

INTEGRATED SYSTEM AS A TOOL FOR IMPLEMENTATION OF SIMULATION- AND OPTIMIZATION-BASED DESIGN METHODOLOGY

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Abstract. Within the framework of the work, topology optimization program module and integrated computer-aided design and engineering system are developed. Topology optimization of bracket and parametric design optimization of space waffle shell were carried out through ISCDE. The obtained results will be used in the Russian space companies.

Keywords: design, modeling, space bracket, topology optimization.

1. Introduction

Today in the world design engineering practice two approaches to design of structures can be distinguished. The first, more traditional, is that the designer on the basis of operational requirements and his experience invent a sketch of the structure, which then turns into a CAD-model. After that, a real prototype is created and full-scale tests are carried out. CAE calculations are also performed, mainly to verify those loading cases that have not been tested in full-scale tests. In case of dissatisfaction with some requirements, the model is returned to the designer, and the loop is repeated.

With the traditional approach, the engineers use other approach based on mathematical modeling and optimization methods. Using this approach, called simulation- and optimization-based approach, allows one to get a design of structure under specified operating conditions through the use of computer simulation and optimization. This approach is currently being implemented by leading Western industrial companies in the development of new aircraft, ground vehicles, etc. A key role in this approach is topological optimization, allowing for predetermined loads to predict the most effective material distribution in structure.

This work is devoted to the development of a tool for implementing the design approach based on mathematical modeling and optimization. The work includes the development of an integrated computer design and engineering system, a topological optimization module in the ANSYS APDL environment, and demonstrates obtained solutions.

2. Topology optimization program module

The problem of topology optimization, in the classical formulation, is the problem of choosing the optimal distribution of material in fixed space (Fig. 1). For each point of the body, we should answer the question whether there is material in this place or not. To look at this initially discrete problem as on the continuous problem we use the SIMP (Solid Isotropic Material with Penalization) method, which allows associate the elastic properties of a material with an additional parameter called "density" [1].

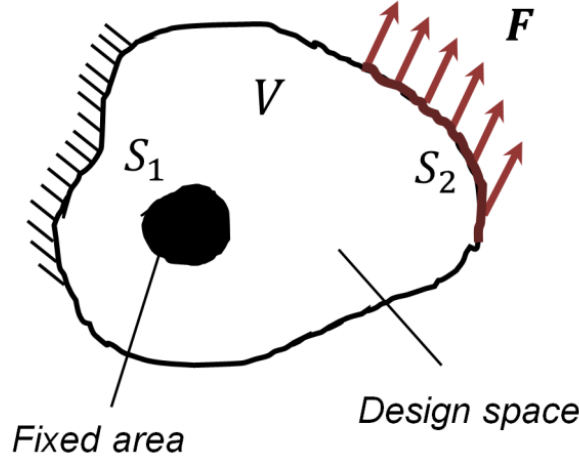


Fig. 1. Formulation of topology optimization problem.

$$E(x) = \rho(x)^p E^0 \quad (1)$$

In ANSYS APDL, this was implemented by assigning each finite element its own material. The further task is to achieve a minimum of the functional of external forces work, when the equilibrium condition of the system is satisfied.

$$\begin{aligned} & \min_{\mathbf{u} \in U, E} A^{ex}(\mathbf{u}) \\ \text{s.t.} \quad & A^{ex}(\delta \mathbf{u}) = \delta \left(\rho_T \psi(\boldsymbol{\varepsilon}(\mathbf{u})) \right), \forall \delta \mathbf{u} \in U \\ & V \leq \alpha V_0, 0 < \alpha < 1 \end{aligned} \quad (2)$$

For this goal, we use the Method of Moving Asymptotes (MMA) [2]. This method now is used in most popular world optimization software, like Altair Optistruct and DS Simulia Tosca Structure [3, 4]. To apply this method, it is necessary to define the partial derivatives (sensitivities) of an object with respect to design variables. In the case of minimizing the compliance of the system with a constraint on the volume, these derivatives are related to the potential deformation energy at each point.

$$\frac{\partial c}{\partial \rho_e} = -\mathbf{u}^T \frac{\partial \mathbf{K}}{\partial \rho_e} \mathbf{u} = -p \rho_e^{p-1} \bar{\mathbf{u}}^T \mathbf{K}_{0e} \mathbf{u} \leq 0 \quad (3)$$

