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NUMERICAL FEM ANALYSIS FOR THE PART OF COMPOSITE HELICOPTER ROTOR BLADE

Hubert Dębski

Lublin University of Technology, Department of Machine Design
Nadbystrzycka Street 36, 20-618 Lublin
tel.: +48 538 42 01
e-mail: h.debski@pollub.pl

Monika Ostapiuk

Lublin University of Technology, Department of Materials Engineering
Nadbystrzycka Street 36, 20-618 Lublin
tel.: +48 538 42 11, fax: +48 538 42 14
e-mail: m.ostapiuk@pollub.pl

Abstract

Composites are a group of materials applied more extensively in aviation constructions. Their good physical-chemical and mechanical properties, and particularly from the ratio of strength to low density give a dominant place for applying in thin- walled constructions as a load carrying-capacity structure. One of the most effort parts of the helicopter is the thin-walled structure of rotor blade. The numerical calculations are a very helpful tool for solutions and analysis of materials. In this paper was presented the preliminary analysis of the effort of composite materials. Then it was possible to identify the region where is the high risk of failure in load- carrying capacity structure. The numerical tool applied to the analysis was the ABAQUS/Standard program. The estimation of the level of effort in the composite materials in the performed studies were the maximum stress criterion, the Tsai-Hill criterion, the tensor Tsai-Wu criterion and the Azzi-Tsai-Hill criterion. The mechanical properties required for analysis were performed in the way of experiments way, according to the standard specifications for this type of materials. FEM analysis was shown the effort elements of the construction, where were the highest level of tension stresses.

Keywords: *glass/epoxy composite, FEM analysis, thin- walled structure, strength*

1. Introduction

What designing modern aviation structures impose on designers is the need to apply contemporary materials with very strict strength and stiffness requirements [1, 2]. It concerns mainly thin-walled load-carrying elements, which are exposed to very complex exploitation load. The group of materials which are applied more extensively in aviation constructions is constituted by polymer composites – laminates and sandwich type structures. It results primarily from their high physical-chemical and mechanical properties, and particularly from the ratio of strength to low density in the composite material. Also the high level of advancement in the technology of polymer composite shaping (autoclave technology) allows for the application of these materials in aviation structures [2, 3]. They are defined as *primary* (critical elements) and *secondary structures* [1-3]. An example of application of the composite materials in thin-walled aviation structures can be helicopter rotor blades. At the same time these elements constitute an example of a structure composed of various materials contains mainly laminates and sandwich type structures with Nomex honeycomb and foams [1-5]. The most often used computer-aided tool to aid the process of design and analysis of composite structures are numerical methods, FEM (Finite-Element Method).

The present paper describes a technique of modelling of a structure composed of multi-ply composite materials, which allows for the analysis of the degree of deformation and effort state of the thin-walled load-carrying structure under the conditions of complex load [6-9]. Numerical calculations constituted also the preliminary analysis of failure in composite materials, which allowed for the estimation of the risk of failure of the laminate in the critical parts of the structure. For the estimation of the level of effort in the composite materials in the performed studies were the maximum stress criterion, the Tsai-Hill criterion, the tensor Tsai-Wu criterion and the Azzi-Tsai-Hill criterion [10]. The strength properties indispensable for performing numerical calculations were established in the way of experiments for the examined types of composites, which were a part of the load carrying structure (glass fiber reinforced polymer-GFRP), according to the standard specifications for this type of materials.

The numerical tool applied to the analysis was the ABAQUS/Standard program, which allowed for geometrically non-linear calculations by using incremental-iterative Newton-Raphson method [6, 7].

2. Subject of research

The subject of the research was the numerical modelling of a composite load carrying structure, taking a helicopter load carrying rotor blade as an example, for a selected exploitation load. A scheme of this construction and the cross-section was presented in Fig. 1.

