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OVERHAUL OF THE PIPER CUB AIRCRAFT REPLICA IN ULTRALIGHT CATEGORY

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Abstract

The subject of this article is focused on the description of the overhaul process involving a classic aircraft design, which is registered under the administration of the Light Aircraft Association of the Czech Republic. The research is divided into three chronological parts; the introduction, the main part and the conclusion. The first part outlines the subject of the research and its individual objectives. The main part deals with the historical background of the Piper Cub type and the current state of operation in the Czech Republic and Slovakia, both from the technical and legislative point of view. A description of the given aircraft will follow and then, mainly, the elaboration of each part of the overhaul process and its individual procedures. Among the individual steps, there will be a description of the required process for increasing the maximum take-off weight of the overhauled aircraft. In the final part, the evaluation of the inputs described above will be performed and the results of the given study will be outlined. The research should provide a comprehensive description of appropriate maintenance and the overhaul process in complexity involving the vintage classic aircraft design under the legislation of the ultralight aircraft category. Another output will be the definition of a procedure for increasing the maximum take-off weight thanks to new, updated legislation.

Keywords

Ultralight, Aircraft Overhaul, Restoration, LAA CR

1. INTRODUCTION

The intention of this article is to describe the overhaul procedure of an airplane of classic design, operated in the category of ultralight aircraft, and the process of restoring its airworthiness. While classic construction generally refers to airplanes made using materials such as wood, canvas and steel fuselage frames.

The aircraft in question, described in this work, is an ultralight named Kaero. This is in fact a replica of the very popular training and sports aircraft type Piper J-3 Cub, which was first flown in the late 1930s and its derivatives are still produced today.

The subjected Kaero aircraft was damaged by a hangar collapse in the past, its airworthiness was lost, and it has not yet been put back into service.

In the first part of the article, the history of the Piper Cub aircraft is outlined as an introduction to the issue, the circumstances of the conditions of operation of these aircraft in the Czech Republic and Slovakia and the current situation are further described. This will be followed by a characterization of the technical specifications of the aircraft and a comparison of the design differences with the Kaero aircraft.

The practical part of the article is focused on describing the condition of the aircraft before the overhaul. This will be followed by an evaluation and choice of the methods applicable for the processing of the overhaul process itself and its technical aspects.

The article will then propose an overhaul procedure and its steps, while the given topic provides an opportunity to develop comprehensive documentation that will describe the methods and available technologies used today in the repair and maintenance of ultralight aircraft of classic design in the given category. This comprehensive output will then serve as documentation for restoring the airworthiness the Kaero / Piper J-3 Cub replica. Furthermore, the output can also be used as background material for determining the procedure and choice of repair technology by other operators of the given category of ultralight aircraft.

2. PIPER CUB HISTORY

Despite its age, the Piper Cub is still very popular in the sport aviation segment today. This is mainly due to its excellent flight characteristics, simple yet robust construction, and the resulting low costs of operation and maintenance. It is often referred to as a Ford Model T of aviation with its later revolutionary approach to the aviation market in the USA.

The beginning of the development can be dated back to 1930, when Clarence Gilbert Taylor at Taylor Brothers Aircraft in Bradford, Pennsylvania, designed and built the Taylor E-2 Cub, first predecessor of the famous line of Cub aircrafts.

Company goal at the Taylor Brothers Aircraft was to construct an all-round cheap airplane that could bring aviation closer to wider social strata with its affordable price and enable them to buy and operate their own airplane. This idea met with success, and from 1931 to 1936, when the production of the Taylor E-2 Cub type ran, a total of 353 units were produced at a price of 1,325 US dollars of the time [1].

This initial success motivated the manufacturer to further develop and innovate the design. However, in the meantime, the company's structure also changed. Businessman William Thomas Piper, originally an investor and partner who saved the company from collapse during the economic crisis of the early 1930s, decided to buy out the remaining shares in the company after internal disputes with Taylor Brothers. Thus, a company named Piper Aircraft Corporation was born. After Clarence Gilbert Taylor left the company, Walter Jamouneau became the new chief type designer [1].

Development continued with an innovative type already named Piper J-2 Cub. The new J-2 had better designed wing tips with oval shape, and the shapes of the horizontal and vertical tail surfaces were also modified. The design of the main landing gear was partially changed, which now used bigger low-pressure Goodyear Airwheel tires. The cockpit was now also glazed and fully enclosed. Production of the Piper J-2 Cub type ran from 1936 until a fire at the company's production facilities in 1938. A total of 1,207 units were produced [1].

