INNOVATIVE DESIGN OF THE COMPOSITE LATTICE FRAME OF A SPACECRAFT SOLAR ARRAY

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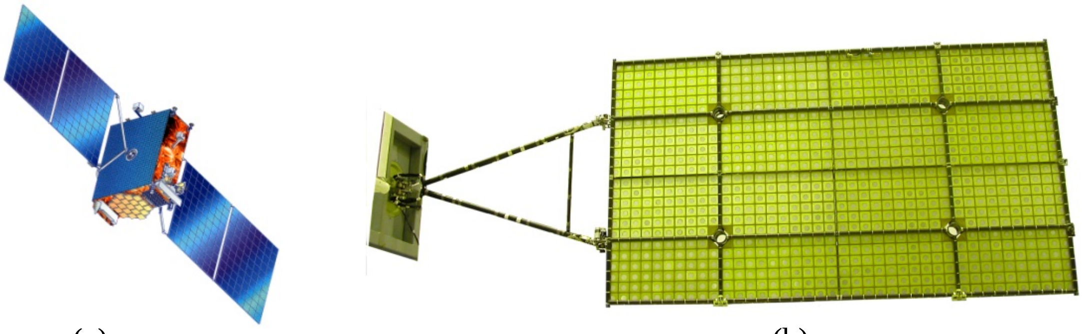
SUMMARY

A novel design of the composite structural frame for the spacecraft solar arrays is presented in the paper. The frame is composed of two parallel lattice composite plates assembled into the three-dimensional panel using frame-like connectors. Modelling and modal analysis of the panel solar arrays based on the proposed technology are discussed.

Keywords: Spacecraft solar array; Composite lattice frame; Design optimisation;

INTRODUCTION

Photovoltaic solar arrays are the major components of the systems providing spacecraft power generation. Greater capabilities of the spacecraft designs and mission applications require implementation of more cost and mass efficient high power systems. Solar array structural frames evolved over the years from various body-mounted configurations and single panel flip-out designs to multi-panel sun-oriented deployable systems [1]. Most designs of the deployable solar arrays employ panels and modules that are stowed folded and could be deployed in various configurations [2]. One of the typical architectures is shown in Fig. 1 (a) where the panels are deployed in an array of two solar wings (see Fig. 1 (b)) attached to either side of a spacecraft.



(a) (b)

Fig.1 Spacecraft solar array architecture: (a) spacecraft; (b) solar wing design. *Courtesy of ISS-Reshetnev Company.*

An important criterion of the solar panel efficiency is the mass per unit area covered by photovoltaic cells. The less the value of this parameter, the higher the total area of the photovoltaic cells for the same mass of the panel and, correspondingly, the greater amount of solar energy can be accumulated. The substantial reduction of the mass per unit area of the panel covered by photovoltaic cells can be achieved through the reduction of the mass of the panel frame assembly. Besides the mass efficiency, the other set of important requirements to the panel frame design includes system cost, power growth capability, overall deployed stiffness and dimensional stability under operating temperatures. The frame should withstand the mechanical loadings exerted on the structure during the delivery to orbit and deployment. Also, the frame assembly is subjected to the substantial temperature changes. In order to comply with these requirements, conventional designs of the rigid solar panel arrays normally employ honeycomb sandwich structures or frames made from composite tubes joined by metal fittings.

This paper presents a novel design concept of the composite lattice frame of the deployable solar arrays made from carbon fibre reinforced plastic (CFRP) including the appropriate fabrication techniques. The finite element model of the frame assembly is developed to allow for the dynamic and thermal analyses to be performed. Some aspects of the structural design of the solar panels based on the proposed concept are discussed taking into account constraints imposed on the vibration frequencies.

LATTICE FRAME DESIGN

The frame is composed of two parallel grid composite plates made from unidirectional carbon fibre reinforced plastic by filament winding and assembled into the lattice frame panel. Both plates are fabricated simultaneously by winding of the pre-tensioned carbon fibre tape or roving into the slots regularly arranged on the flat mandrel (see Fig. 2).

