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Computer simulation techniques for solving the tasks of optimal design of aerospace composite structures

The paper provides some of key results of using computer simulation techniques based on finite element analysis to solve the tasks of optimal designing of the aviation and rocket-and-space composite structures. It is shown that these results allowed providing significant increase in mass efficiency of the composite assemblies of the engineering category in question.

Introduction. Searching for ways to improve the efficiency of the modern aviation and rocket-and-space equipment (ARSE), in particular, in recent decades gave rise to the growing trend of polymeric composite materials' (PKM) use in such equipment with constantly increasing volumes and product criticality rating [1, 2]. At present time, R&D support of the efficient designing and manufacturing of ARSE units of PCM, starting with the issues of product design and planning, choice of the rational design-and-technology solutions (DTS) and their implementation, is based on applied methods of the mathematical and computer simulation which are intensively developed and used during the last decade [3]. Best practices of the leading aerospace enterprises dominating in the world market prove that designing and manufacturing of high-tech products under current conditions becomes impossible without the concept named "Simulation-Based Design", i.e. computer-aided designing of competitive products based on the efficient and comprehensive application of the world-class Computer-Aided Design (CAD) systems and finite-element modeling in the framework of Computer-Aided Engineering (CAE) software systems [4]. This concept relies on the modern, versatile and highly efficient finite element method and advanced computer technologies which actively use state-of-the-art visualization tools.

Main points. The paper deals with presentation of some of key results of the usage of computer simulation techniques on the basis of finite element analysis to solve the tasks of the optimal design of ARSE, available by now at the Department of rocket design and engineering of National Aerospace University "Kharkiv Aviation Institute" [5]. All research efforts are presented in the form of scientific support of development of the efficient DTS for the ARSE composite assemblies implemented at a number of the national enterprises of space industry: Yuzhnoye State Design Office, Antonov Company, SE "Instrument-Making Research and Technological Institute", PJSC "Ukrainian Research Institute of Manufacturing Engineering".

The first area of focus of the work refers to development of the integrated approach to weight optimization of design parameters of the shell load-bearing structures for space applications, made of composite materials, at multiple-factor (static, heat, dynamic) loading (Fig. 1).

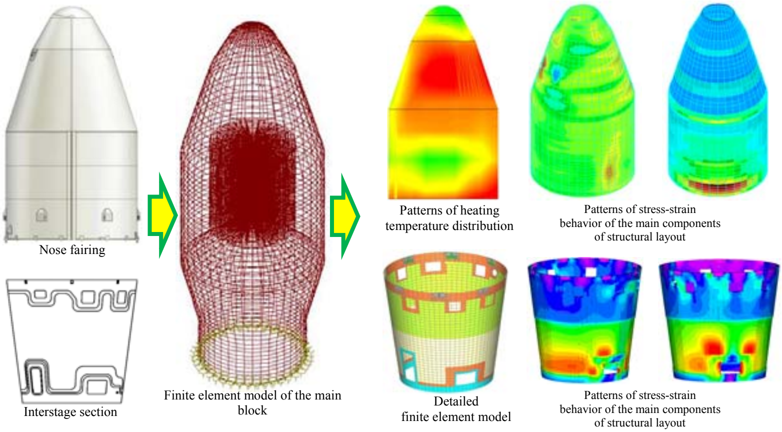
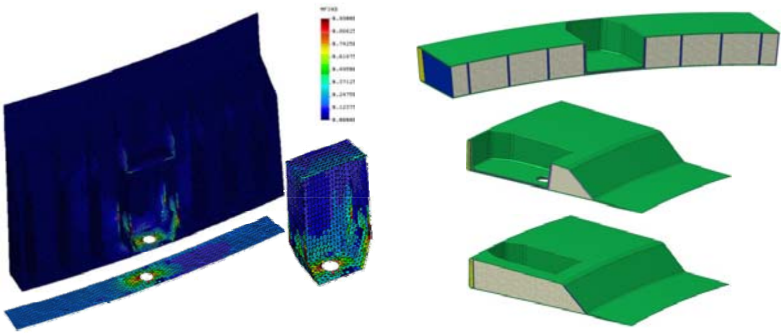


Fig.1. Bearing composite sections of the launch vehicle in which the suggested approach was implemented

The paper reviews the results of in-depth studies of stress-strain behavior (SSB) and evaluation of the bearing capacity of interstage section of the launch vehicle in the regular zone, as well as fragment of its joint, comprising the stiffening ring and first developed coupling composite fitting (Fig. 2). It is noted that full-scale static tests confirmed the rationality of all adopted parameters of DTS.



a b

Fig. 2. Pattern of distribution of the adopted failure index in the fragment of fitting/stiffening ring joint (a) and obtained rational DTS for the fitting (b)

Practical implementation of the suggested approach ensured realization of the potential opportunities of reducing the mass of structural elements of the launch vehicle main block at specified bearing capacity (strength and stability) taking into account almost all spectrum of external actions.

The second area of focus relates to studying of SSB of stress concentration zones in the areas of polar holes of the composite housings of solid propellant rocket engines (SPRE) with the metallic embedded parts in the polar holes of bottoms (Fig. 3). Recommendations on the increase in bearing capacity of SPRE housings made of PCM in the area of polar holes of bottoms are provided.

