

IMPROVEMENT OF A WEEDHOPPER 2 ULTRALIGHT AIRCRAFT BY USING MODERN MATERIALS

IZBOLJŠANJE ULTRALAHKEGA LETALA WEEDHOPPER 2 Z UPORABO SODOBNIH MATERIALOV

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Abstract

The goal of this research was to make airworthy, to modify, and to improve the performance of a Weedhopper II ultralight aircraft (ULA) (JC-24)) manufactured in 1986. In this paper, the renovation of the existing construction and improvements with the use of modern materials and current construction techniques have been carried out. This improved the aircraft performance and removed some of the original design defects. The whole avionics system has been replaced. As the usage of composite materials has resulted in a decrease in the total mass, the determination of the new centre of gravity was carried out to ensure that the airplane remains balanced after being modified. Keeping the weight of the aircraft within the prescribed limit and ensuring that aircraft is in balance has a profound impact on flight safety. The position of the Airplane Centre Stick was changed to increase pilot ergonomics. Then, with the inspection of the engine, it was found that the replacement of the engine carrier was necessary, and the construction and production of the new carrier were performed. Furthermore, an appropriate propeller was selected, and the gearbox ratio was checked. The performances of the propeller have been measured experimentally. The construction of the trimmer of the vertical rudder was made in order to balance the aircraft. Before the flight test, aircraft balancing was performed.

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Povzetek

Cilj raziskave je spremeniti in izboljšati delovanje ultra lahkega (ULA) letala podjetja Weedhopper II, serijske številke 03786 (JC-24), izdelanega leta 1986. V članku je prikazana prenova obstoječe konstrukcije in izboljšava s sodobnimi materiali in sodobnimi gradbenimi tehnikami. Omenjene novosti so izboljšale zmogljivosti letala in zmanjšale nekatere pomanjkljivosti, ki jih je zasnova imela že od začetka. Celotna letalska elektronika je bila zamenjana. Ker je uporaba kompozitnih materialov povzročila zmanjšanje skupne mase, je bila izvedena določitev novega težišča, da se zagotovi, da bo letalo po spremembah ostalo v ravnotežju. Ohranjanje teže letala v predpisani meji in zagotavljanje, da je letalo v ravnotežju, ima velik vpliv na varen let. Položaj palice Airplane Center je bil spremenjen z namenom, da bi povečali ergonomijo pilota. S pregledom motorja je bilo ugotovljeno, da je bila potrebna zamenjava nosilca motorja, izvedena pa je bila gradnja in proizvodnja novega nosilca. Nadalje je bil izbran ustrezen propeler in preverjeno razmerje menjalnika. Izvedba propelerja je bila izmerjena eksperimentalno. Pred preskusom letenja je bilo izvedeno tudi uravnoteženje letala.

1 INTRODUCTION

In the early 1970s, the Weedhopper differed from most other UL aircraft of that period. First developed by American John Chotia in 1970, it had its first flight in 1976, causing a revolution in ultra-light aviation. According to the FAA, all aircraft that were lighter than 250 kg at take-off (aeroplane weight, baggage, fuel, and pilot) needed no permits, insurance, or maintenance to be performed by authorized companies.



Figure 1: Weedhopper JC-24 from 1978

The JC-24 (Figure 1) was designed as a single-seat airplane weighing only 113 kg; it differed from other aircraft by having 2-axis manoeuvrability (transverse and vertical), rather than 3-axis (transverse, vertical, and longitudinal). The JC-24's lack of manoeuvrability in the longitudinal axis is compensated for with dihedral wings. Early versions of this aircraft had a bad reputation because of the unreliable and heavy engines available in the 1970s; that earned it the name Weedhopper. Available engines at that time were too weak and too heavy for proper flight.

2 INITIAL INSPECTION OF THE AIRCRAFT

Inspection of the aircraft and the test flight at 26°C were conducted, and the following performances were established (Table 1):

Table 1: Initial performances of JC-24

Parameter	1 passenger	2 passengers
Min speed	35 km/h	40 km/h
Cruising speed	80 km/h	70 km/h
Max speed	120 km/h	120 km/h
Take off distance	40 m	60 m
Rate of climb	2 m/s	1 m/s

A flight with two passengers requires a high engine speed of around 5800-5900 rpm, resulting in high fuel consumption of some 20 l/h and significantly lower engine life. With two crew members on board, the rate of climb at the air temperature of 26°C is very poor: 1 m/s. Increasing the air temperature to 30-35 °C results in a drop in the rate of climb for 0.2-0.3 m/s, while at even higher air temperatures the aircraft could not take off. This was one of the faults of JC-24 that was to be addressed by carrying out the modifications with the usage of composites.