After a fire at the factory in Bradford, the Piper Aircraft Corporation moved to the city of Lock Heaven, where the production of the later most popular type Piper J-3 Cub began from the end of 1938 [1].

Modifications of the J-3 type compared to the previous generation consisted primarily of strengthening the structure of the fuselage and wings, which also had new aluminium alloy ribs. The main landing gear was equipped with hydraulic brakes. At the customer's request, the aircraft could also be equipped with a steerable tailwheel. The choice of Powerplant has also been greatly expanded. Franklin, Lycoming and Continental flat four-cylinder engines with higher power were also newly offered. The most widespread Powerplant then became the Continental A-65 engine with an output of 48 kW (65 HP). The aircraft modified in this way was certified in the United States on July 14, 1938 and received the type certificate A-691. The aircraft achieved considerable popularity at the time, which was reflected in great sales successes. A total of 3,016 were produced in 1940 alone, the year before the United States entered the war [1].

The military also showed interest in the aircraft for its front-line observation and courier aircraft program. After bad experiences with larger types, such as the Stinson L-1 Vigilant or the Curtiss O-52 Owl, which were difficult to maintain and operate in field conditions it was decided to choose the light aircrafts for this role.

The army's requirement for this category was to obtain an aircraft with a short take-off and landing, which would be easy to operate and which would be able to be maintained by ground personnel in front line conditions without special training [2].

The modified army version was then designated L-4 Grasshopper. Modifications, were not extensive. It mainly included new modified cabin glazing for a better view for air observing tasks. The Military versions were produced extensively in the four following variants, designated as L-4A, L-4B, L-4H and L-4J. Depending on the version, the aircraft could be further equipped with an electrical system and a radio station. In total, from 1941 to the end of the army contracts in 1945, more than 5,400 L-4's of all versions was produced for the army [2].

After the end of the Second World War, a significant number of these aircraft remained in Europe, which were sold off to the civilian market later on. Thanks to this, Cubs are still widely popular across all the countries of Western Europe, where they helped to restore sport aviation after the war.

The production of the J-3 variant continued from 1945 to 1947 and its popularity is also evidenced by the fact that there are still about 3,000 Cubs registered and operating in the USA as of the date of publishing of this article [3].

3. FURTHER DEVELOPMENT

Due to the success and constant demand for aircraft such like the Piper Cub even after the end of factory production, several other companies took the initiative. With their activities, they continued and helped to keep a considerable fleet of these aircraft in operation and gradually developed and further modernized this concept. Initially, they focused on the production of spare parts, kits and later even complete aircraft.

One of such companies is a Wag-Aero. American company that first started producing spare parts for and later complete kits for amateur construction led by the American Experimental Aircraft Association. It has also released construction plans for their Piper J-3 Cub replica, which is called the Wag-Aero Sport Trainer.

4. PIPER CUB IN CZECH REPUBLIC AND SLOVAKIA

After the end of the Second World War, there was urgent need for new airplanes that could be used in re-established aeroclubs in Czechoslovakia. Therefore, at the beginning of 1946, the Ministry of Transport decided to proceed with the purchase of 200 used Piper L-4 Grasshopper aircrafts from the surplus of the US Army in Europe. Another 100 L-4 aircraft were also purchased by the Ministry of National Defense for the needs of the army. Aircraft operated in the army were then assigned the code type designations C-8 and K-68.

With the gradual rise of the domestic aviation industry in Czechoslovakia, the Cubs began to be replaced by more universal airplanes of the Zlin Trener series, which enabled both basic pilot training, aerobatics and glider towing. A few ex-Czechoslovak were sold off to the western countries and the rest was scrapped at the end of 1950's.

Today the Piper Cub can be certified either as a GA category aircraft or as a Light-Sport under Light Aircraft Association. The Czech Light Aircraft Association Light-Sport category is primarily suitable for aircraft replicas and amateur built aircraft with MTOM up to 600 kg.

5. TECHNICAL SPECIFICATIONS

The aircraft is designed as a two-seater cabin high-wing monoplane of mixed construction with a tailwheel landing gear. Information and performance data are valid for Piper J-3C-65 Cub powered with Continental A-65-8 engine.

The fuselage frame structure is welded from chrome-molybdenum steel tubing. Access to the cockpit is from the right side. The arrangement of the pilot's seats is in a tandem configuration with dual flight controls.

