-Loks is not possible, as the pin and collar have no place to lean on. It just will not be able to clamp the materials together.

An improved design was introduced with two additional components for the Hi-Loks to clamp onto. This design was determined as best reflecting the real conditions on the wing hinge.

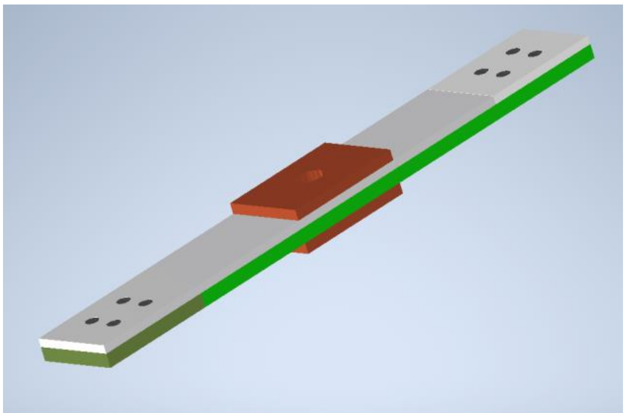

Figure 3: Control sample for tensile tests. [Authors]

Sadly, this design could not be built because of lack of material and time pressure. Workaround had to be made to successfully carry out the tensile tests. The design and materials had to be changed. Steel metal strip was changed for an aluminium one, as it is easier to drill into. Sadly, neither the Hi-Loks could be used, as no supplier was able to deliver them in time. The redesign consisted of two metal strips, one from conventional aluminium, the other one from 2044-T4 aluminium. That is a high strength aluminium with a tensile strength of 475 MPa, twice as strong as regular aluminium. These components will be joint together using a M10 bolt. Three types of samples were designed with varying oblique hole angles of 0°, 30° and 45°. Each type was produced three times, nine in total.

4.1. Simulated Tensile Tests

The tensile tests were simulated at first. They showed the same results as the beforementioned article from the ICCOMIM 2012 conference. With increasing hole angle, the strength of the material decreased, but the stress distribution changed, as it is more spread into the environment, viz. figure three [15].

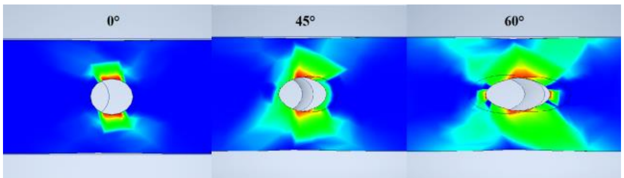

Figure 4: Stress distribution during simulated tensile tests. [Authors]

According to these simulations and to determine precise results, real tensile tests are needed to prove or disprove the hypothesis.

4.2. Tensile tests

The tensile tests were carried out on the before described samples, viz. figure four.

Figure 4: Control sample for tensile tests. [Authors]

The results of the tensile tests of the control sample are shown in table two. We can use these numbers to compare and evaluate the results of the other tensile tests. The table contains the number of the sample, original cross section, maximal strength, and tensile strength.

Table 2: Control sample tensile test results. [Authors]

Sample number	Original cross section (mm^2)	Max. Strength (N)	Tensile Strength (MPa)
1	37.81	7748.30	204.93
2	38.00	8357.17	219.93
3	38.19	7998.84	209.45

The same goes for the results of the samples with 30°- and 45°-hole angles. The results are written in their respective tables numbered three and four.

Table 3: 30° sample tensile test results. [Authors]

Sample number	Original cross section (mm^2)	Max. Strength (N)	Tensile Strength (MPa)
4	36.29	7245.03	199.64
5	35.72	7119.62	199.32
6	35.91	7016.44	195.39

Table 4: 45° sample tensile test results. [Authors]

Sample number	Original cross section (mm^2)	Max. Strength (N)	Tensile Strength (MPa)
7	36.48	7133.73	195.55
8	36.29	7246.52	199.68
9	36.49	6618.01	181.41

As you can see, the tensile strength and maximal strength both decreased with increasing oblique angle. You can see the samples after the tensile test in the figure lower. To prove the accuracy of the results, tensile tests for aluminium metal strips with a hole were conducted as well.

