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DEVELOPMENT OF LIGHTWEIGHT AND RELIABLE JOINTS FOR AIRFRAMES BASED ON UNIDIRECTIONAL COMPOSITE ELEMENTS

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Abstract

Fuselage barrel assembling from different lattice parts and novel hybrid metal-UD-composite concept of joining are presented.
Numerical simulation technique of loading process of new metal-composite joints was developed and experimentally validated.

1 Introduction

The development of reliable and lightweight joints is one of the most critical tasks for the composite primary aircraft structure. Joints in traditional (like "black metal") primary composite structure decrease dramatically the strength and weight efficiency. The joining is also the actual problem for novel composite primary structures based on unidirectional (UD) composite elements.

However for UD structures the principal possibility for creation of lightweight and reliable joints exists due to topological and design features. Development of such kind of joints for UD structures (Fig. 1.) allows to assemble the fuselage barrel from different lattice panels and thereby to solve the number of important problems for barrel structures:

1. significant improvement of reparability,
2. extended possibilities for optimization of different structure parts,
3. decrease in manufacturing cost.

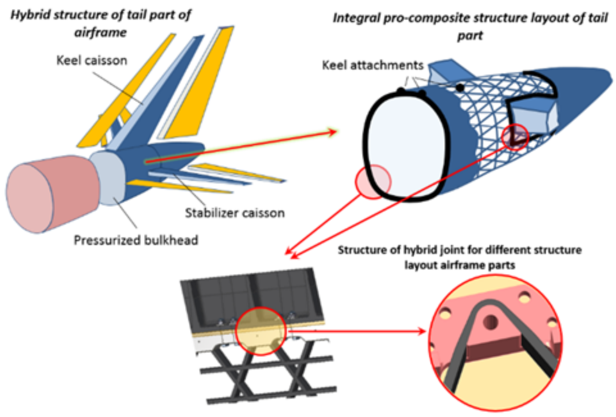


Fig. 1. New Pro-Composite and Hybrid Structure Layout Investigation for Primary Structure of Airframe.

Investigations of lattice unidirectional composite airframe structure performed in frame of Russian project "CM Fuselage" and European project FP7 "ALaSCA" [1], FP7 "PoLaRBEAR" [2] demonstrate high potential of fuselage weight reduction of civil aircraft due to structure separate panel using (Fig. 2).

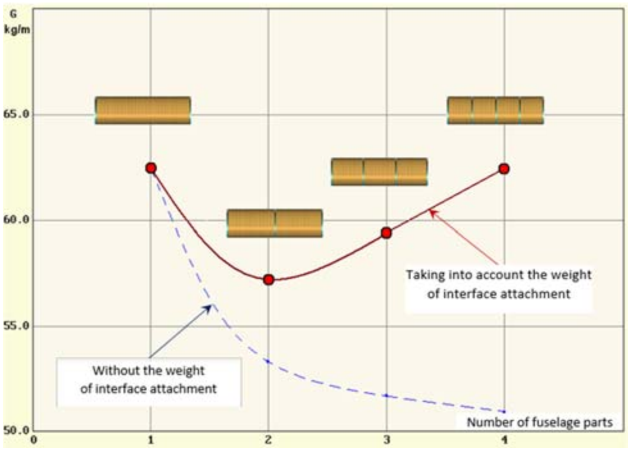


Fig. 2. Weight Reduction of Lattice Fuselage Barrel Due to Several Parts Using

2 Main Features of Reliable and Lightweight Metal-Composite Joint.

In effective aircraft composite structure developing manufactures has some problems with structure joints. This fact is explained by low strength characteristics of composite material on micro level. Generally high concentrated forces pass thru structure joints. For traditional metallic aircraft structure the shear bolt and rivet joints have wide application, which have high weight efficiency due to high viscosity of metallic alloys. Stress intensity around hole rapidly dumped under structure loading. In reference to composite aircraft structure, joints stress intensity decrease slowly, since force flow from one cut fiber layer to another thru the resin, which has low shear characteristics. The maximal effectiveness of bolted composite structure joints no more than 30-40% from allowable values in compare to metallic structure 70-80%.

In frame of this paper, new joint concepts for lattice fuselage barrel connection with other parts are considered (Fig. 3).