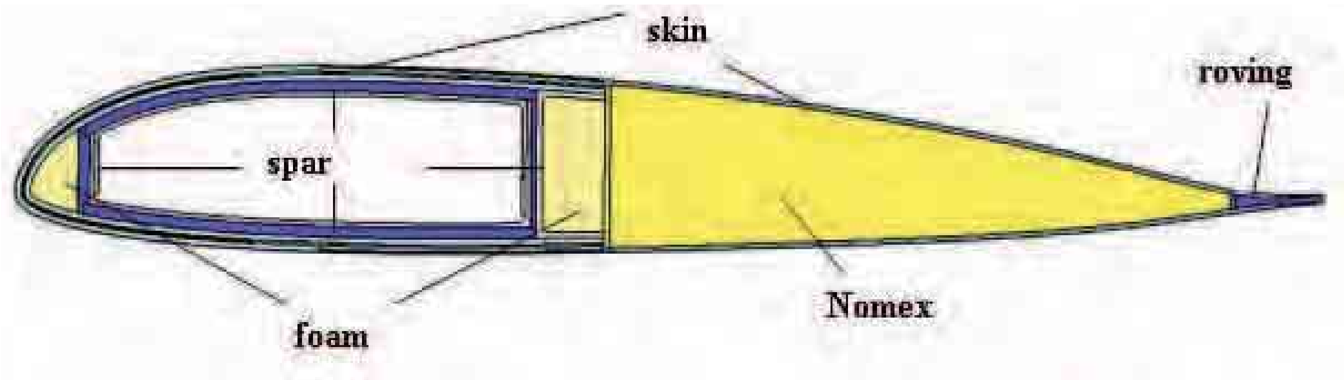

Fig. 1. Cross-section of the helicopter rotor-blade

In the structure of the rotor blade under analysis, we can generally distinguish elements made of GFRP laminates with roving, unidirectional tape and fabrics in „prepreg" system. The unidirectional reinforced composites are used on the elements where the basic issue is to transmit load along fibres, while fabrics composites are used for shells and faces, where the transfer of shearing load is needed. Another group of materials used in the construction of the rotor blade are Nomex honeycomb and foams. They are applied for securing specific stiffness and shape of the structure. The material properties of the rotor blade components are as follows:

- glass/epoxy composite, unidirectional tape, R-glass fibres: E1 = 56 [GPa], E2 = 16 [GPa], G12 = 5.233 [GPa], G23 = 5.233 [GPa], G13 = 5.233 [GPa], υ12= 0.09,
- glass/epoxy composite,fabrics,E-glass fibres, satin woven 8H: E1 = 29 [GPa], E2 = 26 [GPa], G12 = 4.2 [GPa], G23 = 4.2 [GPa], G13 = 4.2 [GPa], υ12= 0.15,
- glass/epoxy composite, roving: E1 = 45 [GPa], E2 = 15 [GPa], G12 = 5.233 [GPa], G23 = 5.233 [GPa], G13 = 5.233 [GPa], υ12= 0.28,
- honeycomb Nomex, Hexcel A1, A10: (the properties depend on a cell size): E1 = 0.001 [GPa], E2 = 0.001 [GPa], E3 = 0.14 [GPa], G12 = 0.0001 [GPa], G23 = 0.021 [GPa], G13 = 0.035 [GPa], υ12= υ23= υ13=0,
- foam PMI, Evonic: E = 0.075 [GPa], G =0.014 [GPa], υ = 0.3.

3. Finite element analysis

A 3D discrete model of a rotor blade was created in the ABAQUS program. It was used for modelling of the composite elements in structure were 8-node finite elements of the *continuum shell* type – SC8R [6, 7], while Nomex honeycomb and foam were reflected by means of 8-node solid elements of the solid type – C3D8R [6, 7]. The boundary conditions were defined by fixing of the end of the rotor blade cross-section. The load was defined by the complexity forces configuration and moment's system which were labelled as follows: P-tension load, M_{g1}, M_{g2}- bending moments, M_{g3}-torsional moment- according to a scheme in Fig. 2.