The wing is of rectangular shape. The construction is of mixed type. The wing spars are wooden, made of solid spruce wood. There are 12 ribs in total, they are riveted and shaped from duralumin profiles. The airfoil used throughout entire wingspan is USA 35B which ensure good slow flying characteristics [4].

The Continental A-65-8s aircraft engine used in the Piper Cub is an air-cooled flat-four with a displacement of 2.8 litres. Maximum engine output is 48.5 kW (65 HP at 2250 RPM. It primarily uses a Sensenich 72C-42 propeller with 1830 mm diameter [4].

The fuel system consists of a fuel tank with a capacity of 45 litres, which is located in the forward part of the fuselage, between the engine firewall and the instrument panel.

6. COMPARISON WITH THE KAERO AIRCRAFT REPLICA

The Kaero aircraft is technically identical to the Piper J-3 Cub, but differs in several design points. When compared, the design changes are in the following points.

The original solid type wing spars were replaced with partly hollow type spars, which are glued together from spruce flanges and plywood webs. The construction of the new spars was designed in order to maintain the same strength as the original solid type spars.

The fuselage was built in accordance with the drawing documentation, but metric tubes were used for the structure. Where it was not possible to use the dimensions of the tubes specified in the drawing documentation, an alternative metric tubes were used, either with a larger diameter or with a thicker wall, so that the strength of the structure was at least maintained or increased.

The building took approximately 3000 man-hours and the aircraft was first test flown in 1995. Since then, it has accumulated 323 flight hours and 900 landings.

7. KAERO CERTIFYING LEGISLATION

The Kaero, as an amateur-built ultralight aircraft, falls into the category of ultralight aircraft. Currently, Kaero is registered under the administration of the Light Aircraft Association of the Czech Republic, which is authorized by the Ministry of Transport to perform state administration in the matter of ultralight aircraft.

8. DAMAGE ASSESMENT BEFORE START OF THE OVERHAUL

Aircraft was damaged by a hangar collapse. This resulted in mechanical damage to individual elements of the aircraft structure.

Ceconite covering on the fuselage was torn and the wooden elements and the steel reinforcements of the fuselage superstructure were subsequently broken through and bent.

On the left wing, the end ribs number 11 and 12 were broken. Furthermore, the adjacent steel members supporting the wingtip were bent.

The damage that was found was common to the total flight time and type of the operation of the aircraft. Further inspections would be carried out during disassembly of each airframe subassemblies and overhaul process of the aircraft.

9. KAERO SERVICE LIFE

During the operation, maintenance and repair of aircraft, it is necessary to assess the overall service life of the airframe structure. This is the time period during which the aircraft is safely airworthy.

In order to determine possible critical elements affecting the overall life limits of the Kaero aircraft structure, we can also use available information on the operational reliability of the Piper J-3 Cub aircraft, due to its structural similarity.

Analysis of the published airworthiness directives and issued service bulletins revealed that corrosion may be the biggest problem of the Piper Cub airplanes in terms of service life. While this problem can be most critical when the wing lift struts are affected. There it is relatively difficult to detect under normal operating conditions as the corrosion mainly affects the inside structure [5].

Because of this critical issue, the US FAA has issued a continuing airworthiness directive AD 2015-08-04. This document mandates the periodic inspection and possible replacement of the original wing struts on all Piper Cub series airplanes [5].

Therefore, during the restoration of the Kaero aircraft, it will be necessary to pay increased attention to the occurrence of corrosion in the wing lift struts and, where appropriate, thoroughly treat the structure of the aircraft against the formation of corrosion.

10. KAERO OVERHAUL METHODOLOGY

To characterize the term Overhaul in aviation and its methodology, we can quote the definition from Czech national Aviation Regulation L 8/A, which describes this term as follows:

"Overhaul is the restoration of an aircraft, engine, propeller or other aircraft component products by inspection, repairs and replacements, carried out to maintain their operational service life in accordance with an approved standard." [6]

Overhaul process of aircraft itself can be then generally defined by the following scope of work:

- The airframe is completely disassembled into individual parts and components.
- Inspection is carried out to making the findings and to evaluate the overall condition of the structure.
- Classification of the assemblies and individual parts into usable without repair, requiring a repair before returning to service and unrepairable.
- Application of NDT inspections to critical structural elements.
- Repair of damaged parts of the airframe.
- Repair of damaged airframe parts or replacement with new ones.
- Execution of mandatory bulletins for safe operability.
- Applying new surface restoration paint and top coat to airframe, including internal and external construction.

