DESIGN AND IMPLEMENTATION OF A MODULAR LATTICE STRUCTURE OF THE BASIC FRAME OF AN UNMANNED AERIAL VEHICLE

Peter Samsely - Karol Semrád - Jozef Hudák

This article deals with a structure design of a modular unmanned aerial device (UAD), which allows building of various unmanned aerial vehicles (UAV), differing in number of rotors, bearing capacity, manouverability etc. This can be done using the same construction parts. Structure design consists of two basic parts (base and arm), to which additional construction parts are tied. These secondary parts can sipmly be modified as needed for building of specific configuration. Structure design has been created and analysed in the enviroment of 3D CAD system CREO. Basic structural analysis has also been executed by CREO CAE module SIMULATE. Theoretically (by a calculations in CAE module SIMULATE) a weight and bearing capacity has been verified for all of its configurations. When defining analysis, different materials has been taken into account for functional specimen (ABS plastic) and for final UAV (titanium). As a production method (3D printing) demonstrator, a 1:2 scaled model has been manufactured.

K e y w o r d s: multicopter, lattice construction, arm, base

1 INTRODUCTION

Multi rotor unmanned aerial vehicles of helicopter type represent, in these days, a topic, where apparently nothing new can be done or thought of. But there always are new thoughts and ideas that can improve known types and configurations of such UAVs by decreasing their weight (increasing bearing capacity) or improving their practical usage, modularity etc. At the Department of Aviaton Technical Studies at Faculty of Aeronautics at Technical university in Košice, this is one of the research tendencies. Problem of creating modular structure capable of creating three mostly used UAV configurations, has been solved as a main theme of one of diploma thesis.

2 REQUIREMENTS FOR MULTICOPTER BASED UAV

The first and the most important of requirements for mulricopter based UAV is ist modularity. This means that it is necessary to take the unification of the construction parts as far as possible. When talking about unification for more configurations, we specifically mean three of them: tricopter, quadrocopter and hexa copter (three, four and six rotor configuration). The biggest challenges in this sphere is represented by different number of rotors (which need their own arms – mounts) and when constructing a tricopter it is a control system, because at least one arm (motor mount) needs to be rotary.

Another, not less important requirements are that for adequate bearing capacity and for flight qualities of the vehicle. From these requirements directly result the need for constructing modular UAV – different configurations have different flight qualities, that satisfy needs for different flight tasks. For example while tricopter has a lower weight and worse stability, it excels in manouverability.

Stiffness requirement flows not only from structure design itself, but also from construction material. As a material for main construction parts a titanium alloy (Ti-6Al-4V) has been chosen, mainly because its low weight in relation to its very high stiffnes and stregth and also because we´re able to use this material for 3D printing. Disadvantage of titanium alloy is its very high price and that it is very hard to machine. Due to these reasons, as a material for functional specimen, ABS plastic has been chosen. Since the mechanical properties of ABS plastic are far worse then thos of titanium, the functional specimen will only serve for verification of basic functionality and flight qualities.

3 STRUCTURAL DESIGN

As mentioned before, structure design and all of its parts has been created and analysed using 3D CAD system CREO. This system has been chosen mainly because its availability at Technical university in Košice and author´s previous experience in using this system.

3.1 Construction parts

Structure design of modular UAV consists of these construction parts: base, arm, fixed arm ending, rotary arm ending, rotary arm ending adapter, base cowling, base board and landing gear leg. Base and arm can be labeled as a main construction parts, because they are used in same form in all configurations. The others can be labeled as secondary since they can be easily modified or replaced depending on UAV configuration, or they are not necessary for flight.

Base represents a thin-walled construction, to which arms, landing gear legs, base cowling, and base board are attached. It is also a part of construction, that carries loads trasnmitted from all other construction parts. Its inner area serves as a compartment for control electronics and sensors. When assembling a three or six rotor configuration, arms are attached through segment gripping on one side of the base, the other is used for attachement of landing gear legs and base board (Figure 1). When assembling four rotor configuration, base is simply flipped on the other side (Figure 2) where there are grippings in correct angular position (90 degrees between the grippings). That way base can be used in unchanged form for all UAV configurations.

Figure 1. Base (side with six segment grippings)

Figure 2. Base (side with four segment grippings)

Arm is a lattice construction, which on one side is attached to the base and secured in position by base cowling, and on its other side there is a slot for fixed ending or rotary ending adapter attachment. Arm (as well as base) is used for all UAV configurations. In the arm construction, there´s a cutout for servomotor for actuation of rotary arm ending.

Figure 3. Arm

Figure 4. Slot for fixed arm ending attachment

Fixed arm ending is a secondary construction part. It is fixed to the arm through a slot and secured in position by two screws. This part is used for four and six rotor configuration, when it is not necessary change the position of the rotor.

