DRAFT OF DESIGN VARIANTS TO THE BASIC FRAME OF AN ULTRALIGHT HELICOPTER

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This thesis discusses several different design proposals of the basic support frame in an ultralight helicopter. The aim of the study is to define possible modifications of the original design and to meet dimensional requirements of the new engine, while maintaining or increasing the rigidity of the structure. Another objective is to create a new arrangement of the supporting frame structures to further increase rigidity and weight reduction. The study was conducted in the programming environment called Creo Simulation and ProMECHANICA Wildfire 5.0; using the idealization of the beam structures. The individual design proposals were evaluated in terms of stress, deformation, beam resultants and buckling stability. Computing knowledge application and mathematics solutions originate mainly from the elastic properties of the parts maintaining the buckling stability of centrally loaded beams. Centrally loaded beams are subjected to compressive loads of other beam structures. The conclusion is to describe the process of evaluation and selection of the most appropriate design frame structure in terms of the weight and stiffness ratio..

K e y w o r d s:Flexibility and strength, Beam structures, Simulation, rigidity, Airframe, Ultralight, Buckling, Design, Analysis, Stress von mises, Displacement, Beam resultant, Compressive stress, Computer analysis, Axis Variable torque, frame, weight, elasticity, Tensile Yield Stress, Tensile Ultimate Stress, Poisson’s Ratio, Young’s Modulus

1 INTRODUCTION

This paper discusses several design variations of the basic airframe in the ultralight helicopter. The analysis and presentation of the current structure in Helicopter DragonFly DFH 333/334 with Hirth F30.A2 engine is included. The aim of the study is to change the drive train and increase the rigidity of the structure. The new beam organization is proposed with respect to the space constrictions and the layout of the engine, as well as the seating arrangement of the crew sitting side by side. The research was conducted in programming environments PTC Creo (Pro Mechanica Simulation) and Pro Engineer Wildfire 5.0. The first chapter contains basic information about the material properties of the beam structures, definition of loading conditions, and contains overall analysis with a comprehensive table. Chapter 2 and 3 are related to modifications in the original design in terms of increased stiffness and structural changes of the engine, and the overall analysis of the buckling stability with analytical calculation. Chapters 4 and 5 cover newly designed structure including overall analysis of the new design. The conclusion includes review process and selection of the most appropriate design as well as the justification of this choice.

2 The basic structure of the supporting frame helicopter Dragonfly DFH 333/334 with engine Hirth F30.A2

Process of ideation and designing variants of basic airframe ultralight helicopter, was based on current construction design of Dragonfly helicopter DFH 333/334 with Hirth F30.A2 engine. Performing analyses of the named helicopter allowed to make a structural modification of the engine UL350iS (ULPower company).

Beams used in the design of the helicopter were made of chromium - molybdenum steel alloy 25CrMo4; with the following mechanical properties depending on the diameter size of particular components:

$d \leq 16mm$	Re = 700 MPa, Rm = 900 - 1100 MPa
$16<d\leq 40$	Re = 600 MPa, Rm = 800 - 950 MPa
$40<d\leq 100$	Re = 450 MPa, Rm = 700 - 850 MPa
$100<d\leq 160$	Re = 400 MPa, Rm = 650 - 800 MPa

Base material properties defined for structural analysis:

$E=2,1.10^5 MPa$;

$\mu=0,3$;

$\rho=7,9.10^{-9}\ ton/mm^3$. [9]

Weight of the whole helicopter as a basic computational model was generated as m=35.28 kg in the program.

2.1 Gripping and loading structures

Based on analysis of engineering designs and calculations, solving such a structure becomes a static problem. In order to introduce dynamic effects, we have doubled the force magnitude arising from the rotor thrust. This simulates the situation, while helicopter is at take-off. The magnitude of this force stated by the manufacturer is 560 kg. In addition, we have further increased the force value by multiplying it with factor of safety equal to 1.2.

$$F = (1{,}2 \cdot 2 \cdot 560kg) \cdot 10 = 13440N$$

Tensile force arising from the construction of the propeller thrust is thus the value of F = 13440N, and its direction and orientation is indicated in the Figure 1 at node No.1.

The structure is rigidly fixed at node No.2; specifically at the central mounting point of the power unit, as well as at the node No.3; which is the central point of the fuel tanks attachment and lastly at the node No.4; which is the central point of the cockpit attachment.