In ANSYS APDL, the procedure for finding sensitivities is consist in performing FE calculation and obtaining the strain energy in each finite element. After that, a convex approximation of objective function is analytically constructed [3]:

$$c^{(k)}(\boldsymbol{\rho}) = c(\boldsymbol{\rho}^{(k)}) - \sum_{j=1}^n \frac{(\rho_e^{(k)} - L_e^{(k)})^2}{\rho_e - L_e^{(k)}} \frac{\partial c}{\partial \rho_e}(\boldsymbol{\rho}^{(k)}) + r^{(k)}(\boldsymbol{\rho}^{(k)}) \quad (4)$$

Minimum of this function can be easily determined by constructing a Lagrangian functional and solving dual optimization problem. The founded solution is the next calculation point for the approximation. The iterative process is repeated until the results converge.

The mapping of optimization results was performed by the exclusion those finite elements, which density parameter is lesser a specified level. To ensure the possibility of the designer to work with obtained optimal not-smooth finite-element model, the postprocess procedure based on the Laplacian smoothing algorithm is carried out. This algorithm was implemented in ANSYS ADPL program module by triangulation of the surface of the optimized finite element model, and further iterative process of averaging the vertices coordinates of neighboring finite elements (Fig. 2).

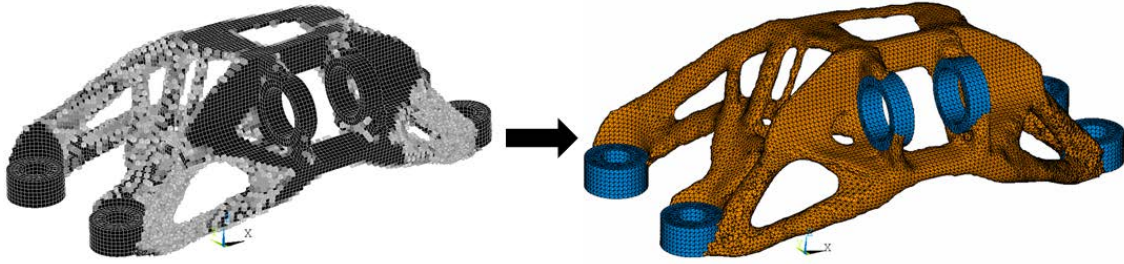


Fig. 2. Laplacian smoothing as a postprocess tool.

Additionally, the mesh density filter was implemented to the program module in order to prevent an appearance of «checkboard» (Fig. 3).

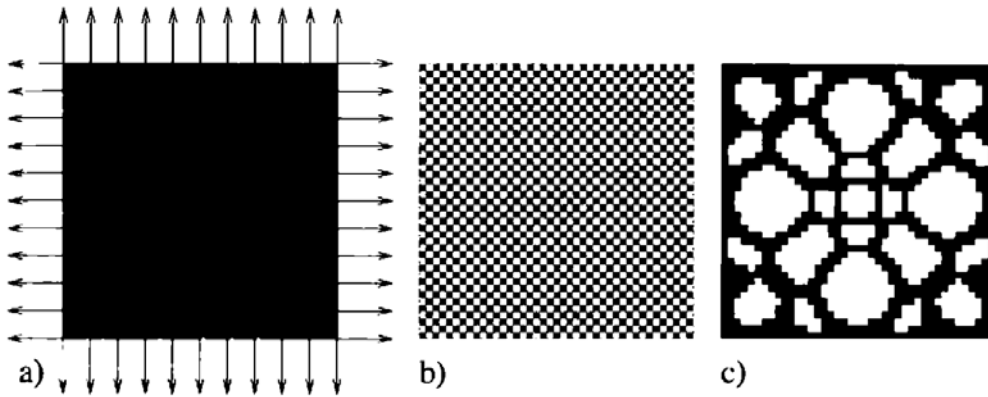


Fig. 3. Checkboard effect [3] a) original task; b) result without filtering; c) result with filtering.