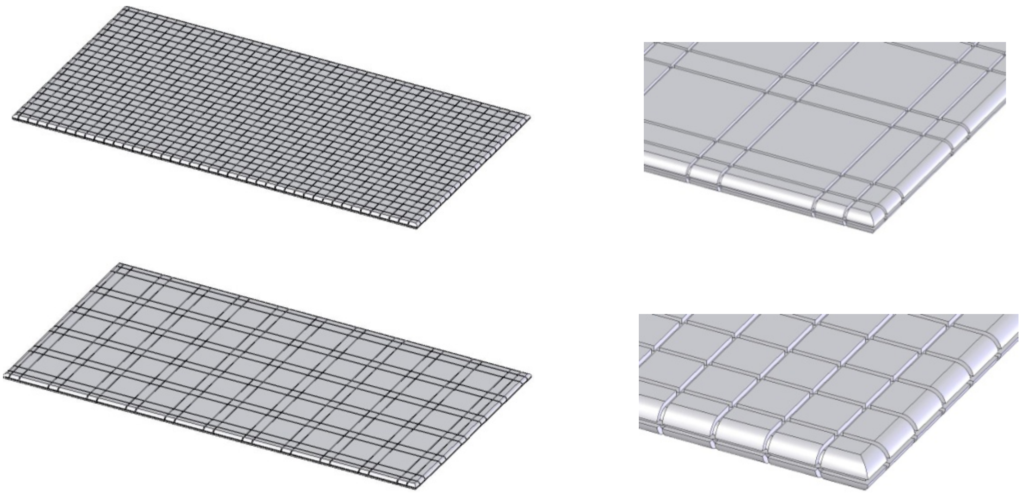


Fig. 2 Flat mandrels with various slot patterns for filament winding.

The slots are made in the silicon rubber elastic coating of the mandrel. Various patterns of the grid can be manufactured depending on the frame design and desired ribs layout, density and orientation (see Fig. 2). The mandrel design could include additional devices exerting extra tension on the fibres in the ribs of the grid providing better uniformity in the pre-tensioning of the frame reinforcement. Once the winding and curing is complete, the plates are cut and removed from the mandrel as shown in Fig. 3.

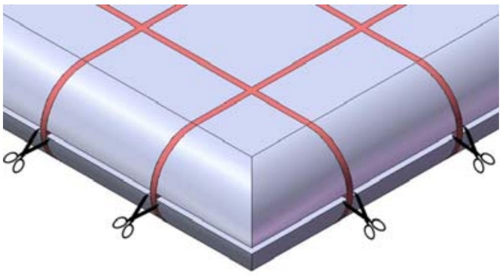


Fig. 3 Removal of the wound lattice plate from the mandrel.

Examples of the grid plates with various lattice layouts are shown in Fig. 4. The bending stiffness of these plates is rather low. Hence, they cannot be used as the frames of the solar panels on their own.

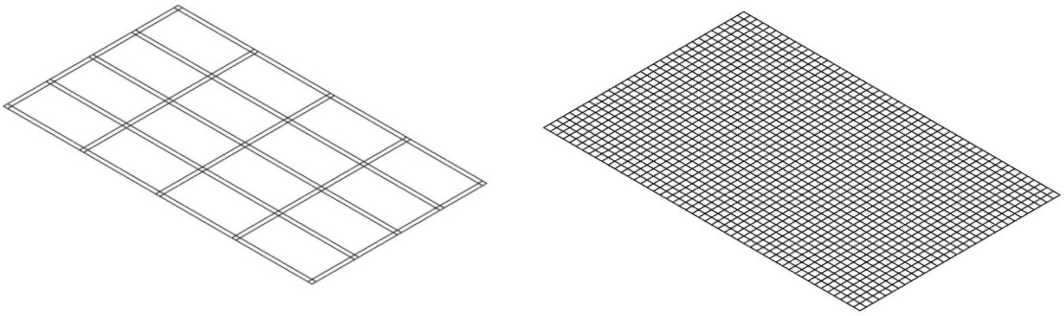


Fig. 4 Grid plates with various types of the reinforcement.