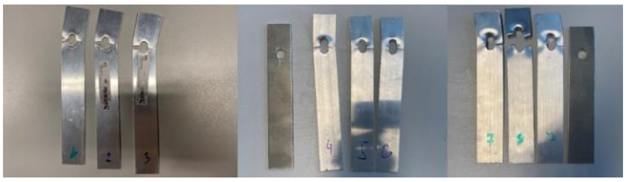

Figure 5: Samples after tensile tests. [Authors]

The results of the metal strip tensile test can be seen in table number five. They show promising numbers, as the increase from 30°- to 45°-hole angle did increase the tensile strength and maximal strength.

Table 5: Tensile test of the metal strip with an oblique hole. [Authors]

Oblique angle (°)	Sample No.	Cross section (mm^2)	Max. strength (N)	Tensile Strength (MPa)
0	10	37.05	7567.60	204.25
	11	37.62	7610.25	202.29
30	12	36.29	7314.07	201.54
	13	36.48	7270.06	199.29
45	14	36.67	7335.58	200.04
	15	36.29	7350.54	202.55

5. DISCUSSION

As the results from the previous chapter suggest, the strength of the joint probably cannot be increased by changing the hole angle. Sadly, due to a lack of time, the tensile test had to be carried out using a non-ideal sample design. By using the design seen in figure two and a Hi-Lok instead of regular bolt to join them together, the results should be more precise and could prove the hypothesis from chapter III.

If the results of the tensile tests were positive, by implementing this modification, the joint between wing hinge and spar could be further reinforced. This could result in decreasing the number of used Hi-Loks, ultimately cutting down costs.

The same can be said about the extension of the Hi-Lok joints' service life. If further research proves that the repeated collar change has no effect on the Hi-Lok clamp force and toughness, maintenance costs could be cut down as well as environmental impact.

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https://doi.org/10.26552/ pas.Z.2022.1.03

CHANGES IN AIRPORT INFRASTRUCTURE CAUSED BY THE HISTORICAL DEVELOPMENT OF AIRCRAFT

Jozef Adamík
Air Transport Department
University of Žilina
Univerzitná 8215/1
010 26 Žilina

Antonín Kazda
Air Transport Department
University of Žilina
Univerzitná 8215/1
010 26 Žilina

Abstract

The airport infrastructure is constantly influenced by the development of aircraft. It has always been, that the aircraft was first designed, and based on its performance parameters and geometrical characteristics, a space for the airport were sought to serve the new aircraft. Even today, we can see the different development of aircraft in different aircraft manufacturers, which determine how the airport infrastructure will change in the future.

In the introductory chapters, we analyze several aircraft requirements for airports that have been affected by changes in ground infrastructure and the subsequent development of airports. The main objective of this bachelor thesis is to document the changes in the airport infrastructure caused by the historical development of aircraft. The discussed development of aircraft and reaches out from the beginning of aviation to the end of World War II through the era of jet aircraft to large-scale long-haul aircraft.

Based on the creation of a database of aircraft and a description of typical aircraft representatives of the period, an analysis of their parameters and the described impact on selected airports is performed. Three historical international airports were selected for a detailed analysis of airport development. There are two analyzed airports in Europe: Munich Riem together with Munich - Franz Josef Strauß and Amsterdam Schiphol. In the United States, John F Kennedy Airport is chosen near New York City in terms of the highest airline utilization.

Until 1951, selected airports were analyzed from historical footage and, after the publication of ICAO Annex 14 Aerodromes, also documented by changes in the regulation. Airports had to adapt to changes in environmental requirements and the introduction of new technologies in the form of more fuel-efficient and smaller commercial aircraft.

One of the benefits of the thesis is to emphasize the need to plan airport changes in relation to the needs of aircraft technology in the future. This area includes the planning and modernization of runways (RWY), terminals, aprons and stands. At present, RWY design pays attention to reducing noise in suburban areas, reducing turn-round time at stands by using jetways, the number of taxiways (TWY) connecting the RWY to the airport and operating aircraft with a smaller code letter.

Keywords

Airport, Aircraft, Runway (RWY), Taxiway (TWY), Infrastructure

1. INTRODUCTION

Air transport became known for the first flight of the Wright Brothers in 1903 and demonstrated new possibilities for using aircrafts as a means of comfortable and fast travelling. Each type of transport means needs its own infrastructure which has certain specifics. Air transport, which is one of the youngest transport sectors is no exception. At present even with the decline in air traffic it is necessary to increase the emphasis on the construction and modernization of airport infrastructure constantly.

