UDK: 623.466.3:621.7:620.192.30.3
COSATI: 11-04, 20-12

Structural Analysis and Static Strength Testing of a Tactical Unmanned Aerial Vehicle

Stevan Maksimović[1)]
Ivana Ilić[1)]
Dragutin Georgijević[1)]
Zoran Vasić[1)]
Marko Bojanić[1)]
Vanja Stefanović[1)]

This paper gives a short summary of the structural analysis and static strength testing results of specific structural parts of an unmanned aerial vehicle (UAV). The UAV was mostly made of composite materials. The main attention was given to the structural analysis of the elements of the horizontal and vertical tails of the UAV. The structural analysis (based on the Finite Element Method) results were compared with the experimental results (displacement and stress state). Good correlation was achieved.

Key words: **unmanned aerial vehicle, aircraft structure, composite materials, static strength, structural analysis, finite element method, experimental testing.**

Introduction

IT is well-known that unmanned aerial vehicles can be used for both civilian and military purposes. In both cases, one of the main goals is to get minimal weight. Since composite materials provide a very good strength-to-weight ratio, they are often used in aircraft structures [1-5]. Structural analysis and testing of a composite wing for an ultralight UAV was considered by Sulliwan et. all. [2]. Structural integrity of the some composite parts is checked by employing the Tsai-Wu failure criterion [3-8].

Fig.1 shows a tactical UAV whose structural elements were considered in this paper.

Figure 1. Tactical UAV

Static strength testing was performed for proof and ultimate load conditions. The results presented here will be given without detailed descriptions of how they were acquired (both analytical and experimental).

The verification testing of the structural elements was preformed after the structural analysis and before the serial production.

Specimens for verification testing must be produced in accordance with the original part documentation. The features that do not affect the stress capabilities of the part in question can be eliminated for the specimens. Other features can be replaced with constructions that imitate the original part and are used to adequately introduce loading into the structure.

Despite advances in materials and technologies as well as in strength analysis methods in modern software, the importance of experiments is not reduced. This is true for common materials as well as for new materials and technologies. When performing a sturctural analysis, we rely on an abstract mathematical model which represents the best aproximation of a physical problem. All mathematical models are idealised by intoducing simplifications in order to create a model that can be analyzed. Because of these inherent problems of a structural analysis, testing and experiments still give most accurate results.

[1)] Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade, SERBIA

Structural Analysis of the UAV

The structural analysis results of the UAV tail beam made of composite materials are shown in this chapter. This structure is modeled using FEM shell elements in order to obtain maximal displacements at the connection point of the horizontal tail. The FE mesh is shown in Fig.3.

Figure 2. Finite Element Model of the UAV tail beam

The structural analysis was done using the software package MSC/NASTRAN [9] with the equivalent modulus of elasticity E_{eq} = 30000 MPa and the plate thickness t = 1.7 mm. The equivalent modulus of elasticity can be determined through experiments or an analytical method based on the mechanical characteristics of each composite ply.

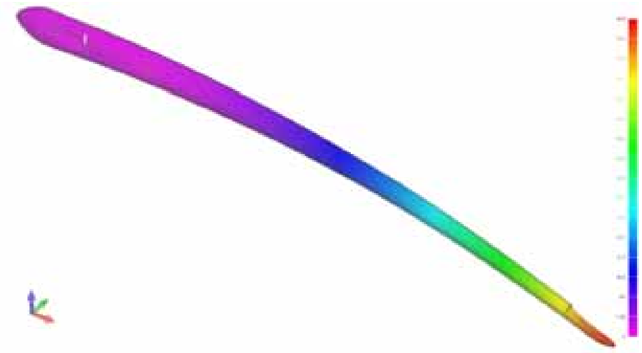

Figure 3. Tail beam displacements (w_{max}=84.83 mm), j=1.0

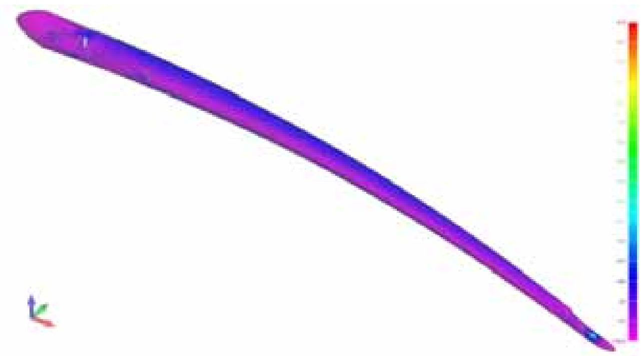

Figure 4. Tail beam stresses - Von Mises=242.9 MPa (j=1.0)