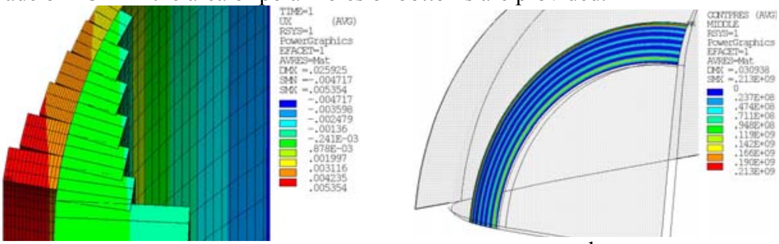


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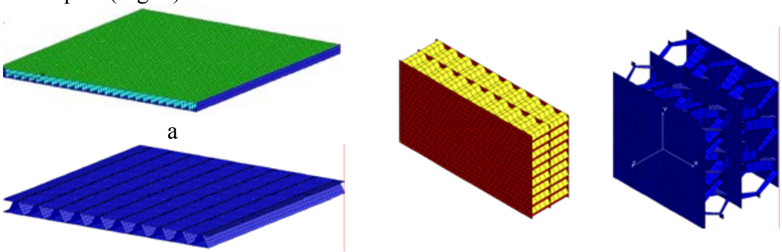
Fig. 3. Patterns of radial displacements in the area of rear bottom of SPRE housing (a) and contact stresses between the bottom and embedded part (b)

The third area was aimed to the scientific support of development of the efficient DTS for the sandwich composite panel assemblies. In the framework of this study, the analytical engineering method of preliminary designing of flying vehicles' sandwich panel structures with various types of composite fillers was proposed. The system of R&D support of stabilization and improvement of the functional characteristics of the composite fillers was developed. It implemented the approach to obtaining the values of adopted characteristics of the various types of fillers, which was based on the information support method to reveal the maximum possible level of their characteristics without the need for expensive full-scale tests of the pilot samples (Fig. 4).



a

b c d

Fig. 4. Example of generated finite element models used for determination of adopted PhMC of various types of composite fillers: a – tubular; b – corrugated, c – honeycomb; d – folded with the cellular structure

Results of verification of accuracy of the analytical models for determination of PhMC and structures are represented. The lower hinged panel of the An-72 aircraft was taken as a basis.

The next area of focus became the scientific support of development of the efficient DTS of the precision composite assemblies for space systems. The paper provides the results of analysis of reinforcement patterns and rational distribution of the material for solar battery (SB) panels of different structural layouts (SL). Application of proposed principles to the synthesis of rational parameters of frames of the planar SB panels of sandwich SL with the honeycomb filler gave the reasons to count on the possibility of realizing their surface mass within 0.5…0.6 kg/m^2 (Fig. 5, a). The synthesis of rational parameters of the frames of panels of concentrator SB allowed choosing the most efficient (by mass) SL of the panel segment of the considered category, and determining the rational parameters of its elements. Usage of that SL gave an opportunity to substantiate the development of the concentrator SB panel for space applications with the surface mass of 0.6 kg/m^2 (Fig. 5, b).

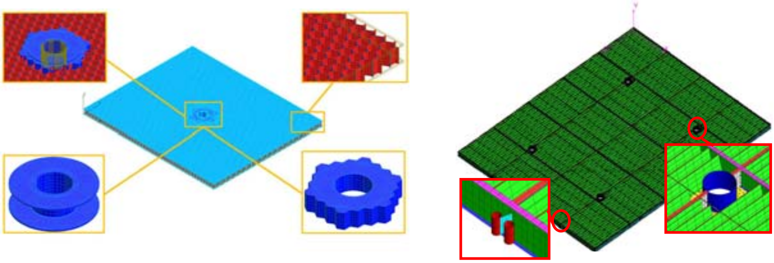


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Рис. 5. Finite element models of planar (a) and concentrator (b) SB

For the product of the considered class, the algorithm for determining the rational structure of the composite package, which provided the maximum shape and dimensional stability of the product, was developed and implemented. The paper includes the example of optimal designing of the precision structure for space applications – monolithic carbon- fiber reinforced plastic of high-resolution scanner for the fixation of optical elements and units of the spacecraft (Fig. 6).

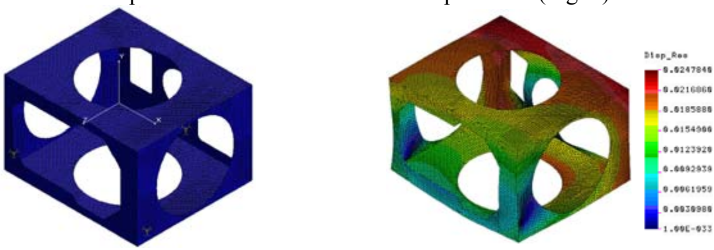

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Fig. 6. Finite element model (a) and pattern of resulting linear displacements (b) of high-resolution scanner housing

In conclusion, in is noted that the Department of structures and designing of missiles of the M. E. Zhukovsky National Aerospace University “KhAI” is now engaged in further works on the scientific support of increase in the composite structures’ efficiency, in order to considerably extend the field of use of this category of structures in the domain of ARSE.

Conclusion

The results of using the computer simulation techniques on the basis of finite element analysis to solve the tasks of optimal designing of ARSE composite structures allowed to:

– substantiate in science terms the procedure for choosing the efficient SL and DTS for assemblies in the design class under study to be implemented in the conditions of enterprises of the national aerospace industry;

– develop the R&D support system for stabilization and improvement of the functional characteristics of composite fillers widely used in the ARSE sandwich assemblies;

– synthesize the rational structural-and-technological parameters of the shell and panel units of the ARSE, including the load-bearing sections of the launch vehicle main block, solid propellant rocket engine housings, planar and concentrator panels of spacecraft solar batteries, precision structures for space applications, panels of various flaps and plates in the aircrafts, and other assemblies of flying vehicles.

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