From a historical point of view the aircraft was always first designed and the airport was built according to its parameters. This relationship between aircrafts and airports can be seen to this day in the history of aviation. Graphical analysis of aircraft key parameters can illustrate the changing aircraft infrastructure requirements of aircraft.

To document the impacts of changes in aircraft parameters on airports, an analysis was performed on the examples of some airports. In terms of airport history three international airports were selected. At individual airports, various designs and modernizations of airport areas are pointed out, which were caused by the historical development of aircraft.

The construction of new parts of airport terminals and runways is also analyzed at selected airports. At present the completion of existing airports is influenced by a number of factors, including: the geometric characteristics of F-code aircraft, the different types of boarding bridges and the environmental impact of aircraft operations.

2. RELATIONSHIP BETWEEN PERFORMANCE PARAMETERS, AIRCRAFT GEOMETRIC PARAMETERS AND AIRPORT CHARACTERISTICS

Different forces affect on the aircraft during takeoff and landing. Some have to cross the plane to take off and land. These forces include lift, gravity, thrust and drag. In addition to these forces, several other factors affect the take-off and landing performance.

2.1. Wing shapes

In aviation, different shapes of wings are used, each of which has its advantages and disadvantages. The shape of the wing is determined by the needs of the aircraft in service, for example, transport aircraft use swept wings and aircraft for supersonic operation use a delta wing. From the point of view of airports, the wingspan is especially important, the smaller the wingspan, the generally the smaller the size of the stands required. The wingspan also affects the width of the TWY and the width of the runway, alternatively runway side strips.

2.2. Different types of power units

Three types of power units are used in aviation. From a historical point of view, piston engines were the first, at the end of the Second World War aircraft with jet engines were designed, and the last of these was a hybrid of these two engines in the form of turboprop engines.

2.2.1. Differences between piston and turboprop engines

Piston and turboprop engines are quite similar in their flight modes. However, these two types of engines are different in different categories. These categories include the areas of safety, efficiency, cost and performance of individual engines. Reciprocating engines are usually cheaper and less maintenance than turboprop engines. The advantage of turboprop engines is their reliability, longer resources, higher efficiency at higher power and provide better performance at high altitudes [1].

The performance of reciprocating engines decreases with increasing height. This disadvantage can be partially compensated by using a compressor or turbocharger on the engine, which maintains power at higher altitudes. After exceeding the limit height, the power on the piston engine starts to decrease again. Turboprop engines are suitable for aircraft that have higher cruising speeds at higher altitudes, where the engine is able to achieve higher performance. The disadvantage of using higher power (turboprop engines) is the higher weight and higher fuel flow [2]. The advantage of turboprop aircraft is the possibility of reversing the propeller, which reduces the landing distance and thus improves the landing characteristics of the aircraft [1].

2.2.2. Differences between turboprop and jet engines

Turboprop and jet engines operate on the same principle in terms of thermodynamics. Both engines are equipped with a gas turbine. The main difference is in the use of engine exhaust gases. Turboprop engines use a turbine connected to a reducer to drive the propeller, and jet engines accelerate the exhaust gases, which in turn create thrust to the engine.

The power of turboprop engines decreases with increasing height. This is due to a reduction in air density. Jet engines still maintain their thrust if sufficient air and fuel are supplied to the engines. Examples of applications are the Aerospace-British Aerospace Corporation (BAC) Concorde and Tupolev Tu-144 transport aircraft, which also had afterburning and flew at Ma = 2. Jet engines can have a split airflow into primary and secondary. The secondary airflow has a great influence on the final thrust of the engine [3].

These factors indicate that both types of power units are safe to operate on commercial aircraft. Turboprop engines are more efficient for lower altitudes with flight speeds up to Ma = 0.6 [3]. Jet engines, on the other hand, are more suitable for operation at higher flight speeds and altitudes [4].

2.2.3. Impacts of various factors on take-off and landing length

The weight of the aircraft and the power of the propulsion unit, the range and the required take-off and landing length are closely related. A longer runway is required during takeoff at a higher aircraft weight, as is landing.

The length of take-off and landing is also affected by the air density, which depends on the altitude of the airport and the outside temperature. At airports located at higher altitudes, a longer runway is required for take-off and landing. Conversely, at airports located at sea level, a relatively shorter take-off run is required. In some cases, at high temperatures and sufficient take-off run, the engines may not be set to 100% power / thrust, but smaller ones will suffice, e.g. 85-90%. This not only reduces fuel consumption but also extends engine life. The prevailing higher temperatures of the airport resp. alternatively lower pressure (altitude), can significantly affect the runway length for take-off and landing [5].