Mesh density filter is based on operation of weighted averaging of sensitivities in the area of initially defined radius r_{min} :

$$\frac{\partial c}{\partial \rho_e} = \frac{1}{\rho_e \sum_{i=1}^N \bar{H}_i} \rho_e \sum_{i=1}^N \bar{H}_i \rho_i \frac{\partial c}{\partial \rho_i}, \quad \bar{H}_i = r_{min} - dist(e, i) \quad (5)$$

The developed topology optimization module shows good consistency with the results given in Ref. [6] and shown in Figure 4.

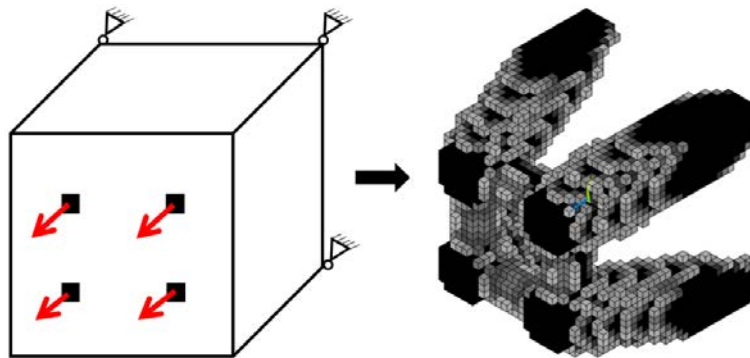


Fig. 4. Results of topology optimization for solid block with developed program module (Minimizing compliance with volume fracture 20 %).

3. Integrated system of computer design and engineering (ISCDE)

For conception simulation- and optimization- based design, only the topological optimization is not enough. This approach requires the following functionality:

1. For optimization of structure one needs to know the layout volume, interface elements, and functionality of design structure. For this you need a hierarchical database of structures. This database should also contain information about all loading conditions for structure.
2. Both for structural or parametric optimization, one needs to know the technological limitations - this requires a technology database.
3. To perform engineering and optimization calculations of structures, a database of materials, available for design engineer, is needed.
4. To ensure simultaneous access of specialists of all profiles and levels to the design process, the system should have a client-server architecture.
5. In order to cover all nuances of design behavior in simulation, the system should integrate the best world modeling and optimization solutions: ANSYS, DS Simulia ABAQUS, MSC NASTRAN, Alatair Optistruct, DS Simulia Tosca Structure, Esteco modeFrontier. The system also will integrate the developed topological optimization ANSYS APDL module (for case, if company have no optimization software).
6. The system should have automated postprocess tools to track the specified target values for part or for assembly during simulations.

All this was implemented in the integrated computer design and engineering system (ISCDE) (Fig. 5).

