Albi II – a new generation development

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Abstract. The UL-39 Albi university© all-composite ultralight aircraft project, powered by a piston engine and ducted fan, continues at the Department of Aerospace Engineering at Faculty of Mechanical Engineering CTU in Prague and its partners ZALL JIHLAVAN airplanes, s.r.o. and LA composite, s.r.o. by developing its new generation. The article is a follow-up to a contribution from 2017, where the entire genesis of the first prototype was described. The introduction summarizes the experience of the prototype operation and analyzes the deficiencies that required a major redesign of the propulsion unit. Aspects leading to the choice of another propulsion unit arrangement and changes in the ducted fan, airframe and systems are described. The fuselage of the airplane has undergone a dominant change. The paper describes not only structural changes leading to the reduction of the width of the fuselage and its wetted area, but also the changes in manufacturing process of composite parts leading to weight reduction. Following the changes in the fuselage design modifications of the wing (mainly high lift devices) and modification of the horizontal tail plane are described. At the end there is a plan of further development described, which should ultimately lead to the commercialization of the project.

1 Laboratory, ground and flight tests of the UL-39 Albi

By the maiden flight of the prototype one of the most important developmental stages of each new aircraft type will begin. The unconventional type flight tests have a particularly important role in obtaining airworthiness, the design of which could not be based on previous experience of similar conceptual, constructional or technological solutions. This was also confirmed for the UL-39 Albi, which, thanks to its unconventional propulsion unit, stands out of all established design conventions in the category of ultralight aircraft.

Despite the extensive program of laboratory operational tests, during which the functionality of all airframe and especially engine systems was verified, only ground and flight operation of the prototype (Fig. 1) showed its weaknesses.

The hydraulic system controlling the retractable landing gear and Fowler flaps was designed with minimal weight in mind. A strong emphasis on minimizing weight was also reflected in the concept of locking the end positions of the undercarriage. A solution was sought with a minimum of hydraulic elements operated by heavy electromagnetic valves.

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The solution was hydraulic-mechanical locks, in which the hydraulics provided only unlocking, locking was realized mechanically using spring latches. This system proved to be unreliable in operation. The imperfect locking of the extended position in one case led to undesired retraction of the nose landing gear during taxiing after landing. Subsequent modifications to the lock design eliminated the problem. The Albi II version uses a principally different retractable mechanism, which completely eliminates the delicacy of the spring mechanisms.

Fig. 1. Flight tests of the UL-39 Albi

The strict minimization of weight was also reflected in the construction of the fuel system. Plastic hosepipes with the required clearance and minimum wall thickness were used for the ventilation tubes. The bend radiuses of the tubing (Fig. 2) were chosen in such a way as to prevent breakage and subsequent deactivation of the ventilation. Neither laboratory nor ground tests of the fuel system identified any malfunction. During take-off the tubes broke, which led to the underpressure in the fuel tank and engine failure followed by an emergency landing. Tubes in the engine compartment were replaced with aluminum thin-walled tubes, which definitely eliminated the problem and also meant weight savings. More than two years later, during a normal pre-flight inspection, a delamination of the inner layer of the sandwich skin of the integral tank (Fig. 3) was discovered.

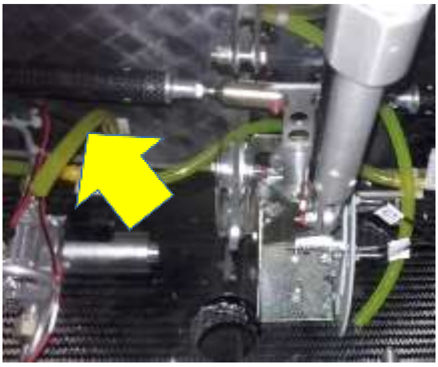

Fig. 2. The position of the breaking ventilation tubes

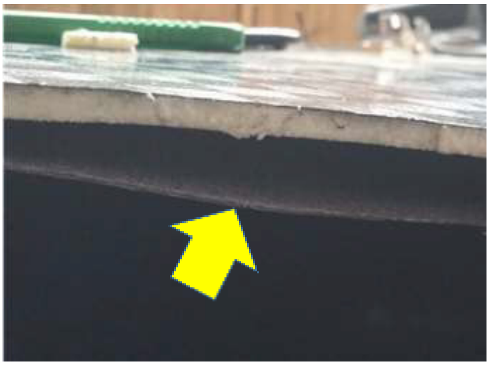

Fig. 3. Delamination of the integral tank cover

The most serious drawback in the airframe and its systems caused by the effort to minimize the weight showed the design of the horizontal tail plane (HTP). Although aerodynamic calculations showed the adequacy of the proposed area and deflections, during the flight tests to verify the flight characteristics, when the flap was deflected into the landing configuration, the critical angle of attack on the HTP was exceeded with the consequent loss of lift on it. This was followed by a sharp overturning of the aircraft to its back, accompanied by a sharp increase in speed and loss of altitude. The pilot, due to the height above the terrain, activated the parachute rescue system. Due to the fall over the tree tops the right wing and the rear fuselage was damaged, but the pilot was unharmed and the damage was repairable.