Another factor that affects the length of takeoff and landing is the slope of the runway. If the runway slope is negative - descending, a shorter runway is required for take-off. Positive runway slope - ascending, prolongs the required runway length for take-off. A shorter runway is sufficient for a landing and a positive runway slope; for a negative runway slope, the aircraft needs a longer runway for safe braking [6].

3. DEVELOPMENTS FROM THE BEGINNING OF THE AVIATION TO THE END OF WORLD WAR II.

Aviation is one of the youngest industries in terms of transport history. Initially people used road transport for short distances and rail or water transport for longer distances. The first breakthrough in aviation occurred in 1903 by the flight of the Wright brothers [7]. That's when we started talking about the birth of planes. Later, spaces had to be created for these aircraft on which they could take off and land.

The greatest technological boom of aircraft came during the First World War, when the armies of the warring countries began to use aircraft for various actions, whether for the defense of their territory, reconnaissance or bombing. From the beginning, the aircraft had different types of fuselage, wings, power units, which changed over time. The aircraft manufacturers tried to ensure that the resulting design parameters were optimal for the aircraft (Maximum take-off mass (MTOM), range and performance). At this time, the construction of biplanes with a fixed spur landing gear prevailed. Aircraft on takeoff and landing had poor longitudinal and lateral stability, and the wing profiles themselves had a low lift coefficient, which produced quite high drag [8]. Rolling on the runway was relatively difficult due to the use of an uncontrolled spur type landing gear. With this type of landing gear, the pilot could not see directly in front of him and the plane could crash into an object. The airports were with unpaved runways. Because hard landings could not be ruled out, the landing gear was designed with a more robust construction.

The requirements of the above-mentioned aircraft at airports differed considerably from the first transport aircraft. The Junkers F-13 needed only 200 m to take off, with new aircraft from Douglas up to 1 200 m to take off and 600 m to land. The exception was the Junkers Ju 52, which had only 400 m to take off and land. Airports had to increase runway lengths because of these aircraft. The new aircraft already had better take-off and landing stability and maneuverability than their predecessors. Also their more robust design allowed aircraft to take off and land at higher crosswinds. These planes still had a spur-type landing gear and the pilots did not see in front of them when taxiing. The capacity of the airports gradually began to fill with new, larger aircraft, and the movement of passengers between the terminal and the stand was very dangerous. For this reason, the construction of the first terminals, which would provide greater safety and comfort to passengers, began to be considered. The first terminal was built in 1936 at London-Gatwick Airport [9]. It had a circular shape and rotating stands which allowed the aircraft to turn on the stand without the need to push them out [10]. The passengers got to the plane using a telescopic jetways.

During World War II several transport aircraft began to be used as transport aircraft. The construction of paved runways, which were needed for aircraft with higher weights, began. Two parameters were important for the bombers - range and weight of cargo (bombs), which they could carry on board [7]. The chassis type also began to change from a spur landing gear to a landing gear with a nose landing gear. The most famous bombers were the Boeing B-17, Heinkel He111 or Avro Lancaster [7]. These aircraft no longer had a fixed spur on the tail, but a spur wheel, which allowed better controllability and maneuverability of the aircraft when taxiing and to guide the aircraft to the stand.

4. THE BEGINNING OF THE JET ERA

Even after the end of World War II the Air Force still used piston-engined aircraft, either for short distances or on routes across the Atlantic Ocean. After the war it was possible to see the difference in airport infrastructure requirements. In Europe, for example, most airports were equipped with concrete runways, while the USSR still had many airports with unpaved runways or taxiways.

A big change occurred in the use of jet engines in commercial aircraft. The first jet was the de Havilland D.H. 106 Comet 1, which made its first flight in 1952 [7]. A few years later, he was followed by an aircraft manufacturer from the USSR Tupolev with a Tu-104 aircraft [7]. These aircraft belonged to the group of low wing with a nose landing gear. Such an arrangement gave the pilots a better view from the cockpit during taxiing and take-off, and compared to the spur landing gear, the controllability of the aircraft during taxiing and take-off was significantly improved. During takeoff and landing, the aircraft with the nose landing gear were more stable and maneuverability was improved by allowing pilots to adjust the balance of the aircraft before takeoff or landing. The export of the aircraft appeared in the Air Force at the end of World War II on North American P-51 Mustang aircraft [11].