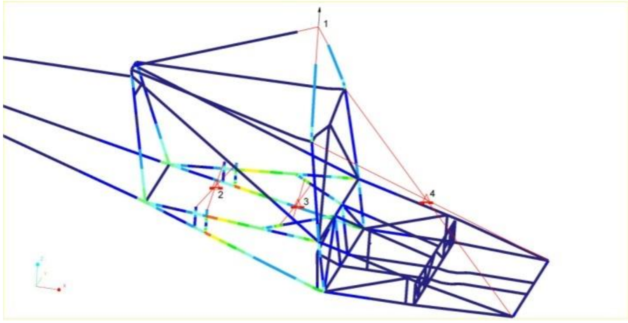

Fig. 1 Gripping and loading structures

2.2 Computer analysis of structures

2.2.1 Stress von mises and displacement analysis

When analysing the structure, Von Mises stresses were computed with values ranging from $2{,}379.10^{-16}$ to 467.7MPa. The largest concentration of tension loads occur around the sites of attachment to the power unit, as seen on the Figure 2. Since the maximum stress does not exceed the value of Re = 600MPa, and same states for the range of values Rm = 800-950MPa, support beam with diameter of 25.5mm (designed by manufacturer) is suitable and safe for use in the parts of the frame structure.

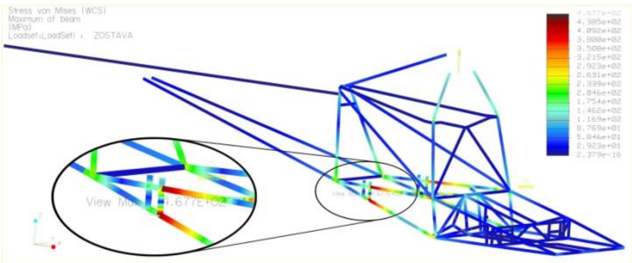

Fig. 2 Stress von mises

When analysing the displacement, we have observed that maximum deformation at the end of the helicopter tail has a magnitude of 26.24mm. It is an acceptable value,when taking to account the overall length of helicopter being nearly 3000mm. Figure 3 displaysboth deformed and unaffected structures of the model.

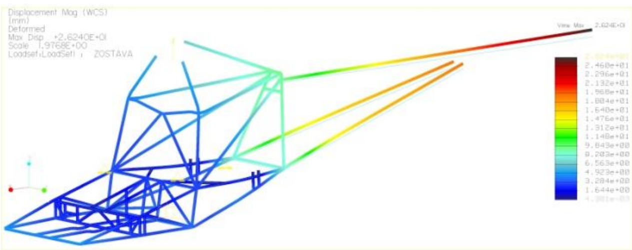

Fig. 3 Diplacement

2.2.2 Beam resultant analysis

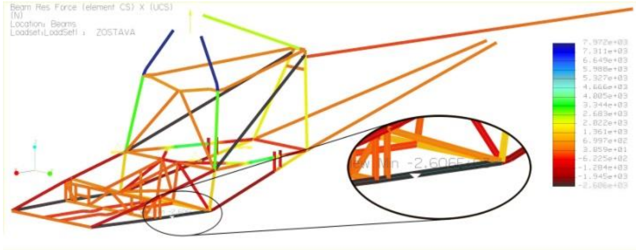

Fig. 4 Beam resultant

To achieve the most detailed evaluation involving extreme loadings is useful to examine the structure in terms of axial forces applied in beams. This analysis is needed to define input values for further examination of the most loaded member prone to buckling. This will determine whether beams lose stability at given dimensional parameters while applying maximum compressive stress. The variability in the beam resultant forces is shown in the Figure 4. Rods exposed to compressive forces have negative values, and vice versa beams loaded in tension are those of the positive values. The colour code for this analysis is inverted to better display rods exposed to compressive force.

2.2.3 Buckling analysis

Idealized computational models of parts in the assemblies are commonly used to locate the most stressed parts of structures in the preliminary studies. Later on are those parts modelled in the computations as rigid elementswithout idealization. This significantly reduces the computational time and usage of complex computer hardware, because it is not necessary to calculate the parts of structure being loaded by negligibly small load. Even though the resulting values do not exceed the allowable stress is suitable for the safety check up on the buckling load of the beam and analytical calculations. According to the analysis of the effect of axial forces on the rod, the largest impact is caused by compressive stresses as indicated in Figure 4.