This was followed by an extensive analysis of possible causes and the search for corrective measures. At that time, a detailed model of the aircraft (including wing flaps and adjustable rudders) for wind tunnel measurements was coincidentally completed within two diploma theses of the Department of Aerospace Engineering students (Fig. 4.).

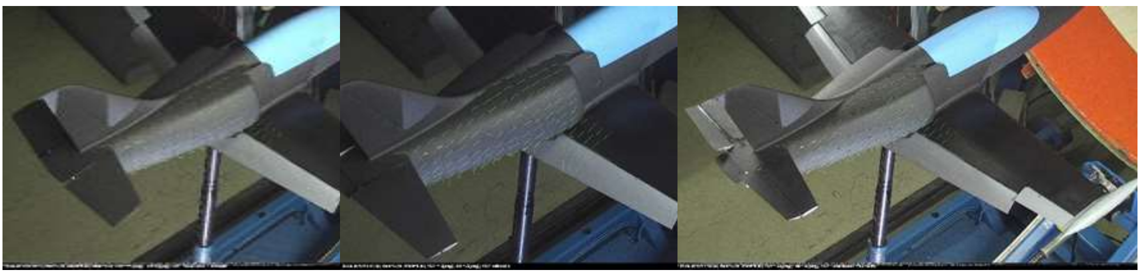

Fig. 4. Wind tunnel testing of the HT

It has been found relatively quickly that the part of the flap under the fuselage generates a turbulent flow in the root part of the HTP, especially in the landing configuration, and thus becomes ineffective. After various considerations about increasing the area or using a slot on the allmoveable HTP, it was finally decided to use a classic HTP (with stabilizer and elevator) with an increased area, which would ensure the balance of the aircraft in the landing configuration even without an adjustable stabilizer. In addition, it was decided to remove the part of the flap, which reached under the fuselage and was a source of turbulence on the HTP. After the analysis in the wind tunnel, the design of the HTP modifications was made and a new HTP was manufactured. The rear fuselage and wing were repaired. After installation of the new HTP on the repaired fuselage (Fig. 5) and its necessary static strength tests, a new flight test program was launched. Although the complete program has not yet been completed, the first results indicate that corrective measures are correct.

Fig. 5. Flight tests with the new HTP

If the above-mentioned deficiencies were quite easy to design and technologically solve, insufficient performance (maximum speed in horizontal flight) found by flight tests required major changes of the power unit and consequently the whole fuselage structure.

The main drawbacks of the powerplant were:
• Insufficient thrust
• High operating speed of the piston engine (engine life and noise)
• Unsymetrical engine instalation in the fuselage (wide fuselage and large wetted and front area – i.e fuselage drag)
The key to a possible improvement of propulsion characteristics of the propulsion unit was to find a more suitable engine. This should allow higher performance of the new ducted fan at lower engine rpm, narrowing the fuselage (due to the more symmetrical engine mount) and straightening the inlet channel of the duct. The searches offered engine from water scooter Rotax 4-TEC 1503 XHO. It is an in-line three-cylinder petrol engine with a mechanically driven compressor with an output of 160 kW at 8000 rpm, which is the speed suitable for a fan diameter still reasonably accommodated into a narrower fuselage. The disadvantage of the engine is higher weight (about 20 kg more than the existing modified BMW). Consistent analysis of the flight prototype revealed possible weight reserves, mainly by reducing the bonded joints. Technological reconstruction of the wing and tail surfaces, could save approximately 10 kg.

2 Albi II

Modifications of propulsion and airframe were so extensive that it was decided to name the second prototype UL-39 Albi II.

2.1 Propulsion unit

In the first phase of the aircraft reconstruction, the development work focused on the design of a new propulsor - inlet duct, fan stage (Fig. 6), outlet channel with cooling bypass, nozzle and the modification of the engine itself. Due to the position of the engine near the airplane center of gravity, it was not necessary to significantly change the arrangement (longitudinal position) of the main masses of the propulsion unit.

Fig. 6. Fan stage of the Albi II

Thanks to the more compact engine arrangement and the fan drive shaft directly connected to the crankshaft without further gearing, the inlet duct could be tightened around the engine. This made it possible to reduce its curvature, which contributed to reducing losses compared to the original solution.