Airports also had to adapt to the new aircraft. The runways began to lengthen and their width also increased. During taxiing pilots were not allowed to use increased engine power so that engine exhaust gases would not damage airport facilities or airport facilities in their vicinity. Airport stands have been enlarged to prevent airport equipment from being sucked into the jet engine.

5. USE OF LARGE-SCALE AIRCRAFT FOR LONG-HAUL FLIGHTS

In the late 1960s several well-known and successful aircraft from various aircraft manufacturers were built. One of the basic changes concerning the construction of aircraft was the more frequent use of the swept-shaped wing. The advantage is less drag at higher speeds [12]. Disadvantages include the complex mechanization of the wing, such as the use of flaps on the trailing edge and slots on the leading edge. This ensures sufficient lift even at lower speeds. All aircraft are already equipped with a retractable landing gear.

Between 1960 and 1970 the idea arose to design supersonic transport aircraft. The first supersonic aircraft was created in the USSR by the aircraft manufacturer Tupolev. Tupolev Tu-144 managed to make the first takeoff and landing before its competitor from Europe Aérospatiale-BAC Concorde. The wingspan, MTOM, seat capacity and take-off distance are similar. From aircraft requirements to airports, Aérospatiale-BAC Concorde needed a longer takeoff length. In contrast, the Tupolev Tu-144 had several technical shortcomings and sometimes when taking off from some runways due to the high speed of exhaust gases, tore pieces of concrete on the runway. Aérospatiale-BAC Concorde with its neo-Gothic wing shape had good flight characteristics at both low and high flight speeds and was the first aircraft to be equipped with an electro-impulse control system "Fly By Wire" [13].

In the field of subsonic aircraft a novelty came in 1969 in the form of large-capacity aircraft [14]. These aircraft belonged to the group of wide-body aircraft. This meant that there were two aisles in the passenger cabin. The first wide-body aircraft was the Boeing 747, also called the "Jumbo Jet", and in the following years the McDonnell Douglas DC-10 and Lockheed L-1011 Tristar were designed [14]. These aircraft were deployed over long or medium distances, where their high seating capacity was used the most. With a higher number of passengers the airline's operating costs are also lower. The Boeing 747-200 and McDonnell Douglas DC-10 aircraft had a larger wingspan compared to the aircraft manufactured before 1969, and the MTOM value increased up to threefold compared to the first jet Boeing used on long routes. The passenger seating capacity has doubled, for example the Boeing 707 could carry 179 passengers and the Boeing 747-200 up to 366 passengers. The McDonnell Douglas DC-10 had a capacity almost 100 passengers greater than the Douglas DC-8. The airports had to increase the runway length again to 3 000 m. The taxiways were also modified for wide-body aircraft, as the wheelbase was significantly larger than previous aircraft. The maneuverability of the aircraft and its weight were also taken into account. According to these data, restrictions have arisen for TWY airports. Airports have begun to modernize boarding bridges for faster boarding and disembarking of passengers.

6. AIRCRAFT REQUIREMENTS AT AIRPORTS IN ICAO ANNEX 14

Until 1951 there was no standardization at the international level in the field of airports. The creation of Annex 14 for airports was first discussed during the Chicago Conference in 1944. Annex 14 - Aerodromes was adopted on 29 May 1951 under Article 37 of the 1944 Convention on International Civil Aviation and entered into force on 11 November 1951 [15].

In the first editions terms such as runway strips, clearways, taxiways or aprons were defined. From the beginning, the forecourt was located just behind the end of the runway, today it is moved 60 m further from the end of the runway. The various requirements for runway parameters were gradually supplemented until 1958 [15].

With the advent of larger large-capacity aircraft a new letter was introduced in 1999 in the Aerodrome reference code-F [15]. Airbus A380-800 aircraft or their competitors Boeing 747-8 later fell into this category.

During the take-off of large-capacity wide-body aircraft, there was damage to the unpaved area in front of the runway threshold behind the runway and dangerous runway edge detection due to strong exhaust gases. This problem was solved by adding a paved area in front of the runway - Blast pad [15].

7. DOCUMENTING THE IMPACTS OF AIRCRAFT PARAMETER CHANGES ON AIRPORTS ON THE EXAMPLES OF SOME AIRPORTS

Documenting the historical development of airports is described on the examples of 3 historic international airports.