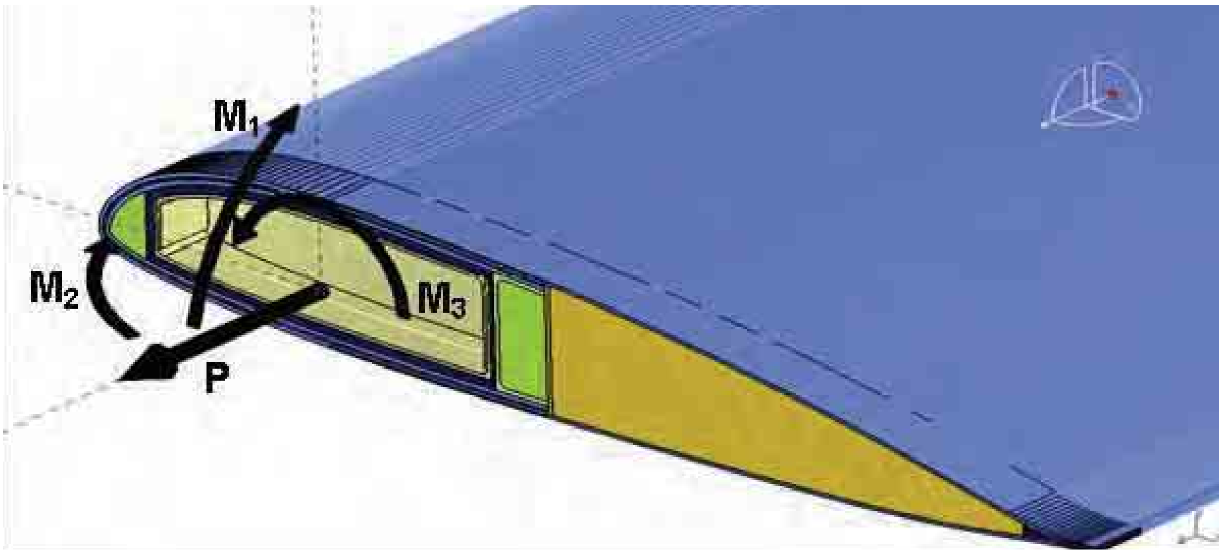

Fig. 2. General load case of the helicopter rotor blade

The main issue for the construction of a numerical model of the rotor blade structure was the modelling of the composite elements. The Lay-up technology as a pattern in laminate structure was applied in the volume of 3D elements as a type *continuum shell* [6, 7]. The way of modelling of composites, allowed to define precisely the different layers of the laminate, by describing individual properties for each layer was presented in Fig. 3.