Figure 5. Fixed arm ending

Rotary arm ending (Figure 6) is similar to the previous construction part. It differs in way of attachment to the arm and it also has a gearing in its upper part. For its rotary attachment to the arm, another construction part ist necessary – rotary ending adapter. Adapter is attached to the arm the same way as a fixed ending. It has a circular slot, to which fits and attaches a slot on a rotary arm ending. Movement of a rotary arm ending (Figure 8 and 9) in this slot causes a formation side thrust component. This force is esential for compensating reaction moment of the third rotor of three rotor configuration.

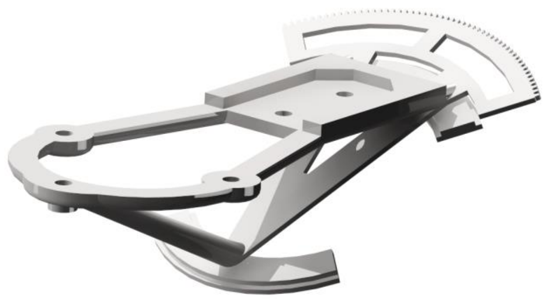

Figure 6. Rotary arm ending

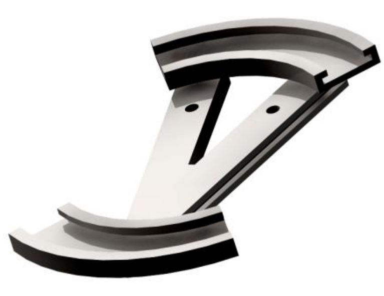

Figure 7. Rotary arm ending adapter

Figure 8. Rotary arm ending in neutral position

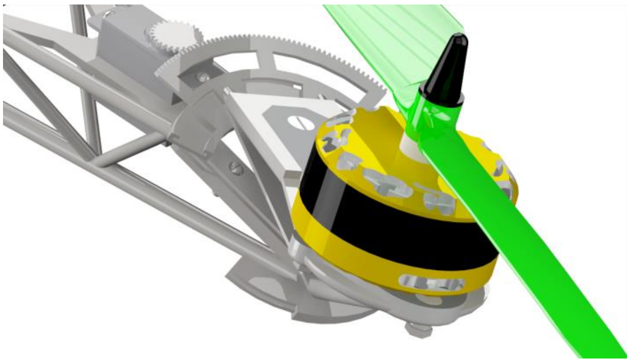

Figure 9. Rotary arm ending in extended position

Landing gear leg is a lattice construction, serving as a „link“ for transmitting loads to the base and as a impact absorber during hard landings. For this reason leg is intently designed as unstable. This means that we expect large elastic deformations for this construction part. This is also a construction part, that is expected to colaps as first during the hard landing. Its function is therefore to protect other parts of construction from destruction, mainly those that are essential for flight. It is screwed directly to the base.

Figure 10. Landing gear leg

Base cowling serves, besides the protection of base inner compartment and improving aerodynamic characteristics, mainly as a mean for securing arms in position. It is also screwed directly to the base.

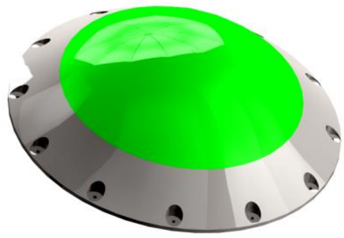

Figure 11. Base cowling

3.2 Configurations

Tricopter is the most manouverable from all configurations, but at the same time it has the lowest bearing capacity. For designed arangement of motor and propeler and calculated weight of the titanium construction, its aproximate maximum bearing capacity is 1 kg (equipment necessary for flight as battery, motors and electronics has been taken into account). Particularity of this configuration against regular tricopters is, that all three rotors are movable. That decreases deflection necessary for one rotor to compensate the reaction moment of the third rotor and simultaneously stress occuring in the rotary arm ending.

Figure 12. Tricopter

Figure 13. Tricopter

Quadrocopter is the most commonly used configuration for this type of UAV. It represents the compromise between bearing capacity, stability and manouverability. Aproximate calculated weight of the titanium quadrocopter is 3,5 kg.

Figure 14. Quadrocopter

Figure 15. Quadrocopter

Hexacopter has of all configurations biggest bearing capacity, but worse manouverability. For its stability it is the most appropriate configuration for tasks such as aerial photography. Its aproximate calculated weight is 4 kg (for titanium).

Figure 16. Hexacopter

Figure 17. Hexacopter

4 MODEL REALIZATION

As for demostration of production technology of 3D printing, a 1:2 scaled model of the UAV has been manufactured. In regard to the material used for model printing (soft plastic that does not have defined mechanical properties) and model scaling, it is not possible to used this model for flight or load tests. Principle of 3D printing plastic models sustains in spraying thin layers of liquid plastic, that are then hardened by light radiation. Such plastics are called photopolymers. 3D printing of titanium models works on similar basis, but instead of liquid polymers, very soft titanium dust is sprayed in thin layers and then hardened by laser beam.