The overall panel bending stiffness can be substantially improved if the panel is composed of two parallel planes kept apart at some distance. In order to achieve this, the special joining elements: frame-like connectors were designed (see Fig. 5). The ribs of the connector are made in the form of profiles with the channel-like cross sections. So, each rib of the connector has a slot as shown in Fig. 5.

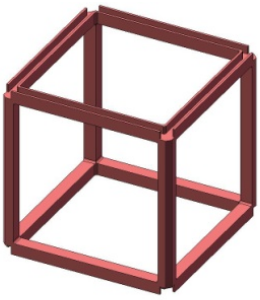
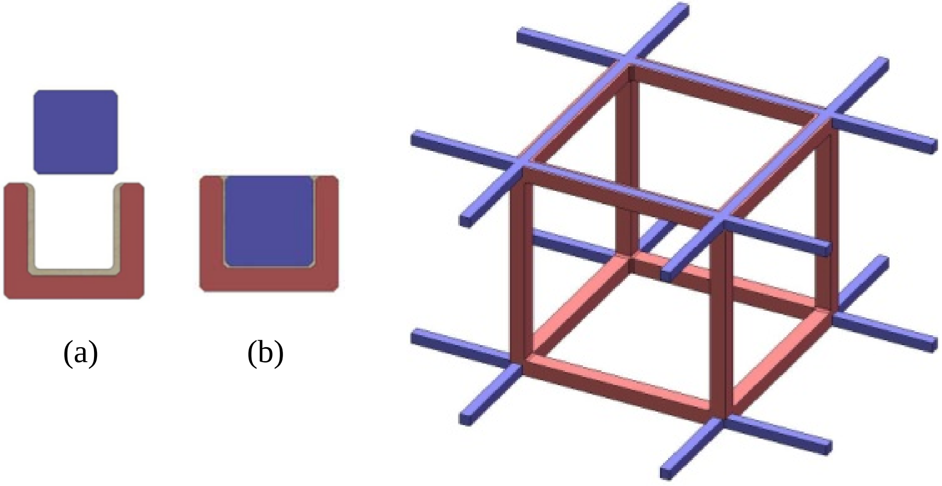


Fig. 5 Frame-like connector.

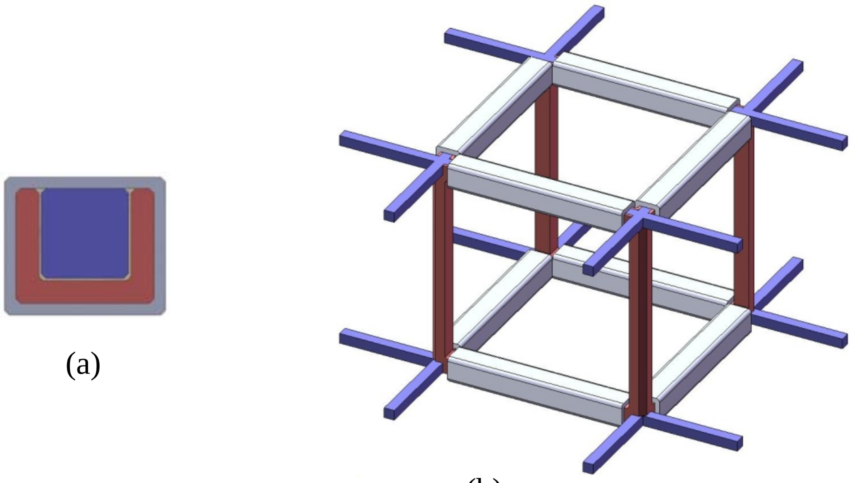
The connectors can be made from lightweight metal alloy by high pressure casting or be moulded from the short fibre randomly reinforced plastic. The grid plates are assembled with the frame connectors by means of “click” joints. The ribs of the grid plates are snapped into the adhesive pre-coated click-joint slots (see Fig. 6a, b) of the connector ribs (see Fig. 6c).