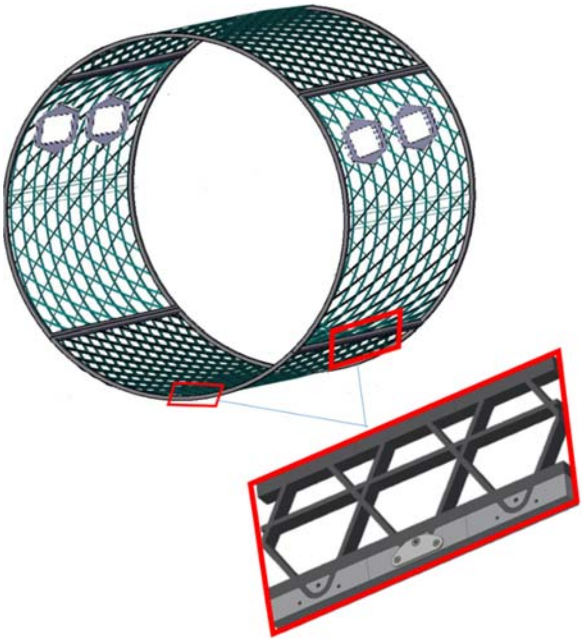


Fig. 3. Fuselage Barrel Assembling from Different Lattice Parts and Novel Hybrid Metal-UD-Composite Concept of Joining.

The main development strategy of new hybrid metal-UD-composite concept of joining is following:

1. Heavy loaded structure ribs should not have any cuttings. As described above any rib cutting is to disable significant part of heavy loaded composite structure.
2. Contact area of composite and metallic part has to maximal size for smooth force flow transition from composite to metallic part and vice-versa.
3. Fiber percentage in contact zone of composite material has to maximal value. It is necessary for pure metal to fiber contact without resin (fig. 3 - 4).

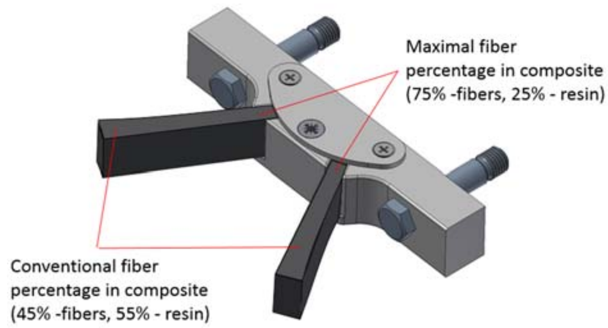


Fig. 4. Hybrid Metal-UD-Composite Concept of Joining Creation Concept.

3 Numerical Simulation Researches of Metal-Composite Joint

Joint scheme description.

Joint scheme of composite unidirectional rib with bulkhead is shown on Fig. 5. It is assumed that unidirectional carbon fiber rib (composite part) interacts with metallic part by means of winding. Fiber prepreg winding process realizes into preliminary milled groove in metallic part. For strengthening milled groove the patch was used.

Inclination angle of composite rib to metallic part is 60°. The resulting force which acting on metallic tooth is determine as $F=2 \cdot P \cdot \sin\alpha$, where P is internal unidirectional rib force (Fig. 6).

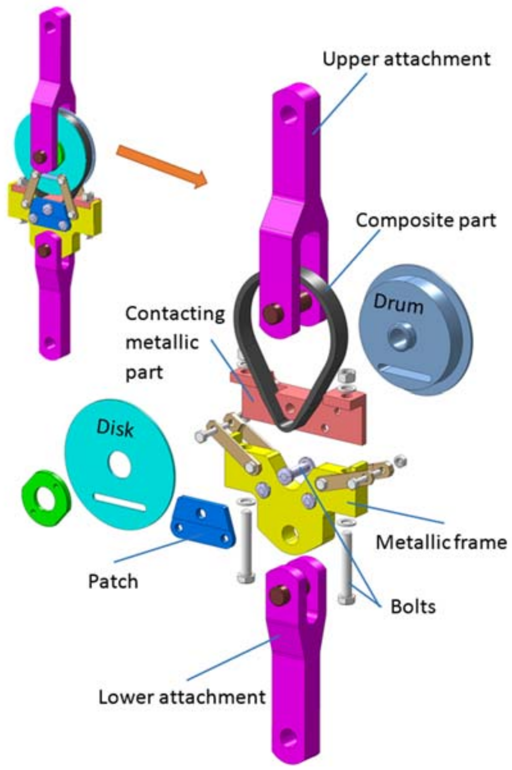


Fig. 5. Geometrical CAD Model of Metal-Composite Joint.