7.1. Munich Riem Airport

At present there are several modern airports in operation in Germany in terms of airport infrastructure, which rank among the most modern airports whether in Europe or in the world. Most of the airports were destroyed or damaged in World War II and the Germans were able to rebuild them and gradually adapt them to the needs of more modern aircraft.

Figure 1: Munich Riem Airport – 1950. [Source: https://www.mil-airfields.de/de1/muenchen-flughafen-riem/1950-02-flughafen-muenchen-riem.jpg]

In Figure 1 we can see the restored airport from 1950. During World War II the airport was bombed several times by Allied aircrafts and the entire airport infrastructure was damaged. In 194, the construction of a new paved runway was completed, which was 1 907 m long and 60 m wide [16]. The load capacity of this runway was 140 t [16]. The length of the runway suited aircraft flying in the following years, such as Sud-Aviation SE 210, Ilyushin IL-18 or Lockheed L-188. In terms of load capacity, it can be determined that the Boeing 707 could move on the runway, as its MTOM is below the load capacity limit of the runway. However, the runway length required to make a safe take-off would not be suitable for this type of aircraft. Even after the completion of the airport, it retained its elliptical shape, as shown in Figure 1. After the period after the World War II, the TWYs have changed - they are reinforced and have a unique shape. From the runway they are located around the perimeter to the apron, where there is a restored terminal with an airport control tower and hangars. On the western side of the airport a new paved apron for aircraft in the shape of a semicircle has been added. In 1958 the Sud-Aviation SE 210 jet landed at the airport for the first time [16]. This indicated the gradual replacement of propeller aircraft by more modern jet engines.

The last flight from Munich Riem Airport took place on 16 May 1992 by a Boeing 737-500 of Lufthansa [16]. The next day a new airport began to be used - Franz Josef Strauß.

7.2. Amsterdam Schiphol Airport

Amsterdam Schiphol Airport is one of the largest airports in Europe. It is the only airport near Amsterdam. For comparison the English city of London serves five airports. It ranks among the oldest international airports in the world. During its 106 years of operation the airport has undergone several expansions and modernizations.

The area where today's airport is located was a large lake before 1852. The Netherlands decided in the second half of the 19th century to dry the lake and use it for agricultural purposes. In 1916 the plan was changed and the area was bought from a local farmer for the construction of the first airport buildings. At the beginning it was considered that the airport would serve as a military air base. The first landing was made on September 19, 1916 by a military aircraft. Later the airport began to focus on commercial aircraft and as early as 1917 it was one of the largest airports in Europe [17] [18].

Figure 2: New Pier C at Amsterdam Schiphol Airport – 1971. [Source j: https://www.airporthistory.org/photos-klm747-schiphol.html]

In 1971 a new Pier C was built at Schiphol Airport, which was primarily designed for wide-body aircraft and was equipped with a new type of jetway [19]. Figure 2 shows 3 types of jetways and KLM aircraft.

The oldest type of jetway is at the Douglas DC-9. From a technical and operational point of view it had several disadvantages, such as limited movement, because it could only move in a circle. Because it was a rotating stand, the jetway had to be moved a long distance from the aircraft after the aircraft was checked in, so that the aircraft could safely roll out of the stand. On the contrary the advantage of this type of stand and jetway was the unrolling of the aircraft without the need for pushback.

The McDonnell Douglas DC-10 shows the type of jetway used to date. Compared to the previous type, it has several advantages, the most significant being the free movement of the jetway on the stand. It is limited only by its length.

The last type of jetway is a novelty that the Dutch themselves came up with in 1971 [19]. It consists of two separate jetways, one is designed for the front aircraft door and the other is used to operate the rear door. We can distinguish this type according to its robust steel construction, as it must be located at a higher height so as not to damage the wings. It has no grip or manoeuvrable wheels from below. Such an arrangement of jetways allowed two or more categories of passengers to board at the same time, for example: business and economy class passengers. Figure 2 shows this type on a Boeing 747-200 aircraft, which is between two McDonnell Douglas DC-10s.