The slightly lower speed of the fan drive shaft (in this case the engine speed) allowed to increase its diameter by a significant 18%. The arrangement of the whole fan stage was also changed. From the pre-stator - rotor configuration to the pre-stator – rotor – stator. This arrangement allowed the entire rotor to be accommodated in a smaller bearing in the stator, and at the same time an easy installation of the outlet cone to the fixed stator to reduce the base drag behind the fan stage. The blade geometry and number of rotor and stator blades were also changed.

The outlet channel has also been changed. Both the shape itself and the cross-sectional ratio of the main and bypass channel.

The engine mounting in the airframe has also changed significantly. Originally complicated truss engine mounting made of steel tubes for BMW engine was replaced by suspension via silent blocks on mounting points, which are an integral part of the composite fuselage structure.

Engine modifications related to the control unit, the fuel system, and in particular the compressor intercooler and exhaust system. The original intercooler, using the water the scooter is moving in, has been replaced by air one because of the weight and the difficult availability of a sufficiently cold liquid.

2.2 Airframe

The most significant and visible change of the airframe was the reconstruction of the fuselage.

The main reason for the extensive fuselage reconstruction was the new geometry and arrangement of the propulsion unit mentioned earlier. Increasing the diameter of the rotor and the associated change in the outlet channel and nozzle, together with the narrowing of the inlet duct, necessitated a redesign of the practically entire fuselage. The new propulsor placed in the fuselage contour of the Albi II can be seen in Fig. 7 (The original configuration of Albi is shown in Fig. 8).

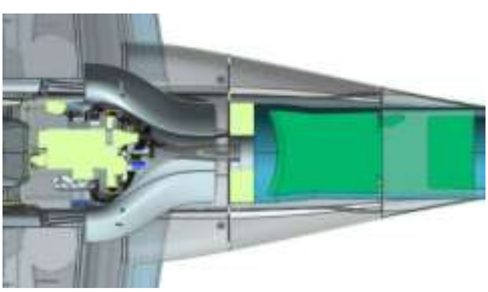

Fig. 7. New powerplant located in the original fuselage [2]

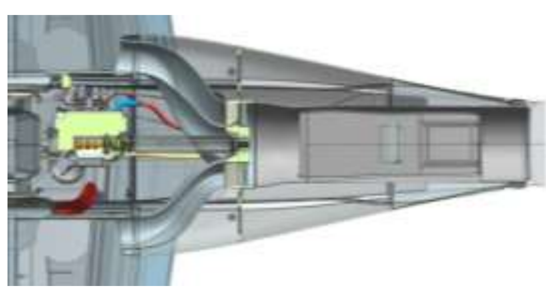

Fig. 8. Old powerplant located in the original fuselage [2]

Shifting the inlet cross-section forward has allowed the rear wing hinges to be aligned with a bulkhead on which the inlet channels are attached. This made it possible to omit one bulkhead from the structure.

The significant narrowing (by about 0.14 m) and straightening of the inlet duct allowed to reduce the wetted area of fuselage by 2% and the frontal area by 25%. Shift of the inlet section forward also allowed unification of some of the structural members. A comparison of the front view of the Albi and Albi II is shown in Fig. 9.

The design of the fuselage is very similar to that of the first prototype of the airplane, with only minor adjustments necessitated by the change of powerplant and based on experience in the production of the first prototype.

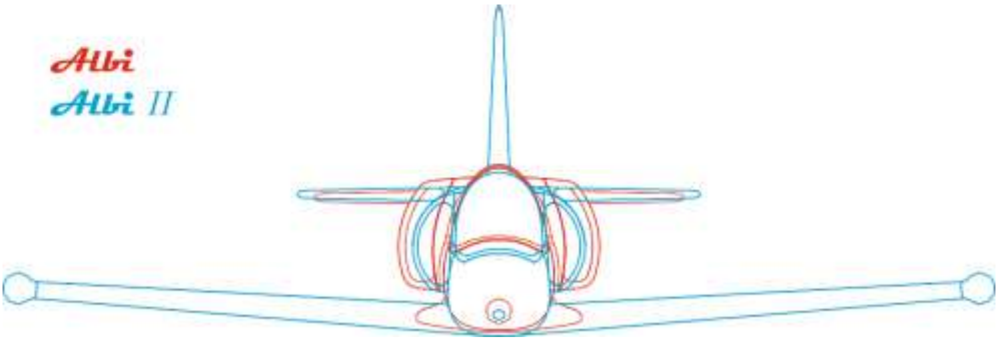

Fig. 9. Comparison of the Albi and Albi II

Structurally, the number of bonded joints in the cockpit has been also minimized by integrating most of the cockpit components into one, which includes a floor with a tunnel for steering installation, seat and side instrument panels.