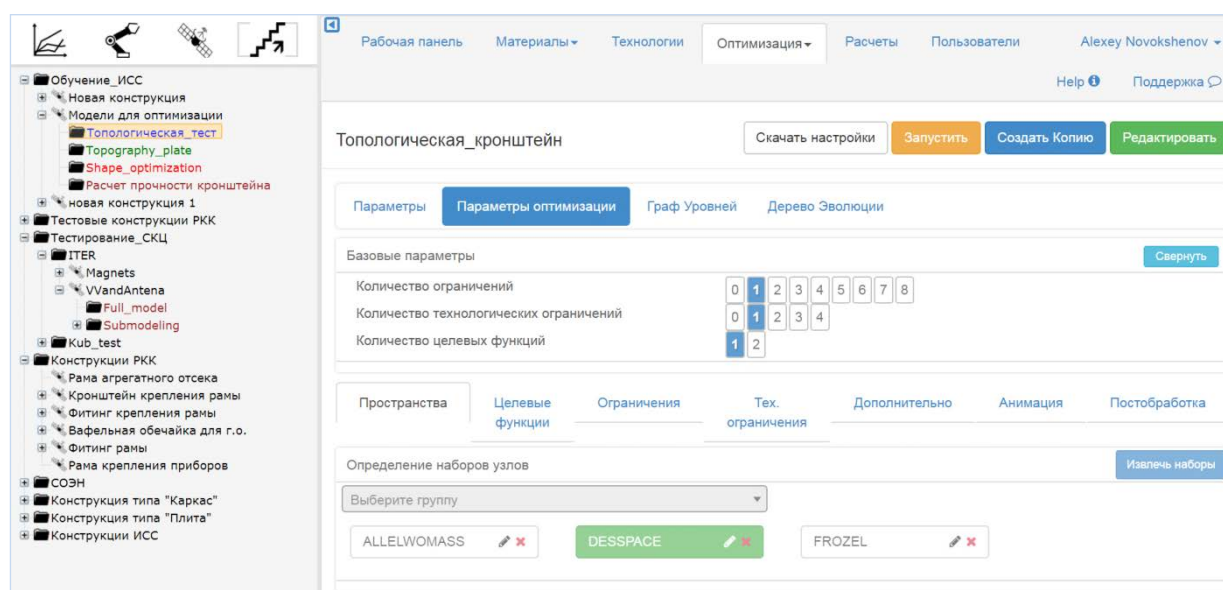


Fig. 5. ISCDE interface in case of optimization with DS Simulia Tosca Structure.

The developed system has a server and a client part. The server part is written in JAVA, the client in JavaScript, the used database is PostgreSQL. The system includes a tree of materials (homogeneous and composite), a tree of technologies, a hierarchical tree of constructions, and the calculation and optimization module. The system implements User Account Control (UAC). Figure 5 shows the interface of the system (available through the web-browser) when optimizing the design in DS Simulia Tosca.

4. Examples

Topology optimization of the space bracket with Altair Optistruct through ISCDE was performed and shown in Figure 6. Mass reduction makes up 43%. The bracket was manufactured using the technology of titanium 3D printing. For optimal design all restrictions (such as stress safety factors, natural frequencies) are satisfied.

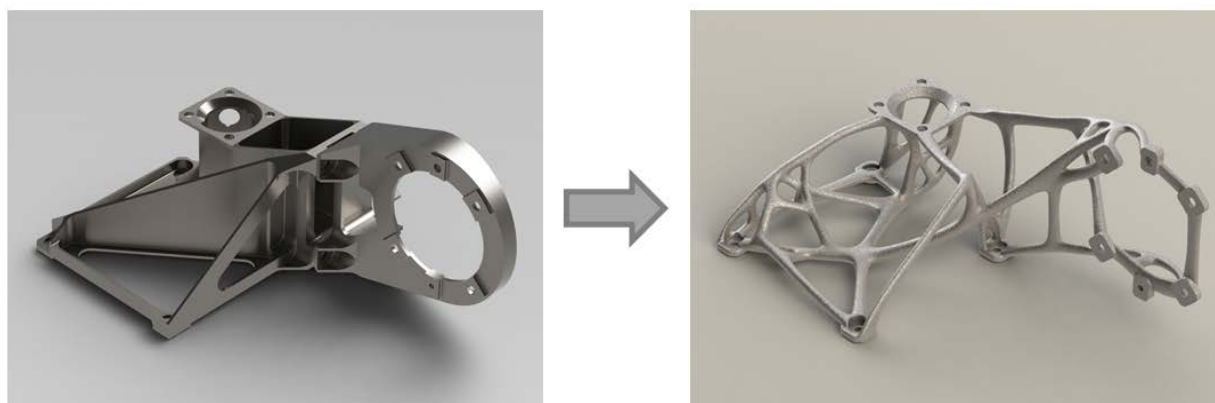


Fig. 6. Topology optimization of space bracket.

Parametric design optimization of space waffle shell Parametric design optimization of space waffle shell with Esteco modeFrontier through ISCDE was performed and shown in Figure 7. Mass reduction is 32%. MOGAI algorithm was used. For optimal design all restrictions (such as stress safety factors, natural frequencies, buckling safety) are satisfied. The original shell is manufactured from aluminum billet by milling.