- Assembly of the airframe and its subassemblies.
- Checking and testing of the individual aircraft systems.
- Final test flight to verify full airworthiness.

According to the findings of the identified defects and damage found on the airframe of the Kaero aircraft, the size of the work necessary to restore its airworthiness fully corresponding with the scope of the overhaul in its entirety, according to the list of individual maintenance tasks listed above.

11. AICRAFT FABRIC COVERING SYSTEMS

An important step during the overhaul process of classic fabric-covered aircraft is the choice of suitable covering material. Its overall characteristics can significantly affect the difficulty of operation and maintenance of the entire aircraft.

Among the key parameters of aircraft fabric is the type of material used, and its lifespan. Materials used for aircraft covering today are mostly synthetic. Another important parameter is the strength and specific weight of the given material, which then affects the resulting empty weight of the aircraft.

Nowadays, the market offers a choice from multiple of available fabric covering systems, both certified and non-certified.

11.1. Oratex

Oratex is a synthetic covering system for aviation developed by the German company Lanitz-Prena Folien Factory in Leipzig. The fabric is made of high-strength polyester fabric, which I coated with a patented polyurethane top covering compound and paint finish already during the production process. The resulting coating material is resistant to UV radiation, temperature extremes and chemicals [9].

That means that after the aircraft has been covered, there is no longer any need to apply additional layers of stabilizing and protective paint layers. In this way, the entire process can be simplified and it is thus possible to achieve a significant reduction in the necessary time and other costs required to paint the aircraft [9]

One of the key advantages of Oratex, on the one hand, can be a faster coating process of the entire aircraft, when the canvas does not need to be further treated after coating, and thus the solution of another production technology of painting is omitted.

On the other hand, due to the fact that the canvas is already coated with a protective paint finish from the factory, it is not as flexible as other covering materials, and it is not easy to remove possible imperfections and wrinkles during the covering process, caused by inaccurate initial placement on the fabric to the structure. This can be a disadvantage for less experienced builders and restorers. Another disadvantage can also be the limited number of available colours options in which the fabric is supplied.

11.2. Ceconite

Ceconite is a range of aircraft covering materials that are also made from synthetic, polyester fibres. Ceconite fabric has been on the market since the 1960s. Nowadays, Ceconite is already the standard in the industry and ranks among the most used [10]

Compared to the Oratex system, Ceconite is delivered as a plain fabric without any surface treatment. Therefore, after the covering and shrinking process, the fabric needs to be further treated with a stabilizing varnish and a top coat.

Its advantages include, in particular, that it is easier to work with. Thanks to its initial state without a covering layer of paint, it is easier to work with during the covering process. Another advantage is better applicability for local in-service repairs of damaged fabric during service life of the aircraft.

12. WING LIFT STRUTS NDT INSPECTION

After disassembly of the individual struts, it was decided, due to the issued AD for the Piper J-3 Cub aircraft, to subject the struts to a borescope inspection to determine the condition of the inner walls of the tubes. A subsequent inspection revealed the occurrence of corrosion inside of all struts in their lower parts, close to the fuselage. Therefore, it will be necessary to proceed with an NDT inspection to determine the remaining wall thickness of all four strut tubes using ultrasonic measurement.

The paint was stripped and a grid was marked around the external surface for measurements in four axes. Measuring spots were divided by 20 mm. The total length of the measured section of the tubes was 600 mm.

The Olympus Panametrics NDT - 35DL Ultrasonic Precision Thickness Gauge was used for NDT measurement of remaining wall thickness in accordance with the ČSN EN ISO 16809 norm. This instrument can measure steel as thin as 0.10 mm with an accuracy of 0.001 mm [7].

Calibration of the device's sensitivity settings was performed for thicknesses of 1 and 2 mm in the test range of 0 - 5 mm. The measured values are summarized in Table below.

Table 1 - Remaining wall thickness of individual struts.

Strut	T_{MAX}	T_{NOM}	T_{MIN}	$T_{NOM} - T_{MIN}$
A	1,327	1,200	1,207	-
B	1,297	1,200	1,127	0,073
C	1,317	1,200	1,170	0,030
D	1,286	1,200	1,147	0,053

After consultation with the LAA technician inspector, it was decided to use a 10% material loss limit of the nominal wall skin thickness for the evaluation of the strut tubes condition. Therefore, for a wall with a nominal thickness of 1.2 mm, the maximum allowable loss is 0.12 mm and the minimum remaining wall thickness limit is 1.080 mm.