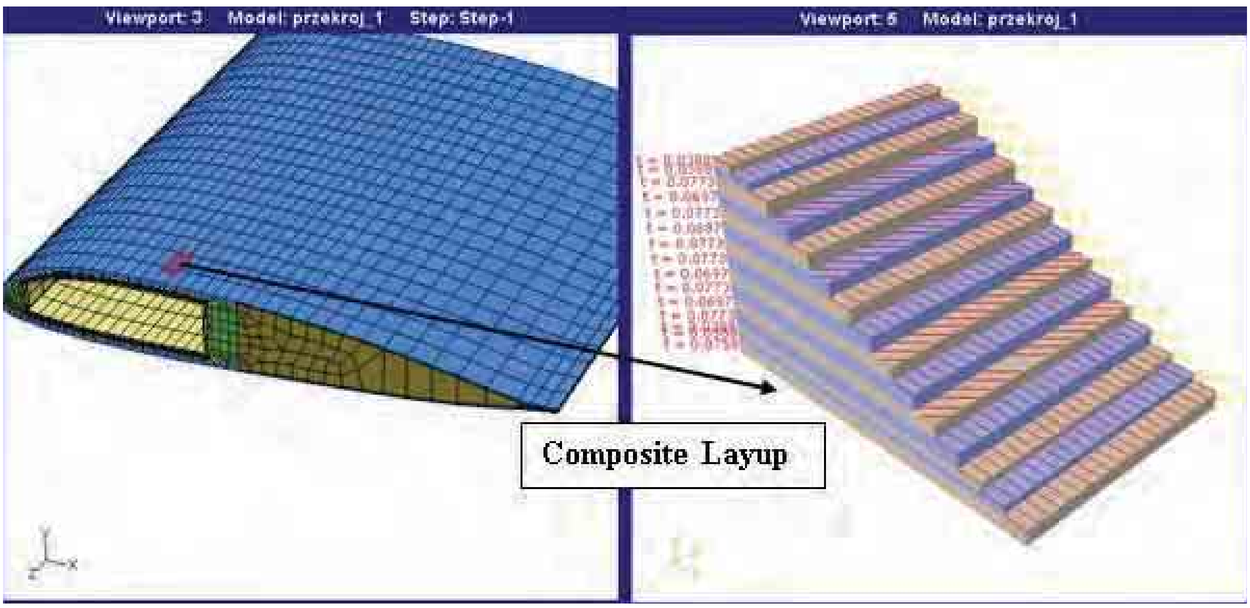

Fig. 3. Numerical modelling of composite layers system in continuum shell elements

The elastic material model was accepted as a type *Lamina.* This enabled the researchers to describe the composite structure for different directions, related to the configuration of fibre directions [10, 11, 14, 15]. The definition of a composite material required the establishment of the value of Young's modulus E_1 and E_2 for 0°direction and 90° which is perpendicular to fabrics, Poisson's ratio υ_{12} in plane layers and the value of Kirchhoff's modulus G_{12}, G_{13}, G_{23} on the three perpendicular directions related to the distribution of the fibres. The honeycomb elements in the blade fillet (Nomex honeycomb) was mirrored as *structural solid* elements with the orthotropic model of the elastic material, which was based on engineering constraints, defined for 3 perpendicular directions such as Young's modulus E_1,E_2 and E_3, Kirchhoff's modulus G_{12}, G_{13}, G_{23} and Poisson's ratio υ_{12}, υ_{13}, υ_{23}. The profile and face of honeycomb spar (foam) are concerned. The isotropic elastic model of material was used, which required the reflection of Young's modulus E and Poisson's ratio υ for *structural solid* type elements. The analysis of the load carrying elements in the blade, which were made of composites, required the application of the strength criteria. [10-12]. In numerical calculations for the effort marked in the composite was provided stress criterion which is available in the ABAQUS program: maximum stress criterion, Tsai-Hill criterion, Tsai-Wu criterion and Azzi-Tsai-Hill criterion. An evaluation of effort state has been true for actual level of stress in material to strength and for transfers this kind of stresses. It was by using above criterions. It was necessary to assign strength properties in composite materials on the basic experimental researches. For this reason was appointed following composites properties: F_{TU} – tensile strength of a fibre direction and perpendicular to fibres, F_{CU} – compressive strength of fibres direction and perpendicular to fibres, F_{SU} – shear strength in plane of layers laminate – Tab. 1.

Tab. 1. Properties of glass/epoxy composites (prepreg, Hexcel)

Tensile strength F_{TU} [MPa]		Compressive strength F_{CU} [MPa]		Shear strength in a plane of laminate layers F_{SU} [MPa]
0	90	0	90	
Glass/epoxy composite, unidirectional tape, R-glass fibres				
1560	55	1300	214	67
Glass/epoxy composite, fabrics, E-glass fibres, satin 8H				
510	415	500	460	80
Glass/epoxy composite, roving				
2207	81	1531	-	114

3. Results of FEM analysis

The performed numerical calculations create the possibility to estimate the deformation and effort state in the examined composite structure. The results were analysed in relation to the effort degree of the elements in the rotor blade structure, especially in the load carrying composite elements. The application of the modelling technique and the assumed effort criteria of the laminates make it possible to analyse the effort in the particular layers of the composite structure. The deformation and effort state of discrete model in the rotor blade under influencing load analysing system are given in Fig. 4.