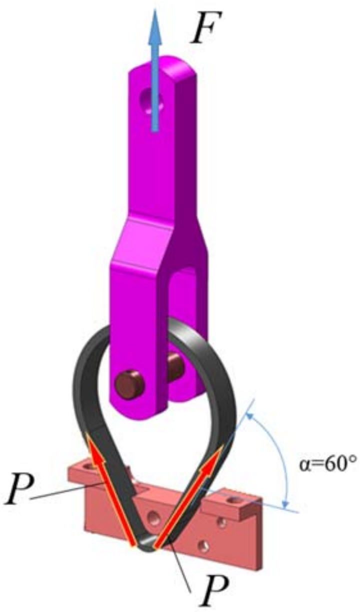


Fig. 6. Scheme of Force Applying on Metal-Composite Joint.

Metal-Composite Joint modelling.

Numerical simulation of metal-composite joint was performed by using MSC.Marc finite element analysis code [3] and MSC.Patran [4] as a pre- postprocessor. General view of finite element model is presented on Fig. 7. Finite element model consist of 131684 nodes and 104688 HEX8 elements.

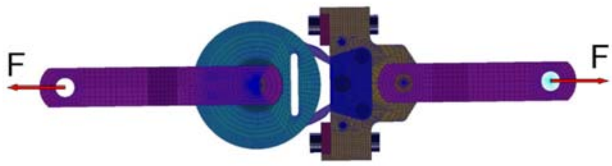
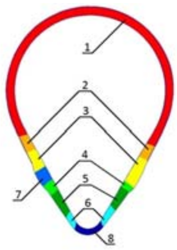


Fig. 7. Finite Element Model of Metal-Composite Joint Concept.

All items of metal-composite joint which are shown on Fig. 5 were simulated. The mechanical properties of composite part of joint concept are illustrated on Fig. 8 and other items have steel material properties ($E = 21000$ kgf/mm^2, $\mu = 0.33$).



Zone	Fiber/ resin, %	E_{11}, kgf/mm^2	$E_{22,33}$, kgf/mm^2	$\nu_{12,13}$	G, kgf/mm^2	Thickness, mm
1	55,3/44,7	11500	896	0,188	800	8,9
2	47,1/52,9	9900	882	0,16	800	10
3	29,3/70,7	6460	850	0,01	800	12,2
4	28,2/71,8	6250	848	0,01	800	12,3
5	48,9/51,1	10300	885	0,17	800	9,8
6	65,8/34,2	14100	922	0,23	800	7,3
7	17,8/82,2	4240	830	0,06	800	13,6
8	68,0/32,0	14900	930	0,25	800	6,4

Fig. 8. Composite part description of Metal-Composite Joint Concept.

Numerical simulation results

The maximal applied force to metal composite joint was F = 10 000 kgf.

The displacement distribution of metal-composite joint is shown on Fig.9

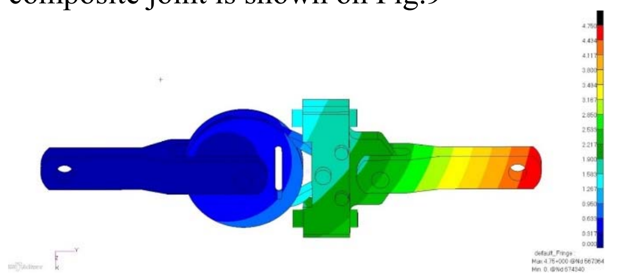


Fig. 9. Displacement Distribution of Metal-Composite Joint.

On next Fig. 10 the most loaded part metal-composite joint are shown.