2.2.3.1 Analytical calculation of buckling stability

In order to define buckling stability and also to control buckling of rods,we have selecteda mean reduced length as follows:

$$l_r = 0{,}8 \cdot l. \qquad [2]$$

$F = 2606N$

$l = 442mm$

$l_r = 353{,}6mm$

$D = 25{,}5mm$

$d = 23{,}5mm$

$E = 2{,}1 \cdot 10^5 MPa$

The area on which the force F:

$$S_D = \frac{\pi \cdot D^2}{4} = 510{,}7mm^2$$

$$S_d = \frac{\pi \cdot d^2}{4} = 433{,}736mm^2$$

$$S = S_D - S_d = 76{,}969mm^2$$

Axis Variable torque:

$$J_x = \frac{\pi \cdot D^4}{64} - \frac{\pi \cdot d^4}{64} = 5784{,}7mm^4$$

The critical buckling force:

$$F_{kr} = \frac{\pi^2 \cdot E \cdot J_x}{l_r^2} = 95890{,}501N$$

Critical compressive stress:

$$\sigma_{kr} = \frac{F_{kr}}{S} = 1245{,}832MPa$$

Checking the slenderness ratio:

Euler's equation for the area of the shock absorber is valid for slenderness $\lambda \geq \lambda_{terminal}$. For chromium-molybdenum steel alloy, following constant may be considered $\lambda_{terminal} = 100$.

$$\lambda = \frac{l_r}{i_x} = 40{,}787$$

$$i_x = \sqrt{\frac{J_x}{S}} = 8{,}669$$

Calculated slenderness ratio of the rod does not meet the condition for elastic buckling area, hence it is not possible to use the Euler method for this case. It is necessary to introduce theJasinski-Tetmajermethod, where the calculation of the critical load relationship includes:

$$|\sigma_{kr}| = a - b \cdot \lambda = 331{,}039MPa$$

the values of coefficients for steel [1]

a = 464, b = 3,26

Stress in struts strained must meet the condition:

$$|\sigma| \leq |\sigma_D| = \frac{\sigma_{kr}}{k}$$

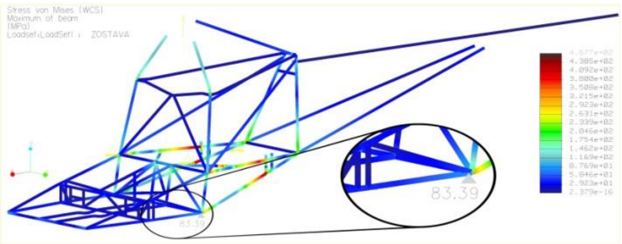

Fig. 5 Max. value of the stress on beam

Maximum value of the stress acting on beam isshown in the zoomed in section of the Figure 5.Maximum tress generated in a given rod has a value of σ=83.39MPa:

$$|\sigma| = 83{,}39MPa \quad |\sigma_D| = \frac{\sigma_{kr}}{k} = 165{,}515MPa$$

$$83{,}39MPa \leq 165{,}515MPa$$

The results prove that the resulting maximum stress does not exceed the permissible magnitude and therefore the beam dimensions are satisfactory and no change is required.

Tab. 1

	Value
Weight [kg]	35,28
Max. stress von mises [MPa]	467,7
Max. displacement [mm]	26,24
Beam resultant (min./max.) [N]	-2606 / 7972

Using the same methods of computation were analysed another two design solutionsinitiating modifications of original construction, as well as two new design proposals, while preserving the engine dimensions.

3 New Design Proposals

3.1 The construction of the basic supporting frame of Dragonfly DFH A 333/334 helicopter with adjustment accommodating changes in engine, draft No. 1

Due to the requirements for engine modifications, which involve changing the shape, size and location of fuel tanks and other components, it was necessary to change the shape of several beams in the structure. Modified beams are marked red on a perspective view in Figure 6.

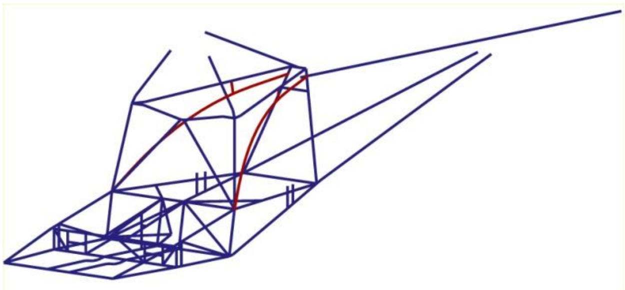

Fig. 6 A perspective view of the basic structure

These design modifications didn't cause any significant changes in resulting values of individual analyses, which could jeopardize the safety of the structure. Following table shows a comparison of the results from the original and newly proposed constructiondesign.

Tab. 2

	DFH A 333/334	Construction No.1
Weight [kg]	35,28	35,33
Max. stress von mises [MPa]	472,7	456,6
Max. displacement [mm]	26,53	28,22
Beam resultant (min./max.) [N]	-2627 / 7971	-3945 / 7973

3.2The proposal of the changes in primary structure by increasing the stiffness and organization of rods, design No. 2

In terms of increasing the rigidity of the original design with minimal increase in weight, it was necessary to change the alignment angle of the main supporting beams carrying the tensioning rotor (Fig. 7). The load needs to get transferred to the nodes, where it can be distributed more evenly.