7.3. New York John F Kennedy Airport

New York City before the Wright Brothers' first flight was a gateway for Europeans who came to the United States by boat for better working conditions. Currently the New York metropolitan area is served by several airports, New York John F Kennedy, LaGuardia and Newark, which are different distances from the center of New York - Manhattan. The most distant airport is New York John F Kennedy. When designing it, the airlines had the opportunity to design their own terminal according to their ideas. The best known example is the Trans World Airlines (TWA) terminal [20].

Figure 3: New York JFK Airport Terminal 4. [Source: https://www.autoprio.com/wp-content/uploads/5122732_geonameid_New_York_JFK_Airport.jpg]

At the end of the 20th century flying with wide-body aircraft to JFK spread in air transport. These aircraft include the Boeing 767/777, Airbus A330 / 340 and newer versions of the Boeing 747-400. The airport infrastructure of both runways and terminals and aprons had to be adapted to this type of aircraft. At present JFK Airport has 4 runways, the shortest of which is RWY 04R / 22L, has a length of 2,560 m and is used mainly for landings. All runways are 61 m wide, which also allows the operation of aircraft with the code letter F, such as the Airbus A380-800 [21].

Figure 3 shows Terminal 4, in the middle of which is the newest airport control tower. It divides the terminal into two parts.

To the right is a terminal for aircraft of code letter F. There are two Airbus A380-800s from Etihad Airways and Singapore Airlines on the stands, the third is located on the apron and belongs to Emirates.

Looking at the left side of Terminal 4, on the stands closer to the center of the terminal, there are wide-body aircraft, such as the Boeing 747-400 from Virgin Atlantic or the Airbus A330-300 Swiss. Towards the bottom of the picture, there are Delta large-capacity aircraft on the stands. At the end of the terminal are the smallest aircraft of this company such as the Bombardier CRJ900 or Airbus A319.

8. CONSTRUCTION OF A NEW AIRPORT INFRASTRUCTURE

In 2019 Munich Airport announced the construction of a new part of the satellite Terminal 2 [22]. The new terminal is designed for narrow-body aircraft on one side and for wide-body aircraft on the other side. The reason for the further construction of stands for large-capacity aircraft is the purchase of new Boeing 787-9 by Lufthansa. Compared to Frankfurt, Munich Airport is more focused on short and medium-haul routes, as a result of which it is not necessary to count on a higher runway capacity in the future.

The construction of a third, parallel runway on the northern edge of the airport is also planned at Munich Airport. It should be primarily intended for aircraft of code letter C, such as: Boeing 737 MAX 8 or Airbus A320neo. These aircraft have a shorter take-off length as well as MTOM. The new runway will be limited to aircraft MTOM and will not be able to be used by large-capacity aircraft.

9. CONCLUSION

Due to the change in various geometric parameters and performance characteristics of aircraft during their development, trends in the field of airport infrastructure design changed rapidly.

Several historical factors have influenced the development of aircraft. The aircraft manufacturers tried to achieve the use of the latest power units as well as wing shapes for the aircraft at the time. The overview of aircraft history is completed by 21st century aircraft, which are important for today's airports.

In the future even greater emphasis will be placed on the environmental impacts of aircraft operations. The main factor will be the correct choice of location with the design of new runways. Airports near large cities will have a problem. Some airports have introduced a slot system to ensure optimal use of the busiest airports. However, this solution was not sufficient. After the completion of the new runways, the airports must reckon with the fact that their operation will not be possible throughout the day, but only at designated hours, e.g. the airport will be closed from 06:00 until 22:00 and at night.

The construction of new runways will also take into account the construction of TWY connecting the runways with the airport. From an operational point of view, it is efficient to have two TWY, in which aircraft can move independently in both directions. The disadvantage of this arrangement is the double price and higher maintenance costs of these areas. The advantage of building new runways is to increase the airport capacity, which allows more aircraft to turn around and reduce the number of aircraft waiting to take off. The disadvantage is the consumption of a larger amount of fuel, which is needed to reach a remote runway.

Since the 1960s new terminals at international airports have started using boarding bridges instead of airport stairs. This has had the effect of increasing the comfort and safety of passengers, but in some cases it has resulted in an increase in the time required to turn - round aircraft on the stand.

The use of airports and aircraft was affected by the pandemic situation of Covid-19. This caused the postponement of the construction of some terminals or their modernization. This situation has forced a reassessment of the operation of individual types of aircraft, which has also caused a change in the view of the airport infrastructure. Air traffic is expected to resume to pre-pandemic levels in the coming years, as well as the need to plan airport infrastructure development in the future.

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