Table 2 - UTT NDT Measurement Evaluation.

Values	*Acceptable max. loss*	*Measured max. loss*
T_{NOM}	1,200	1,200
T_{MIN}	1,080	1,127
Loss in mm	0,120	0.073
Loss in %	10%	6,0833%

all the measurements made is 1.127 mm. The largest measured loss of material is therefore 0.073 mm, which corresponds to 6.0833%. So, all struts passed the NDT inspection.

13. UPDATED MTOM LEGISLATION

In 2019, the LAA approved an amendment to the UL 2 - Part I airworthiness requirements regulation. A substantial modification that was included in the regulation during this amendment was the increase in the operational limit for the maximum take-off weight. Compared to the original form of this regulation from 2002, the MTOM limit was increased from the previous 450 kg up to 600 kg.

The opportunity to implement this legislative amendment at the national level was made possible by the ratification of the new Basic Regulation of the European Union 1139/2018 on common rules in the field of civil aviation and on the establishment of the EASA agency. The amended basic regulation gives the member states the option for the OPT OUT solution. This provides an opportunity to transfer the legislative management of aircraft with the limits described above, which have not previously been certified in accordance with Regulation (EC) No 216/2008, to a national level [8].

The OPT OUT solution and the amended legislation allow already registered and approved ultralights to operate within the limits, as they were previously approved for operation, or, after providing the appropriate documents, allow their MTOM to be increased up to the new limit of 600 kg. This situation will also apply to the Kaero aircraft, which was originally certified with MTOM of 450 kg but the real design limit is 555 kg which is also the MTOM limit of the original Piper J-3 Cub type. This change would make it possible to use the full potential of the Kaero aircraft.

14. MTOM INCREASE PROCEDURE

Czech LAA also defines the required procedures for verifying the airworthiness of ultralight aircraft. The legislation requires to prove the strength of the individually built ultralights in the following points:

1. By calculation
2. Quality evidence of used material
3. Wing static load test
4. Additional tests at the discretion of the technical Inspector [11].

When the Kaero aircraft was first released to service in 1995, all the mentioned points were already fulfilled. However, according to the applicable legislation at the time, a load test was performed only for the then required MTOM limit of 450 kg.

1. In order to approve the new higher MTOM limit, it will be necessary, according to the above-mentioned requirements, to carry out the following range of tests:
2. Check of the wing spars static calculation
3. Preparation of documents for a new wing static load test with a higher load value, which will practically verify the calculated strength values of the structure for operation at an increased MTOM limit.
4. Design of wing fixtures for static load test and subsequent processing of the drawing documentation for their actual production, as the original preparations have not been preserved.
5. Practical execution of the static load test according to the given input parameters.

The actual practical procedure will consist of placing the wing in the fixtures and continuously distributing the calculated designed load on the wing spars. This will be followed by the measurement of the deflection of the wing structure under load and comparison with the calculated values. After the specified time, the load is removed and wing inspected for any permanent deformations of the structure.

15. CONCLUSION

Overhaul of an aircraft is the procedure that allows maintaining and extending the airworthiness of a given aircraft. In the case of the Kaero ultralight aircraft, which was damaged by the fall of the hangar, this work made it possible to describe the overall process, its steps and individual activities that were necessary to restore its airworthiness.

In the first part, the technical parameters of the aircraft and its description were outlined. Furthermore, the article focused on the service life of the Kaero airframe and defined the critical elements given the operational experience on a similar type of aircraft, Piper J-3 Cub. The second part was then focused on determining the individual repair steps that will need to be carried out and further offered a description of practical NDT measurement with evaluation of the measured values.

The most critical part of this overhaul was the finding of the wing struts corrosion, which could potentially threaten the further safe operability of the aircraft. Thanks to the use of today's available non-destructive testing methods, mainly a borescope inspection and subsequent measurement of the minimum remaining thickness using the ultrasonic method, it was possible to check their actual condition, evaluate the level of the damage and propose a repair procedure.

This comprehensive output will be further used as a basis for restoring the airworthiness of the Kaero aircraft and can further serve as inspiration for other operators who will overhaul the aircraft of similar design in ultralight category.

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