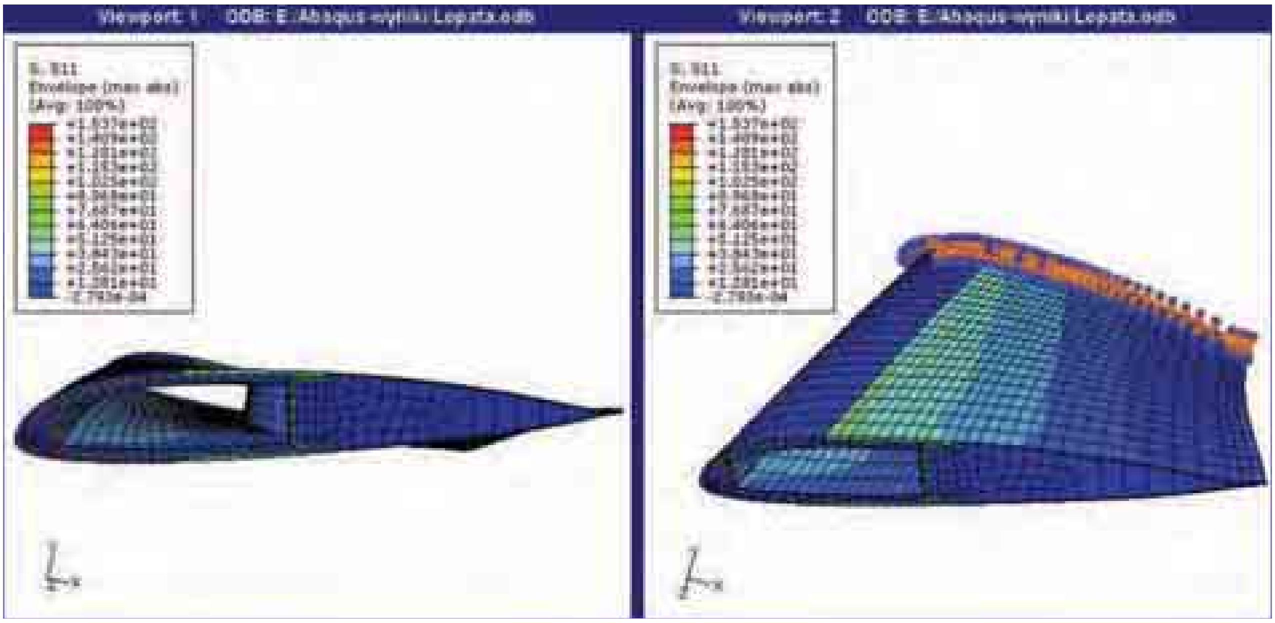

Fig. 4. General deformation and effort state in a model of load carrying rotor blade

On the basic of the obtained calculation results, it follows that the elements exposed to the most effort in the structure are the particular elements where the rotor blade is assembled and where there are the highest levels of tension stress. Therefore the spar of the rotor blade is the element of fundamental meaning as far as strength is concerned, which confirms the construction assumptions related to the rotor blade structure. Fig. 5 shows an example of effort charts for selected composite elements of a rotor blade on the basis of the Maximum Stress criterion and Tsai-Hill criterion.

a) b)