Visual inspection of the construction and the wing fabric revealed that the aircraft was in poor condition (Figure 2). The fabric had cracks, and stitches were loose, so it needed replacement.



Figure 2: Weedhopper before restoration

The initial inspection also revealed the following: connections of aluminium components (bolts, nuts, bolts) were corroded; seats cracked with damaged seat belts; the kinematics (cables) were corroded and cracked; the motor was improperly installed, poor fuel delivery system, lack of electrical installation, etc. (Figure 3).



Figure 3: Weedhopper construction before restoration

3 SELECTION OF A NEW ENGINE

Because the originally installed engine did not meet the aircraft's needs for power, it was decided to change it. Therefore, a Rotax 582 UL DCDI 99 engine was chosen, which is 11 kW (15 hp) stronger than the previous engine.

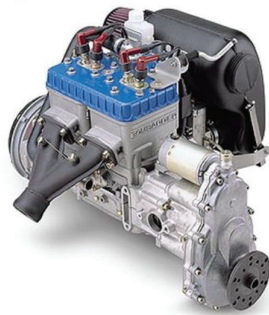


Figure 4: Chosen engine Rotax 582 UL DCDI 99

Engine RPMs are given in Table 2. This factor, as well as maximum RPMs, dictates the propulsion load of the aircraft. When using propellers with an adjustable set angle, it is of great importance to properly set that angle to limit the maximum achievable engine RPMs while obtaining the maximum propeller thrust or traction force of the aircraft, [1].

Table 2: Engine RPMs at different regimes

Parameter	RPM	Allowed time
Max allowed RPM	6800	5 min
Take off RPM	6000-6500	5 min
Cruising (75% power)	5000-5500	limitless
Take off distance	40 m	60 m
Idle	2000	3 min

4 DETERMINATION OF THE NEW CENTER OF GRAVITY

With any serious aircraft modification that requires the addition or subtraction of mass, it is necessary to determine the new aircraft's centre of gravity. This is done to ensure that the aircraft is in balance after its modifications and that has great importance for flight safety, [1].

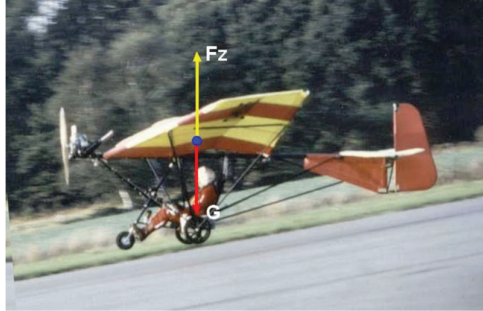


Figure 5: Properly balanced JC-24

A well-balanced aircraft has a centre of gravity on the axis of a lifting force (F_z), so during a horizontal flight, the lift and weight are annulated.

The centre of gravity of this aircraft was determined empirically by suspending the aircraft with ropes on its longitudinal axis. By iterating the position of the rope, a point (using spirit levels) in which the plane is hanging perfectly horizontally was found (Figure 6).

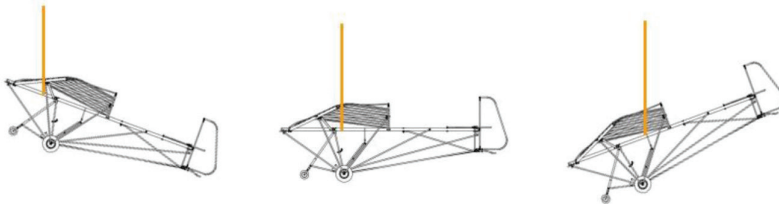


Figure 6: Procedure for determining the centre of gravity by rope

It was determined that the centre of gravity is located 120 mm from the main wing's joint.

5 MODIFICATION OF THE JC-24's CENTRE STICK SYSTEM

During the initial inspection, it was found that the centre system is not suited for further use, Figure 7. The centre shoulder is practically behind the pilot, which is ergonomically awkward for users. It was decided to move the stick 100 mm forward to ergonomically meet the needs of the pilot.



Figure 7: Centre stick system before modification

It was necessary to manufacture a support plate for the centre stick system, and a 3 mm thick aluminium plate (AL6061T6) was selected. The manufactured plate serves as the rear wheel brake support (Figure 8).