Figure 5. Tail beam displacements (w_{max}=93.32 mm), j=1.1 (55daN)

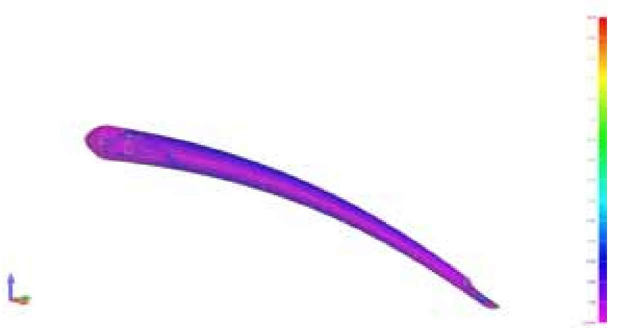

Figure 6. Tail beam stresses j=1.1 (55daN), Von Mises=26.69 hbar

During the structural analysis, Von Misses stress criterion is used for the strength check of the isotropic materials, and Tsai-Wu failure theory is employed for composite materials.

Experimental Static Testing

The structural elements of the UAV were tested for proof and ultimate loading conditions. The deflections were measured at representative locations.

Fig.7 shows the disposition of global static strength experiments for UAVs. The deformations and stresses are measured through the system of strain gages. Special attention was dedicated to the deformation measurement of this structure.

Figure 7. Static strength testing of UAVs

The testing for one case load is done in accordance with the procedure in Fig.16, where the load factor is given on the diagram ordinate. The first step in all tests is to introduce a small load into the structure so that it can "settle" (annulment of gaps between the system elements). After the settling, the proof load testing is performed for the load factor of j=1.1 and the stresses and displacements on the previously determined positions on the structure are recorded. For a structure to pass the proof load test, it is necessary that it has no residual stresses or deformations after load relaxation (no plastic deformations).

The ultimate load test is performed after the proof load test. The load factor for the ultimate load test is j=1.5. For a structure to pass the ultimate load test, it is necessary that it has no failure (plastic deformations are allowed).

If a structure passes both tests, the load factor is raised until effective failure is reached in order to determine the margine of safety.

The forces for a simmetrical load case (j=1) are:

- on the horizontal tail
- Rz = 962 N downward, andon the vertical tails
- Ry = 126 N outward.

Stresses are measured at 14 positions with strain gages -

rossetes (0^o, 45^o, 90^o), and displacements at 16 positions with electronic sensors.

The disposition of the stain gages is shown from Fig.8 to Fig.12, and the displacement senzors are shown from Fig.13 to Fig.15.