(a) (b)

(c)

Fig. 6 Lattice frame assembly procedure.



(a)

(b)

Fig. 7 Lattice frame with wrapped ribs.

Once the panel frames are assembled, the ribs of the connectors could be additionally reinforced by wrapping carbon fibre tape as shown in Fig. 7. Depending on the locations layout and number of connectors used, the various configurations of the solar panel frames can be assembled (see Fig. 8).

LATTICE FRAME STRUCTURE: DESIGN ASPECTS

The frame connectors can be placed with various pitches and layouts creating the frames with certain patterns as shown in Fig. 9. This affects the overall bending stiffness of the assembled panel frame.

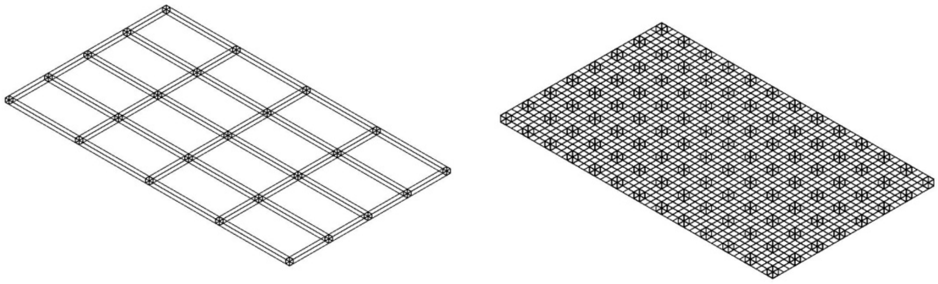


Fig. 8 Solar panel frames

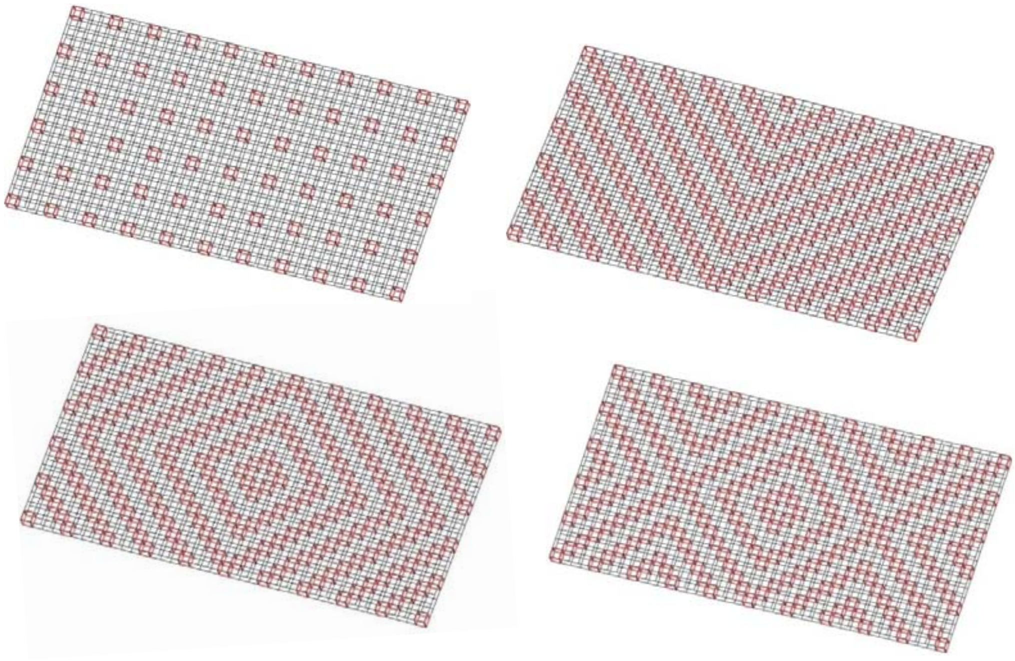


Fig. 9 Solar panel frames: various connector placement patterns

Depending on the specific design requirements, the connectors can be placed more frequently in certain areas, e.g. at the places where the panel is designed to be attached to the spacecraft, deployment rods or to the adjacent solar panels. More rigid frame connectors can be used at the points of external attachments and joints. The lattice structure of the panels allows for various layouts of the photovoltaic cells to be placed on the frame.