Figure 8: Modified centre stick system

6 FEM ANALYSIS OF THE NEW ENGINE CARRIERS

A FEM analysis of the aircraft engine carrier is needed to check the stresses that occurred because the stronger engine was installed, and to check whether the thrust angle had changed. Checking the angle of the thrust is necessary for the possible correction of the engine inclination, according to [2]. A CAD model of the ROTAX 582 with a c-gearbox (Figure 9) was created.

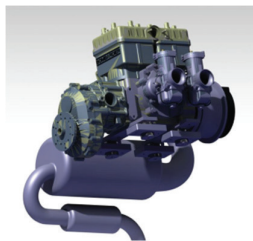


Figure 9: CAD model of selected engine and its gearbox

Furthermore, a simplified FEA model was derived to shorten computational times. When simplifying (Figure 10), the model was loaded with the thrust force of 1500 N.

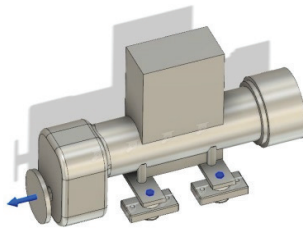


Figure 10: Simplified FEM model with given load and constraints

To determine the necessary node count and finite elements sizes, displacement of the chosen model point with the coordinates (101,4; 106,9; 515,9) was calculated with different mesh properties (Figure 11).

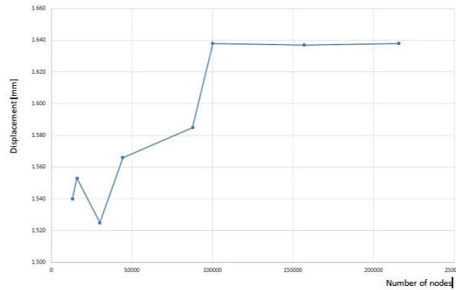


Figure 11: Displacement of chosen point vs. Number of nodes used for meshing

It was concluded that the 100,000 elements were sufficient for further analysis.

The conducted FEM analysis has shown that the safety factor for designed engine carrier is in the range from 6.827 to 15, (Figure 12).

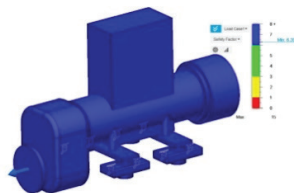


Figure 12: Design safety factor

At the same time, it was shown (Figure 13) that displacement of the output crank of selected c – gearbox is 1.491 mm. According to [3], a displacement of 1.491 mm does not require the engine installation angle to be changed.

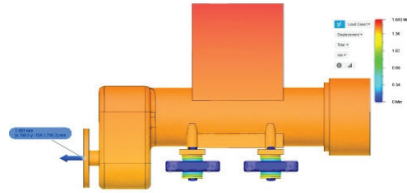


Figure 13: Calculated displacements by FEM

7 MANUFACTURE OF THE NEW ENGINE CARRIERS

During an inspection of the engine carrier, it was discovered that the carriers do not meet minimum safety requirements for further exploitation. Cracks were found in the rubber section. Original carriers could not be obtained due to the year of manufacture and the small number of the aircraft produced. Therefore, it was decided to produce new engine carriers. They were designed in the CATIA CAD package (Figure 14).

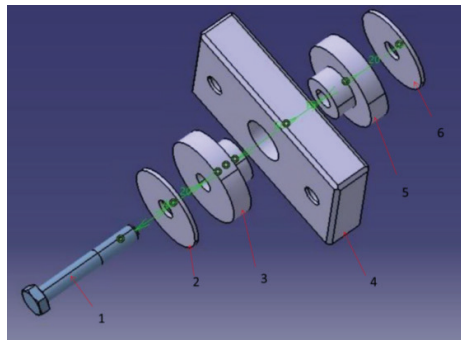


Figure 14: 3D model of engine carriers. 1-bolt; 2-lower washer; 3-lower part of rubber vibration reducer; 4-metal truss; 5-upper part of rubber vibration reducer; 6-upper washer

A tool for the vulcanization of the rubber vibration reducer was designed, and the rubber 75 SH was used (Figure 15).

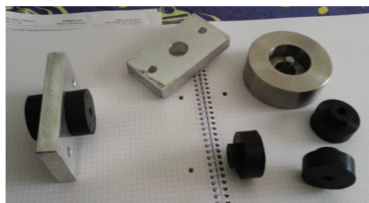


Figure 15: Manufactured engine carrier parts and assembly

When installing the supporting plate connecting the aircraft carrier tube and the engine, it was moved by 20 mm forward, to balance the aircraft.