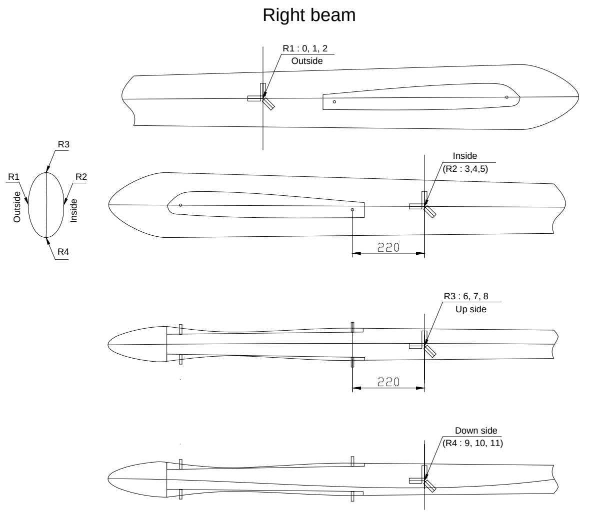

Figure 8. Disposition of the stain gages on the right beam

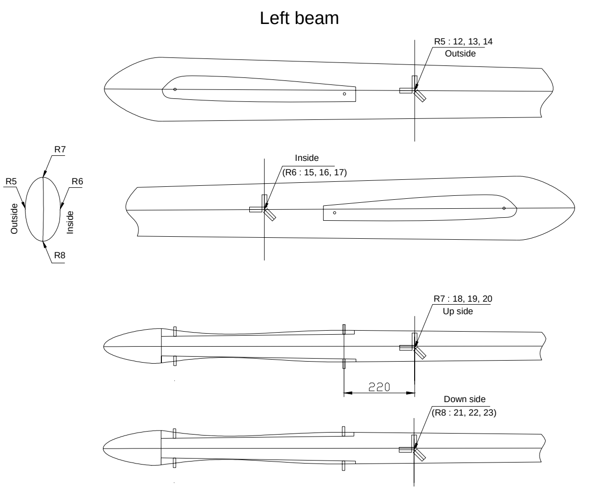

Figure 9. Disposition of the stain gages on the left beam

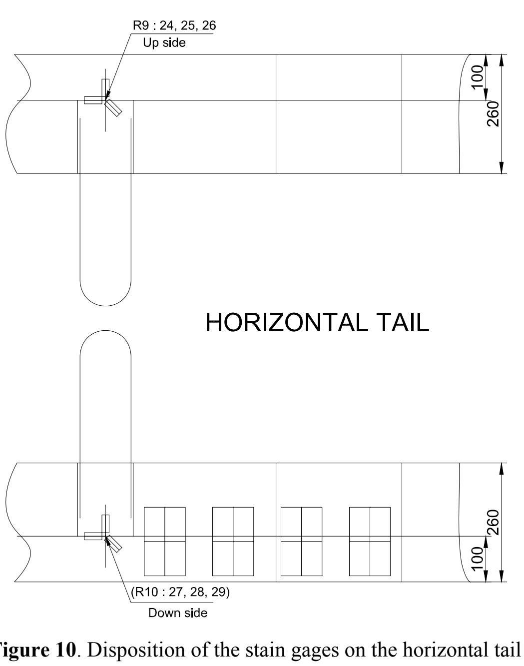

Figure 10. Disposition of the stain gages on the horizontal tail

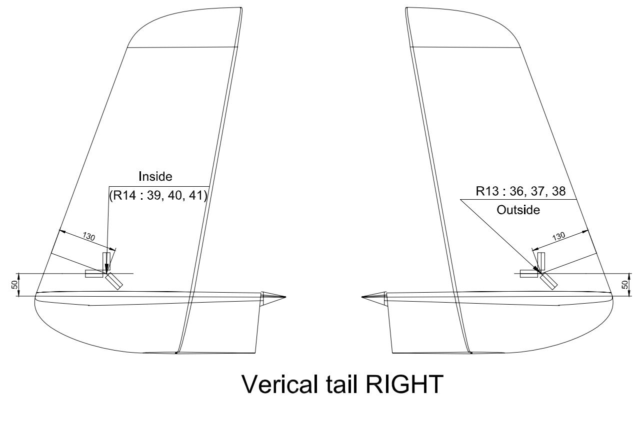

Figure 11. Disposition of the stain gages on the right vertical tail

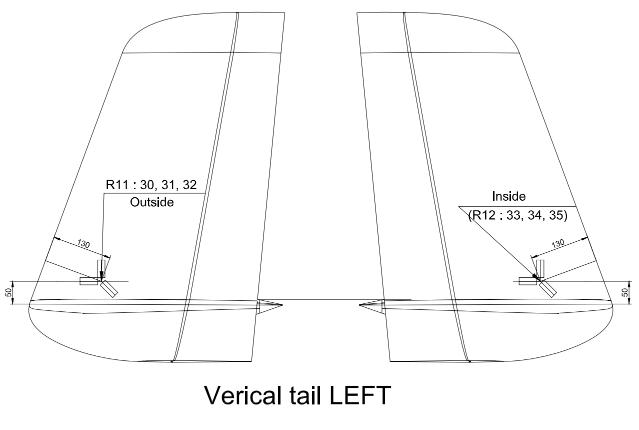

Figure 12. Disposition of the stain gages on the left vertical tail

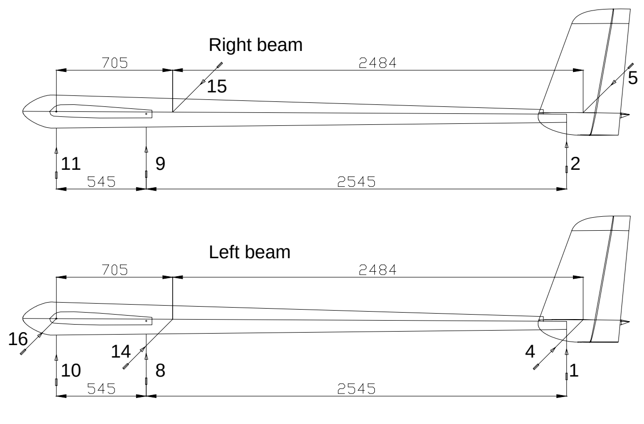

Figure 13. Sensor displacements on the beams

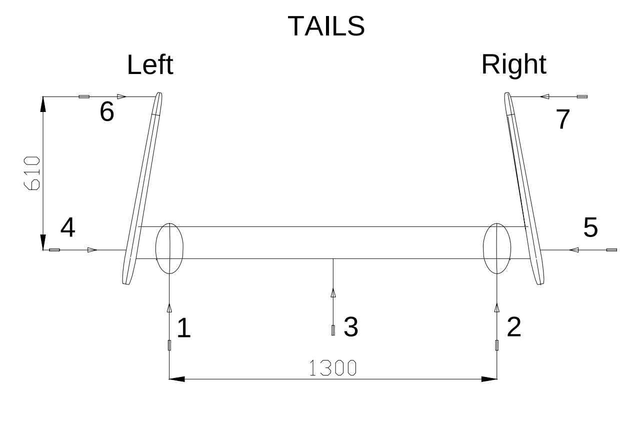

Figure 14. Sensor displacements on the horizontal and vertical tails

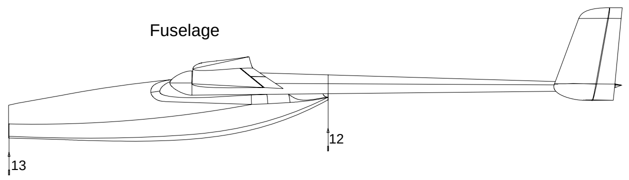

Figure 15 .Sensor displacements on the fuselage

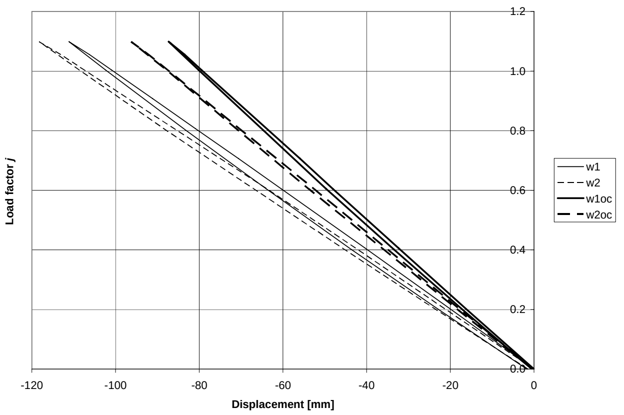

Figure 16. Vertical displacements on measuring positions 1 and 2 (cleaned)

Fig.16 shows the experimentally determined displacements for the load factor *j*=1.1 on measuring positions 1 and 2 (according to Figures 13 and 14).

Comparison of the Results of the Structural Analysis with the Experiments

The diagram in Fig.16 shows the deflection results for a symmetrical load case with the load factor *j*=1.1. The maximum value for deflections using the FEM is W_{MKE}=84.8 mm, while the experimental results give W_{exp}=81.9 mm. The maximum values of stresses at locations R7 and R8, Fig.9, are determined: 44 MPa and 47 MPa by finite elements, and 48 and 52 by the experiment. A good correlation of the results is achieved between the structural analysis and the experiment.

Conclusions

This paper shows the results of the structural analysis and the experimental testing of the static strength of the tactical UAV composite structure. Complete tests were performed for proof and ultimate load cases for symmetrical and nonsymmetrical load cases. For the comparison of the structural analysis and the experiment, only the symmetrical load case and the proof load case were considered in this paper. A good correlation between the structural analysis and the experimental results was achieved.

Acknowledgment

This work was partially financial supported by the Ministry of Science and Technological Development of Serbia under Projects OI 174001.

References

[1] MAKSIMOVIĆ,S.: *Some Aspects of Application and Experimental Verification of Construction made From Composite Materials*, Application of Modern Materials in Technology and Constructions Primena Savremenih Materijala u Tehnologijama i Konstrukcijama, Požarevac, 2012, pp.19-28.