The input data for the solar panel design includes the total area required to be covered by the photovoltaic cells and the way the separate panels are joined. The design constraints are imposed on the overall stiffness of the structure and the allowable thermal deformations. The mass of the panel is normally taken as the objective function in design optimisation. The set of design parameters normally includes the overall thickness of the panel frame, distance between the ribs of the lattice plate, rib's cross-sectional dimensions and the layout of the connectors' placement. A number of fabrication constraints and solar panel configuration requirements could be additionally imposed on the design parameters. The design is based on the finite element modelling and direct analyses of the panels in which the design parameters vary within their allowable ranges.

FINITE ELEMENT MODELLING AND MODAL ANALYSIS OF THE LATTICE FRAMES

Modelling and modal analysis of the composite lattice frames of the solar arrays have been performed using finite-element method (commercial code COSMOS/M [3]). The panel assembly has been modelled as a frame. The beam elements BEAM3D have been used to model the ribs of the grid plates and connectors. Using the internal COSMOS/M programming language, the geometry and FEM model generator was developed. The input data for the modelling includes: frame dimensions in plane, overall thickness, sizes of the lattice cells, dimensions of the ribs' cross-sections for the grid panels and connectors, elastic properties, densities and coefficients of linear expansion for the rib's materials. The generated FEM models have been used for the static, dynamic and thermal analysis of the lattice frames.

The modal analyses have been performed for the lattice frames with various types of the boundary conditions modelling various versions of the panel attachments to the spacecraft or to the deployment rod (see Fig. 10). The first frame was fixed at the corners (see Fig. 10a). The second one had two jointing attachments at the long side of the panel (see Fig. 10b). The third frame was fixed at the four supports symmetrically placed at the short sides of the panel (see Fig. 10c). The rectangular 1 × 2 m frame made from CFRP was analysed. The total thickness of the frame was 50 mm with the size of the grid cell being equal to 50 mm and the cross-sectional rib's dimensions being 2 × 2 mm. The connector pitch was 150 mm along each side of the panel. Moduli of elasticity of the grid panel's and connector's rib materials were $E_{grid\ rib} = 100\,\text{GPa}$ and $E_{conn} = 70\,\text{GPa}$, respectively. The corresponding densities were equal to: $\rho_{grid\ rib} = 1500\,\text{kg/m}^3$ and $\rho_{conn} = 2700\,\text{kg/m}^3$. The total mass of the panel frame was 1.175 kg.