8 MEASUREMENTS OF PROPELLER PERFORMANCE

The propeller performances on our engine and our aircraft configuration were measured on the ground, [4]. The aircraft was tied to the dynamometer and induced traction force, depending on the engine RPM, was recorded, Figure 16.

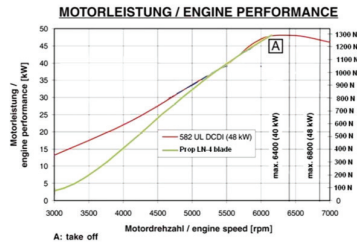


Figure 16: Trust curve

9 MANUFACTURE OF OPEN CABIN

The constructing of the cabin was carried out to increase aerodynamics (decrease of drag), to protect the pilot against strong air stream caused by the propeller, and to improve the aircraft's appearance, [5].

The aircraft cabin was designed as a shell whose construction was made of composite, containing knitted glass fibers 180 g and epoxy resin PR2032. The shell is laminated in two layers of glass fibres and two coats of resin, while its fixation points to the hull of the aircraft were laminated in four layers. The windshield was made of 2 mm thick LEXAN. The total weight of the manufactured cabin is 6.2 kg (Figure17).



Figure 17: Installed manufactured open cabin

10 DESIGN OF THE VERTICAL RUDDER TRIMMER

The engine torque tends to rotate aircraft to the right. The value of this torque depends on the rotation of the propeller and its weight. When the rotations and the weight are bigger, the induced torque is bigger. Furthermore, additional torque occurs in relation to the number of the passengers (one or two). This torque is significant because there is a relatively big distance between the passengers.

For both reasons, the plane tends to turn right. This has to be compensated by the pilot, constantly slightly steering centre stick to the left to keep the aircraft in a straight flightpath. On longer flights, the tension of the arm leads to muscle fatigue, which is not pleasant for the pilot. Hence, the trimmer was designed to supplement the pilot's force to the left. It was designed as a spring whose tensile strength can be increased or decreased, depending on the flight regime. A 100 mm long wire spring was installed in the left lever of the vertical rudder. This spring was connected with an additional cord to the newly installed handle in the cabin for spring force adjustment, as shown in Figure 18.

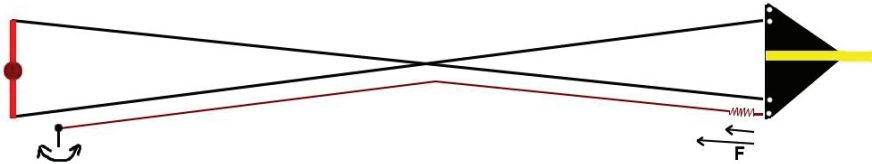


Figure 18: Working principle of the vertical rudder trimmer

11 MEASUREMENTS OF MODIFIED JC-24 PERFORMANCES

Figures 19 and 20 show modified JC-24 aircraft ready for test flight.



Figure 19: Modified Weedhopper 2, right view



Figure 20: Modified Weedhopper 2, front view

After a successful test flight (Figure 21), all the measurements were condensed in Table 3.

Table 3: JC-24 performances comparison before and after the modifications

Parametar	Before		After		Difference (%)
	1passenger	2passenger	1passenger	2passenger	
Total Weight	235 kg		252.5 kg		7.4%
% of load to front wheel	14%		16%		2%
Fuel capacity	19 l		66 l		247%
Engine power	36.7 kW		47.8 kW		30%
Take-off speed	35 km/h	40 km/h	35 km/h	40 km/h	0%
Max speed	120 km/h	120 km/h	120 km/h	120 km/h	0%
Cruising speed	80 km/h	70 km/h	110 km/h	95 km/h	37%
Rate of climb	2 m/s	1 m/s	4.5 m/s	3 m/s	260%
Take off dis.	40 m	60 m	30 m	50 m	27%



Figure 21: Test flight of the renewed JC-24

12 CONCLUSION

From this work, we can conclude that old aircraft and the other old machines can be renovated with proper analysis and the use of modern materials and current design methods. Modern materials and contemporary lighter engines even enable improving these machines and making them energy efficient. This can also be a significant benefit for the environment in the context of reusing them and preventing them to be sent to a scrapyards.

References

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- [5] **Weedhopper II**: Maintenance Manual, USA, 1982

Nomenclature

<i>ULA</i>	Ultralight aircraft
<i>JC-24</i>	Weedhopper II
<i>FAA</i>	Federal Aviation Administration
<i>CAD</i>	Computer-Aided Design
<i>FEM</i>	Finite Element Method
<i>LEXAN</i>	U.S. trademark, a polycarbonate resin