3D printer used for model manufacturing is able to print models up to 260 milimeters long, 260 milimeters wide and 200 milimetres tall (dimensions of baseplate and limited height). In case of exceeding of these dimensions it is possible to manufacture the model by parts and then glue the parts into the final product. This printer works with the resoultion of 600x600x1600 dpi and sprays the layers only 16 μ thick. The thinest wall that the printer is able to create is only 0,6 milimeter thick. As mentioned printer sprays layers of liqiud polymer hardened by light. It can create models from different types of materials, depending on desired properties of final product (transparent or opaque plastic, rubber-like materials etc.).

Figure 18. 3D printer used for model manufacturing[1]

[1] Available on internet: http://commons.wikimedia.org

5 CONCLUSION

Main requirement for this structural design, its modularity, has been ensured at high level, due to fact that two main construction parts can be used for all UAV configurations. That allows to build the specific configuration, depending on demands of flight task.

Two different materials are considered for manufacturing of the UAV. One of them is ABS plastic, mainly because its small weight and price, but its mechanical properties will only be sufficient for functional specimen (not for fully loaded UAV). For final product titanium alloy is taken into account, which is heavier, despite that it allows to carry quite heavy payload. Also mechanical properties of titanium are incomparably higher than those of ABS plastic.

Another problems and improvement needs will be shown by practical flight tests of the UAV. For example it will be necessary to focus on solving the technology of machining the contact and sliding surfaces, or eventually their manufacturing from appropriate materials (moulding contact plates into the construction etc.)

BIBLIOGRAPHY

[1] Available on internet:<http://www.himodel.com/>
[2] Available on internet:<http://www.fortus.com/>
[3] Available on internet:<http://asm.matweb.com/>
[4] Available on internet: <http://commons.wikimedia.org>
[5] Dostupné na internete: <http://ceit-ke.sk/>
[6] ZAHRADNÍČEK, Rudolf – SEMRÁD, Karol: Pružnosť a pevnosť II. Košice: Technická univerzita v Košiciach, Letecká fakulta, 2007. 140s. ISBN 978-80-8073-927-0.
[7] MORAVČÍK, Milan – DEMJAN, Ivo – TOMKO, Michal: Statika stavebných konštrukcií 1: Staticky určité prútové konštrukcie. Košice : TU, 2005. 126s.
[8] MORAVČÍK, Milan – DEMJAN, Ivo – TOMKO, Michal: Statika stavebných konštrukcií 2: Staticky neurčité prútové konštrukcie. Košice : TU, 2009. 300s.
[9] SHIGLEY, Joseph – MISCHKE, Charles – BUDYNAS, Richard: Konstruování strojných součástí. Brno : Vysoké učení technické v Brně / Nakladatelství VUTIUM, 2010. 1160s. ISBN 978-80-214-2629-0
[10] BURÁK, Ján – OSTERTAG, Oskar: Základy projektovania konštrukčných prvkov pomocou metódy konečných prvkov. Košice : Vydavateľstvo Elfa, 2010. 320s. ISBN 978-80-8086-137-7
[11] KOMPAN, František – BARTOŠ, Zdeněk – FABIANOVÁ, Anna: Technická mechanika. Bratislava : Vydavateľstvo Príroda, 1990. 384s. ISBN 80-07-00269-3
[12] HUTTON, V.: Fundamentals of finite element analysis. New York: McGraw – Hill Companies, Inc., 2004.
[13] IVANČO, V. – KUBÍN, K. – KOSTOLNÝ, K.: Metóda konečných prvkov. Košice. 1994.
[14] SAEED, Mohammadi: Extended Finite Element Method. Blackwell Publishing Ltd., 2008.
[15] ZIENKIEWICZ, O. – TAYLOR, R.: The finite element method, volume 2: Solid mechanics. Butterworth-Heinemann, 2000.
[16] DRAPER, J.: Modern metal fatigue analysis. EMAS Publishing, 2008. ISBN 0947817794
[17] STEPHENS, Ralph – FATEMI, Ali – STEPHENS, Robert – FUCHS, Henry: Metal fatigue in engineering. Wiley Interscience, 2001. ISBN 0-471-51059-9
[18] CHEN, W.: Principles of structural design. Taylor & Francis, 2009.

AUTHOR ADDRESS

Bc. Peter Samsely, Ing. Karol Semrád, PhD., doc. Ing. Jozef Hudák, CSc., Department of Aviation Technical Studies, Faculty of Aeronautics, Technical University in Kosice, Rampova 7, 041 21 Kosice, Slovak Republic