It is known from previous analysis that the greatest concentration of stresses occurs in the storage location of the motor unit. Frame was stiffened by additional rod, in order to increase the rigidity of this section. The diameter of the rod was elected to have an outside diameter of 19 mm in the first case scenario, but have failed the buckling stabilityinspection. In the second scenario was an outside diameter of rod adjusted to 30 mm. The results of this analysis were then compared with the results of analyses of the original structure. It has been found that new design modification increased the weight by 3.26 kg.It results in reduction of loading stresses by 66% and decrease in maximum deformation by 76%.

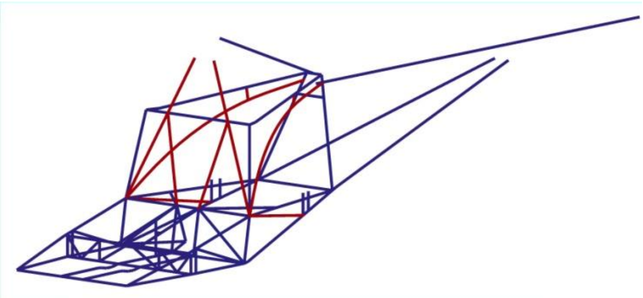

Fig. 7 A perspective view of the structure No.2

Tab. 3

	DFH A 333/334	Construction No.2
Weight [kg]	35,28	38,54
Max. stress von mises [MPa]	472,7	163,3
Max. displacement [mm]	26,53	6,29
Beam resultant (min./max.) [N]	-2627 / 7971	-5233 / 7022

3.3Proposal for a different construction solution of an ultralight helicopter No. 3

For further increase in rigidity of the structure, it was necessary to create a new proposal to change the position of the main supporting structure at connecting nodes (Fig. 8). This proposal was based on the assumption that shifting location of carrier nodes to the lower part of the structure and closer to the longitudinal plane will have a favourable impact on its stiffness. It was possible to reduce the number of supporting rods with a diameter of 25.5 mm, thus reducing its weight by 1.91 kg. Subsidiary rodswerechosen to have 19 mm diameter. Space intended for UL350iS power unit remained unchanged, same as well as helicopter tail section. The most important and effective innovation in the new design proposal is an arrangement of rods in the middle section of the helicopter, located between the backrest of the crew and a compartment of the power unit. In this section are located two out of the three main supporting rods, carrying the load from the main rotor. These supporting rods were designed to go along the axis of the shaft towards bearing nodes, and are located at the bottom section of the helicopter structure.This new design proposal compared with the original design has reduced weight and the best results from overall analysis. It results in reduction of loading stresses by 57% and decrease in maximum deformation by 88%.

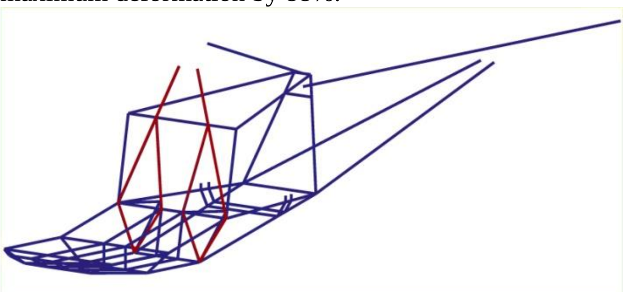

Fig. 8 A perspective view of the structure No.3

Tab. 4

	DFH A 333/334	Construction No.3
Weight [kg]	35,28	32,8
Max. stress von mises [MPa]	472,7	205,2
Max. displacement [mm]	26,53	2,95
Beam resultant (min./max.) [N]	-2627 / 7971	-1086/2618

4CONCLUSION

The aim of this work was to propose an innovative design to the original construction design as well as proposal of several different custom designs of two-seater ultralight helicopter.The most advantageous proposal is No. 3, due to its lightweight of 33kg and ability to sustain stresses without reaching maximumstress of 205.2MPa. This construction design has optimized both the ratio of mass and rigidity of the structure. With such a significant increase in stiffness we can consider using other materials with lower strength and mass, which would result in a further reduction in weight of the structure. It may lead also to reduction in production costs, since such materials are also usually more affordable. If the material remains the same, there are other ways how to add weight. These calculations and computer simulations are only used with idealized elements. Since actual operating conditions (when taking to account other influences such as processing quality of construction joints, aerodynamic effects, effects of rotor balancing, etc..) will undoubtedly vary, is therefore necessary to simulate such conditions on the real model of a helicopter.

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