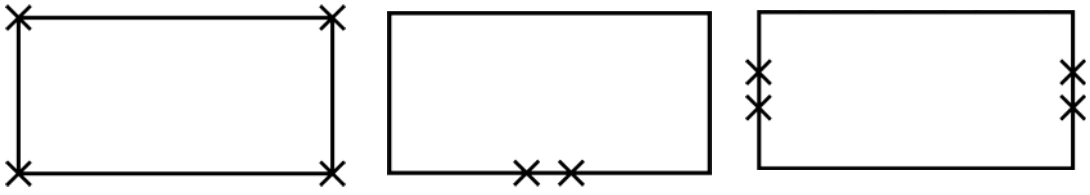
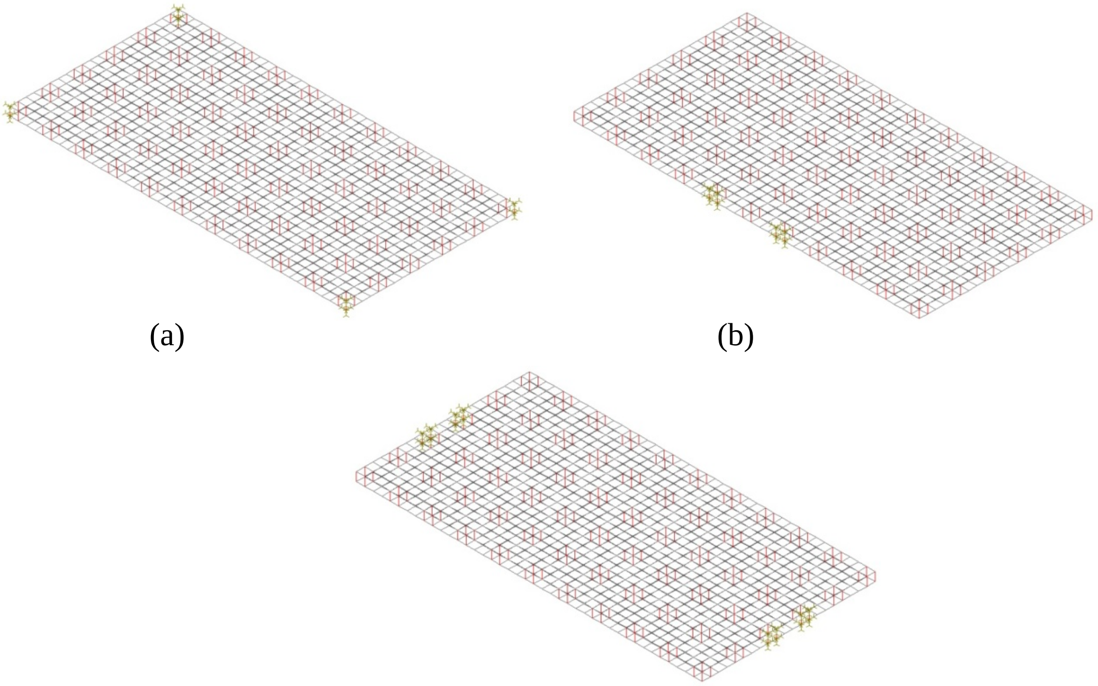


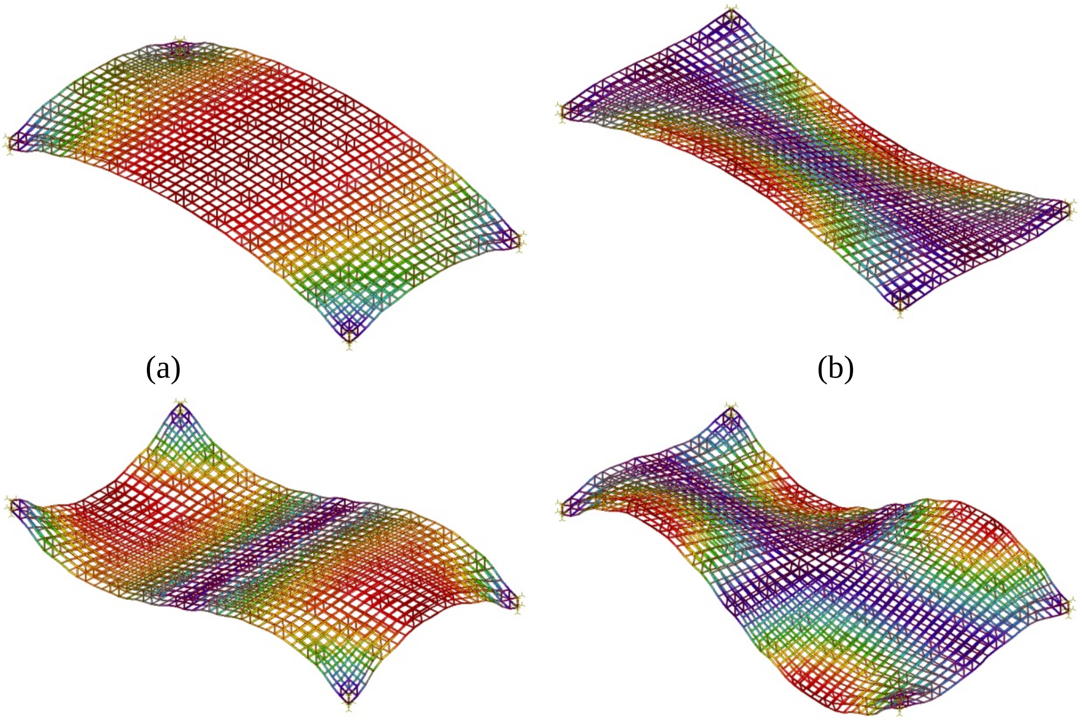
Fig. 10 Panels' supports.