The changes in the wing structure concerned only changes in the position of the hinges of the wing (forced by the narrowing of the fuselage) and reducing the trailing edge flaps span. These were shortened by 0.3 m in the part located below the fuselage compared to the Albi. This change was made on the basis of the above-mentioned wind tunnel measurements, when it was shown that the part under the fuselage rather reduces the efficiency of the high-lift system. In the plane of symmetry, it was also necessary to create a NACA inlet for the air supply to the power unit intercooler.

In addition to the dimensions of the flaps, a major modification of their construction was made. The redesign of the flaps allowed a significant reduction in the number of bonded joints (was reduced by 0.026 m^2) and fasteners (reduced by 56). These modifications resulted in a weight saving of about 9%.

The development of the Albi II HTP is described above and its features have already been partially verified on the flight prototype Albi (Fig. 5). The overall HTP area has been increased and the elevator is now equipped with aerodynamic balance.

Only a change of the damping unit and the leg shell reinforcement with respect to higher MTOM was made on the main landing gear. The original hydropneumatic damper (used from the L-13 glider) is now difficult to access, which corresponds to the price. It was replaced by elastomer blocks, which are standardly used on airplanes of this category. The nose landing gear has been redesigned in principle. The telescopic lower part has been reinforced and the upper part is now fitted with a single lock that locks the nose landing gear in both lowered and retracted positions.

The original control system with sidestick was replaced by conventional control stick in the plane of symmetry. The extension of the levers should remove the unpleasant sensitivity, especially of the longitudinal control.

Taking into account the experience of the planned producer of the UL39 Albi II (ZALL JIHLAVAN airplanes, s.r.o.) with Garmin digital avionics, it was decided to prepare the data network, the necessary interface modules and the interior layout of the dashboards for the installation of Garmin G3X integral displays. Newly, a system for controlling and identifying the position of trimming pads was developed.

Significant changes have been made both to the technological design and the technology itself for the production of composite airframe parts. The common reason for changes in the design from the technological point of view was to minimize the number and size of bonded joints surface. This minimizes the weight and uncertainty in the quality of the joints. Special metal bonding jigs were welded from laser-machined sheets (Fig. 10), to better control the molds©contact with large-size airframe parts when bonding the main assembly groups (wing, fuselage, HTP).

The changes in the manufacturing process of large composite airframe parts consisted in the replacement of combined (metal - composite) curing molds with purely composite ones. This eliminates inaccuracies due to deformations caused by different thermal expansivity of the metal and composite mold parts.

Fig. 10. Metal bonding jigs of the wing

2.3 Further development of the UL-39 concept

There are two possible directions for further development of the airplane.

The first logical and directly related development of the aircraft is its extension within the category of ultralight aircraft according to the currently valid legislation. Based on the EASA Opt-out, a new UL-2 certification specification (2019) has been issued that allows the maximum take-off weight to be increased for ultralight aircraft from 472.5 kg to 600 kg. This, together with a number of weight savings made on the second prototype, will increase the payload of the airplane.

The second step in the development of the aircraft, which is considered, is the version with a suitable jet engine with thrust about 3000 N. This option is currently in the phase of conceptual considerations, in which it will be elaborated in more detail and it is therefore premature to give a detailed description.

3 Conclusion

Airframe and system shortcomings of the Albi that appeared during ground and flight tests have been successfully solved. All changes of the original design resulting from the solution of Albi deficiencies were applied in the design of Albi II.

The powerplant unit has undergone a major change in the Albi II. Another engine was used, the fan diameter was increased, and the inlet and outlet channels were adjusted to achieve a higher thrust. With the change of the powerplant unit, the design of the fuselage was fundamentally changed so as to reduce the wetted surface and the frontal cross-section.

A number of changes have been made to the interior design of the airframe in order to minimize the number of composite parts and thus the size of their bonded areas (ie weight). New large-composite molds were manufactured for large-area parts and special assembly jigs were made for bonding main airframe sections.

The Albi II is designed to meet the requirements of the new UL certification specifications (UL-2, 2019) with the MTOM of 600kg. Another possible way of developing the concept of UL-39 is a variant with a jet engine (with the thrust of the order of 3 kN).

In terms of the Albi II performance static laboratory tests of its powerplant unit promises significant increasing of performance. Wind tunnel tests of the full scale mockup of the fuselage with accommodated powerplant unit are planned on the end of the year. The maiden flight of the Albi II is planned on the start of 2021.

Acknowledgments

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