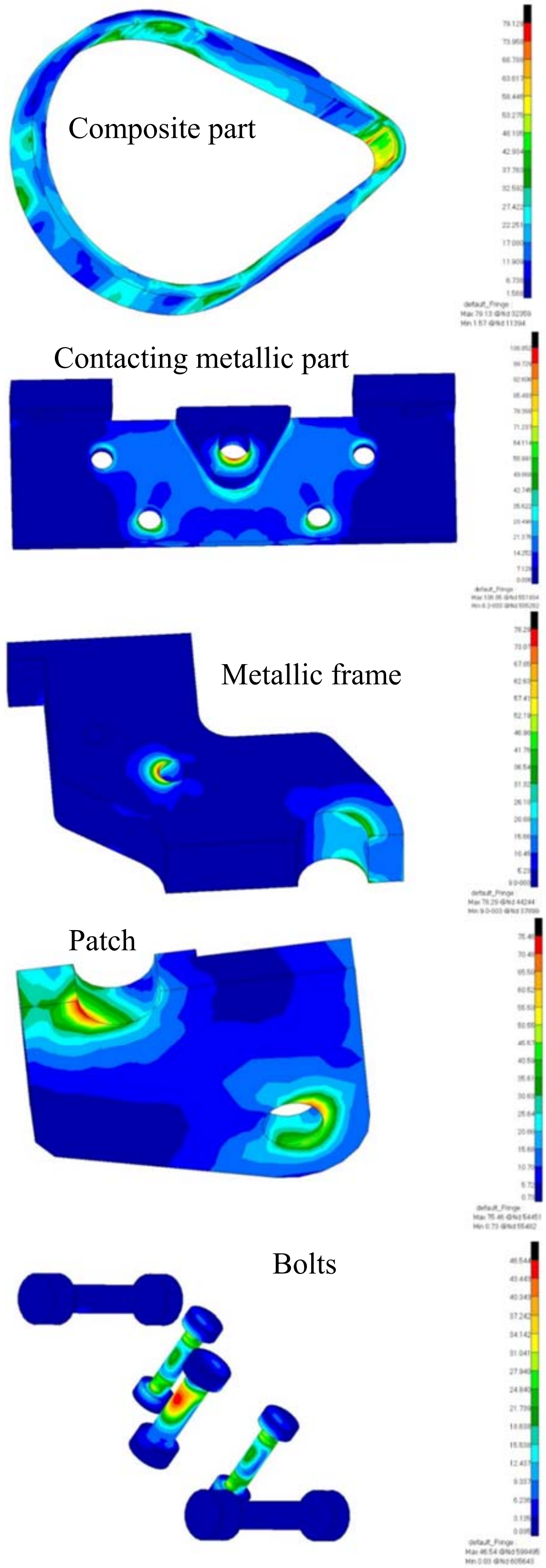


Fig. 10. The Most Loaded Items of Metal-Composite Joint Concept.

On the next table on Fig. 11 the maximal von Mises stresses are presented.

Item designation	Maximal Von Mises stress, kgf/mm^2
Composite part	79,1
Contacting metallic part	106,9
Metallic frame	79,7
Patch	77,7
Drum	31,4
Disk	9,1
Upper attachment	23,8
Lower attachment	19,7
Bolts	46,5

Fig. 11. Summary Table of Maximal von Mises Stresses of Metal-Composite Joint Concept.

4 Technical Solution Validation on real experiment base

For the validation technical solution of metal-composite joint and finite element model results verification the full-scale experiment was performed. Real model of metal-composite joint concept is shown on Fig. 12.

Fig. 12. Real Model of Metal-Composite Joint Concept.

Composite part photo of metal-composite joint concept is presented on Fig. 13.

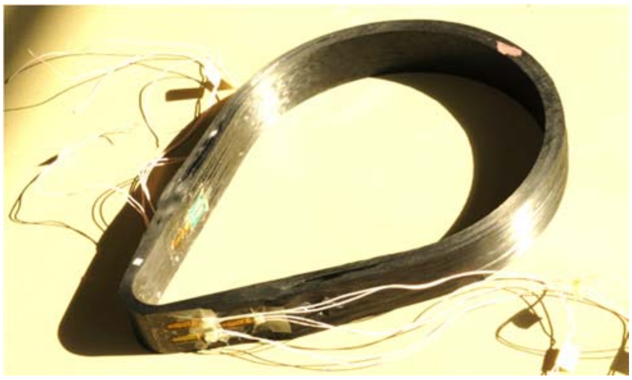


Fig. 13. Composite Specimen in Real Metal-Composite Joint Concept.