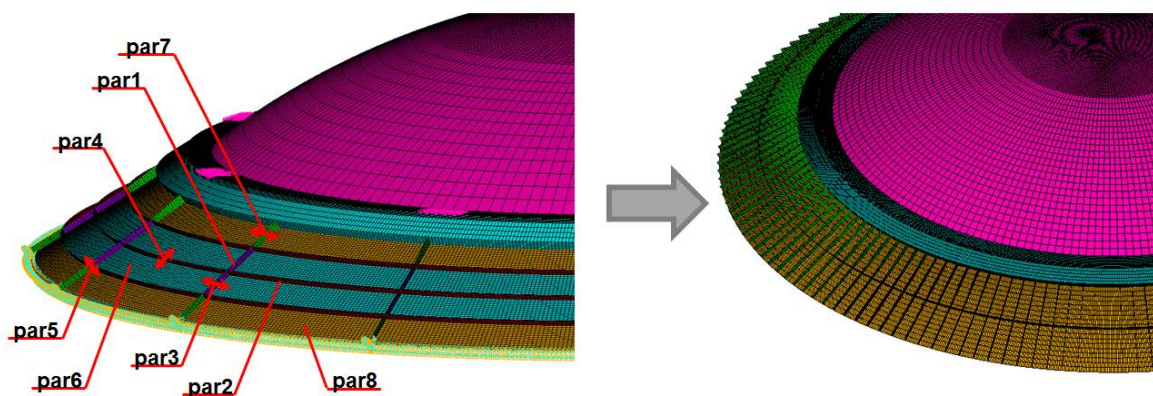


Fig. 7. Parametric design optimization of space waffle shell.

Topology optimization of stellar sensor bracket with Simulia Tosca Structure through ISCDE was performed and shown in Figure 8. Mass reduction is 60%. Topo Sensitivity algorithm, based on SIMP model and Method of Moving Asymptotes was used. For optimal design, stress constraint and first natural frequency are satisfied.

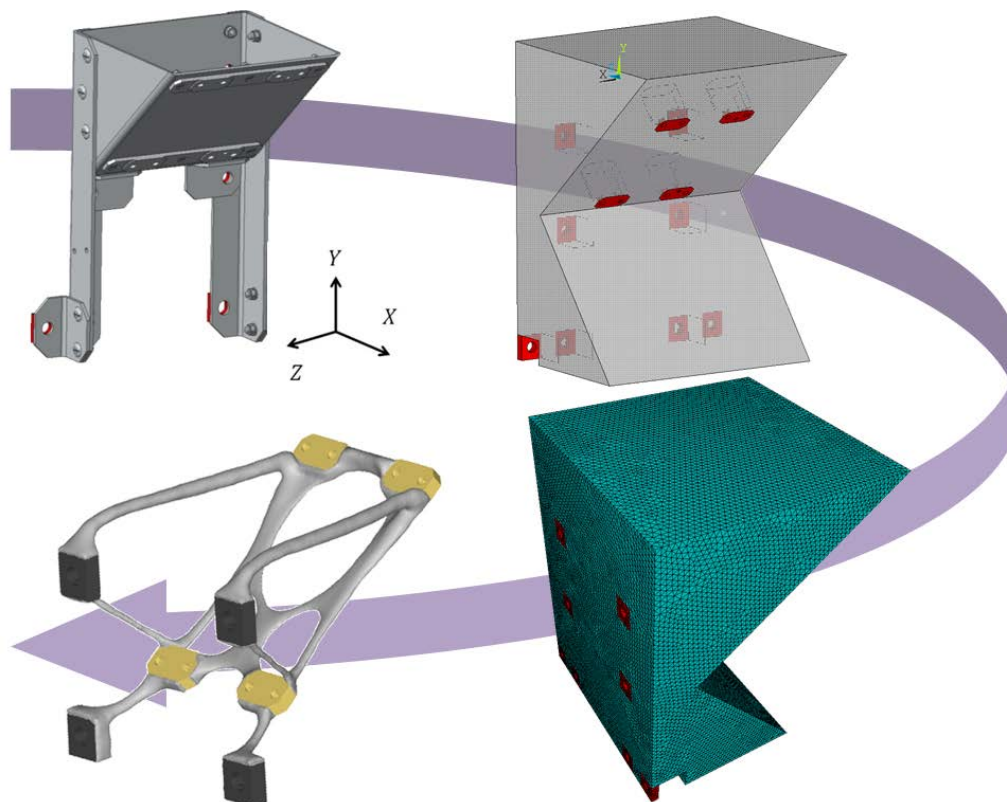


Fig. 8. Topology optimization of stellar sensor bracket.

5. Conclusion

Within the framework of the work, topology optimization program module and integrated computer-aided design and engineering system are developed. Topology optimization of bracket and parametric design optimization of space waffle shell were carried out through ISCDE. The obtained results will be used in the Russian space companies.

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