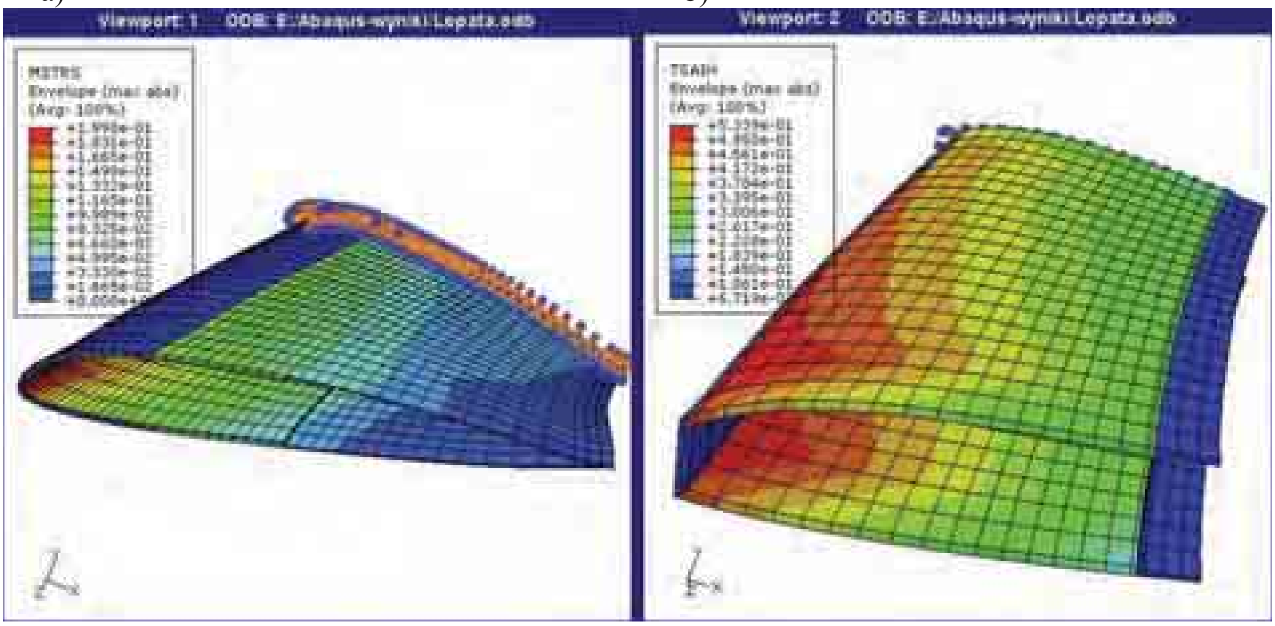

Fig. 5. The effort state in construction of the helicopter rotor blade: a) the effort of shell elements according to maximum stress criterion, b) the effort of spar elements according to Tsai-Hill criterion

In Fig. 6 was shown an example of the effort charts for choosing composite elements of the rotor blade. It is on the basis of Tsai-Wu criterion and Azzi-Tsai-Hill criterion.

a) b)