Composite specimen was manufactured by using winding method. Materials of composite part are Tenax IMS 65 (fibers) and polymer epoxy resin. The fiber percentage in contact zone is 62% and resin 38% respectively. In other zone the fiber percentage is approximately 40% and resin 60%. The strain gage scheme on composite specimen is presented on Fig. 14.

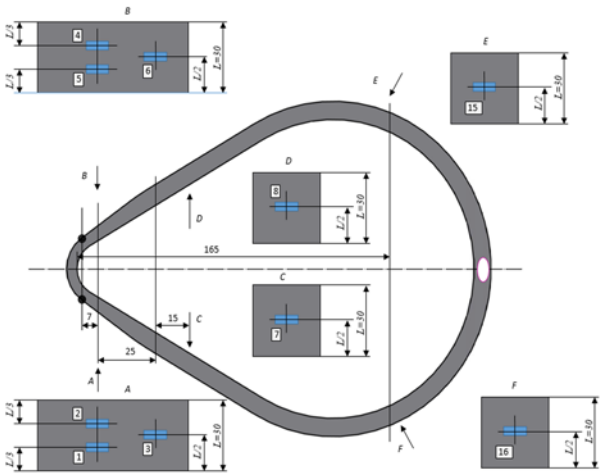


Fig. 14. Strain Gage Scheme on Composite Specimen.

The experiment was performed on servo hydraulic testing machine (LFM 1000 Switzerland). The photo of metal-composite concept in testing machine is shown on Fig. 15.

Fig. 15. Metal-Composite Joint in Testing Machine.

Experimental test results

On Fig. 16 the difference of elongation under loading of metal-composite joint concept between numerical simulation and experimental data is presented. The difference between experimental and numerical simulation data does not exceed 10 %.

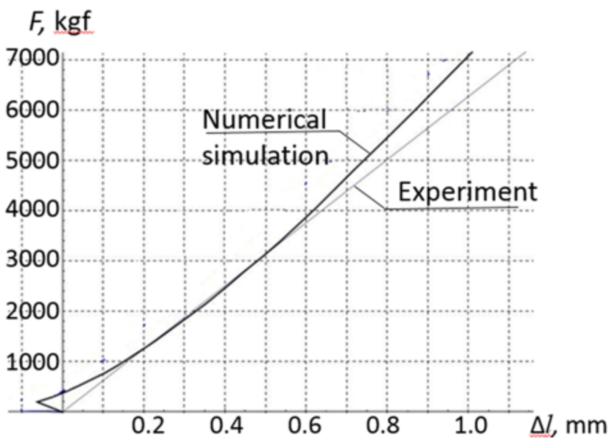


Fig. 16. Elongation under Loading Difference of Metal-Composite Joint Concept

On Fig. 17 the test strain gage data comparison with numerical simulation is shown. Numerical simulation data and experimental results have a good coincidence to each other.

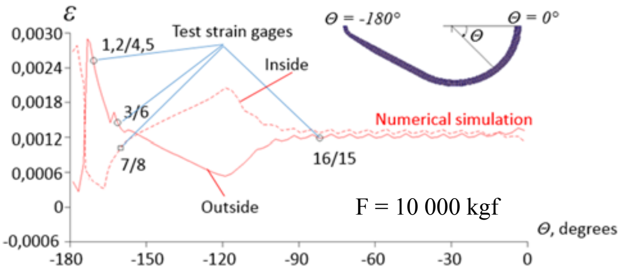


Fig. 17. The Test Strain Gage Data Comparison with Numerical Simulation.

Conclusions

Received experimental results demonstrate the effectiveness of presented novel hybrid metal-UD-composite concept of joining (Fig. 3 and 4). Numerical simulation technique for modelling metal-composite joint by using MSC.Marc code was created. Good coincidence between numerical simulation and test results were obtained.

Scientific and technical background was created for further searching of new structure concepts of metal- composite joints.

References

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[4] MSC.Patran, Version 2013, User manual, 2012

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