[2] SULLIVAN,R.W., HWANG,Y., RAIS-ROHANI,M., LACY,T.: *Structural Analysis and Testing of an Ultralight Unmanned-Aerial-Vehicle Carbon-Composite Wing*, Journal of aircraft, May–June 2009, Vol.46, No.3.

[3] FRULLA,G., CESTINO,E.: *Design, manufacturing and testing of a HALE-UAV structural demonstrator*, Composite Structures 2008, 83 pp.143–153.

[4] GÜRDAL,Z., HAFTKA,R.T., HAJELA,P.: *Design and Optimization of Laminated Composite Materials*, John Wiley and Sons Inc. 1999.

[5] ILIĆ,I.: *Numerical Simulation of Composite Structure Failure in the Areas of Geometric Discontinuities*, Scientific Technical Review, ISSN 1820-0206, 2008, Vol.LVIII, No.2, pp.32-37.

[6] VASOVIĆ,I.: *Strength Analysis of Filament Wound Composite Tubes*, Hemijska industrija, 2010, Vol.64, No.3.

[7] MAKSIMOVIĆ,S.: *Failure analysis of layered composite structures: Computation and Experimental Investigation*, 16th European Conference of Fracture, ECF 16, Alexandroupolis, Grčka, 2006.

[8] TSAI,S.W., WU,E.M.: *A general theory of strength for anisotropic materials*, J. Comp. Mater, 1980, Vol.5, pp.58-80.

[9] Msc/NASTRAN Theoretical Manual.

Received: 10.02.2013.

Strukturalna analiza i eksperimentalno ispitivanje čvrstoće strukture taktičke bespilotne letelice

U radu je dat kratak prikaz rezultata strukturalne analize i ispitivanja statičke čvrstoće pojedinih delova strukture taktičke bespilotne letelice (TBL). Struktura letelice je urađena dominantno od kompozitnih materijala. Primarna pažnja je usmerena na strukturalnu analizu greda/nosača horizontalnog i vertikalnih repova kod bespilotne letelice. Upoređeni su rezultati strukturalne analize na bazi korišćenja Metode Konačnih Elemenata (MKE) u pogledu pomeranja i naponskih stanja za simetričan slučaj opterećenja sa eksperimentalnim rezultatima. Dobijena su dobra slaganja rezultata proračuna sa eksperimentalnim rezultatima.

Ključne reči: **bespilotna letecica, struktura letekice, kompozitni materijali, statička čvrstoća, strukturna analiza, metoda konačnih elemenata, eksperimentalno ispitivanje**

Структурный анализ и экспериментальные проверки прочности конструкции тактического беспилотного летательного аппарата

В данной работе представлен краткий обзор результатов структурного анализа и испытаний статической прочности определённых частей структуры тактического беспилотного летательного аппарата (БЛА).Конструкция самолёта выполнена преимущественно из композитных материалов. Основное внимание сосредоточено на структурном анализе луч / балки горизонтального и вертикального хвостов БЛА. Мы сравнили результаты структурного анализа, основанного на использовании метода конечных элементов (МКЭ) с точки зрения перемещения и стрессовых состояний для симметричных случаев нагрузки с экспериментальными результатами. Результаты показывают хорошее совпадение результатов расчёта с экспериментальными результатами.

Ключевые слова: **беспилотный летательный аппарат, структура беспилотного летательного аппарата, композитнные материалы, статическая прочность, структурный анализ, анализ методом конечных элементов, экспериментальная проверка.**

Analyse structurale et l'examen expérimental de la résistance de structure de l'aéronef tactique sans pilote

Dans ce papier on donne un aperçu contenant les résultats de l'analyse structurale et de l'examen de la résistance statique de certaines parts de la structure de l'aéronef tactique sans pilote. La structure de l'aéronef a été faite principalement en matériaux composites. L'attention a été prêtée à l'analyse structurales des poutres / porteurs des queues verticales et horizontales chez l'aéronef sans pilote. On a comparé les résultats de cette analyse structurale basée sur l'emploi de la méthode des éléments finis (MEF) quant au déplacement et aux états de tension pour le cas symétrique de la charge avec les résultats expérimentaux. On a obtenu un bon accord entre les résultats de computation et les résultats expérimentaux.

Mots clés: **aéronef sans pilote, structure d'aéronef, matériaux composites, résistance statique, méthode des éléments finis, essai expérimental.**