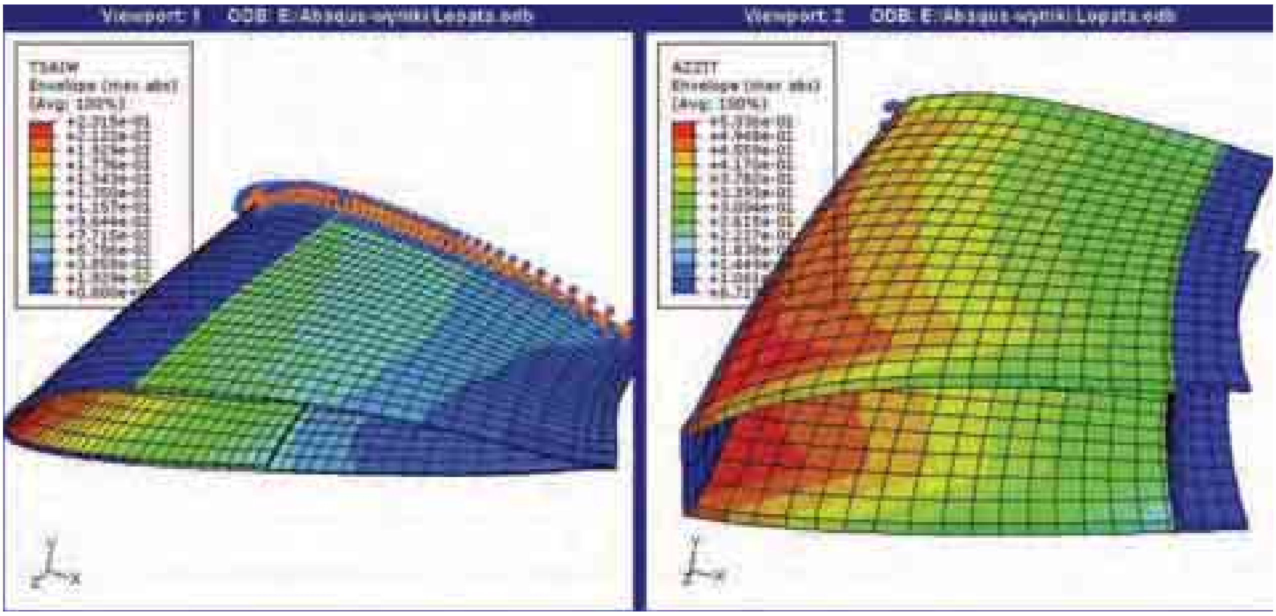

Fig. 6. The effort state as an example in construction elements of the blade: a). the effort of shell elements according to Tsai-Wu criterion, b). the effort of spar elements according to Azzi-Tsai-Hill criterion

The presented results show differences in the assessment of the effort state of the composite elements depending on the applied effort criterion. In the analysed case, the lowest effort state in the composite elements was obtained for the maximum stress criterion, which results from the adopted procedures for establishing the effort state of composite through different criterions. In Fig. 7 was presented the example of limited envelopes in space of stresses for Maximum Stresses criterion (a rectangular envelope) – Tsai- Hill criterion (an ellipsoidal envelope) and Tsai-Hill criterion- Tsai-Wu criterion.

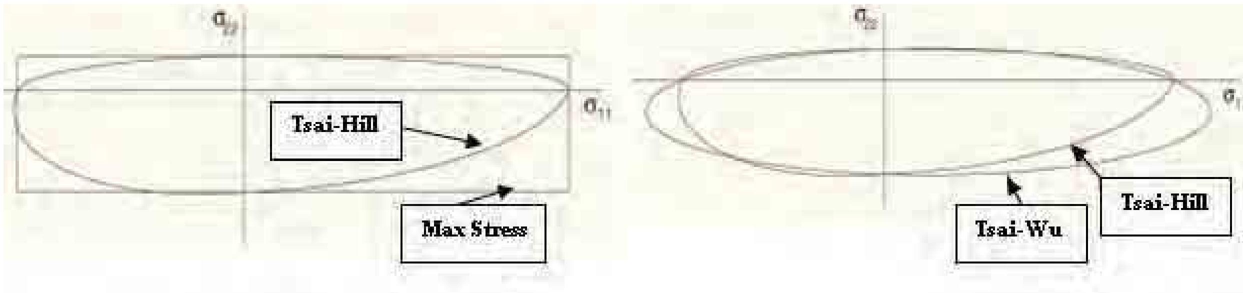

Fig. 7. Limited envelopes for the criterion of maximum stresses- Tsai-Hill and Tsai-Hill-Tsai-Wu criterion

4. Conclusions

The methodology for modelling of a thin-walled structure of a rotor blade with load carrying composite elements as presented in this paper creates the possibility to perform the analysis of the degree of deformation and effort in the structure under a complex external load condition. It is very essential in load carrying elements which the modern aviation constructions are made of composite materials in a wider range [1, 3, 14, 15]. Therefore, knowing effort degree in critical elements represent the main issue and applying the finite element method allows analysing the effort in construction elements which are under complex load condition.

The conclusions from this study can be drawn:

The most effort elements of construction are the particular elements where the rotor blade is assembled and where there are the highest levels of tension stress. The spar of the rotor blade is the element of fundamental strength meaning.

The results confirmed possibility for applying FEM calculations to analysing and optimization strength parameters of composite structures.

The numerical calculations with application of the modelling technique and the assumed effort criteria of the laminates make possibility to analyse the effort in the particular layers of the composite structure where there are a potential risk of failure in load carrying- capacity structure.

Acknowledgements

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