The finite element meshes for the three panels with different supports (see Fig. 10) are shown in Fig. 11. The first four frequency modes found for each panel are presented in Figs. 12 – 14. The corresponding frequency values are given in Table 1.



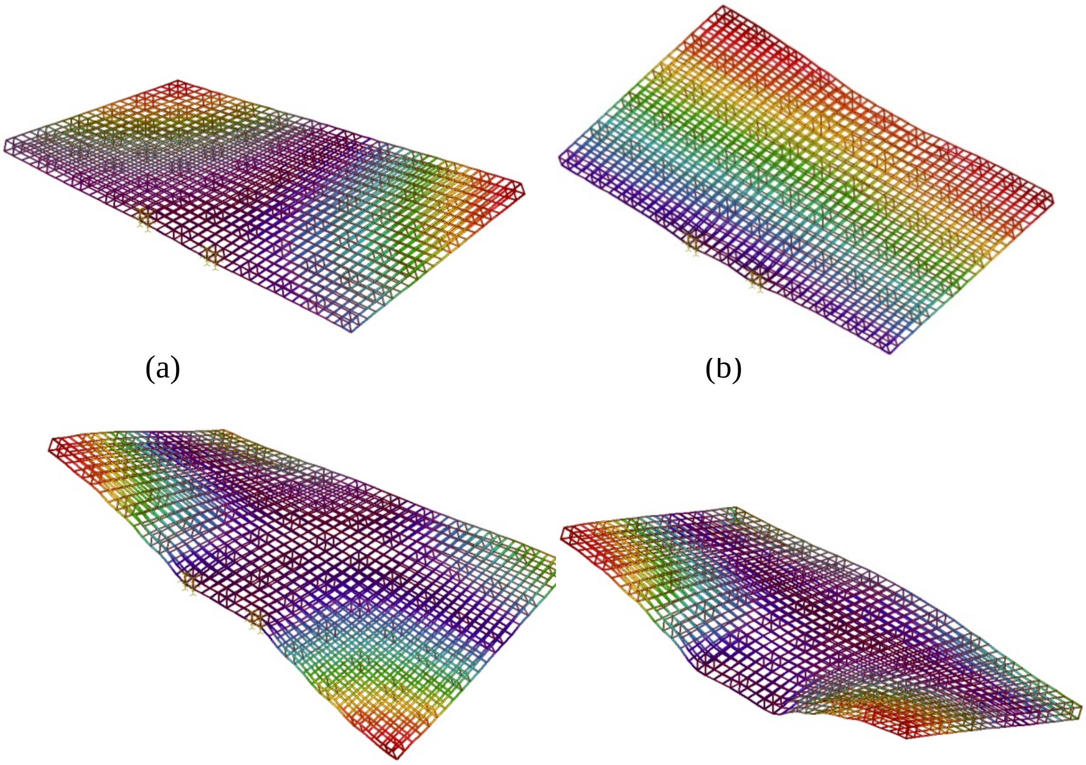
(a) (b) (c)

Fig. 11 Meshed plates with various supports.



(a) (b) (c) (d)

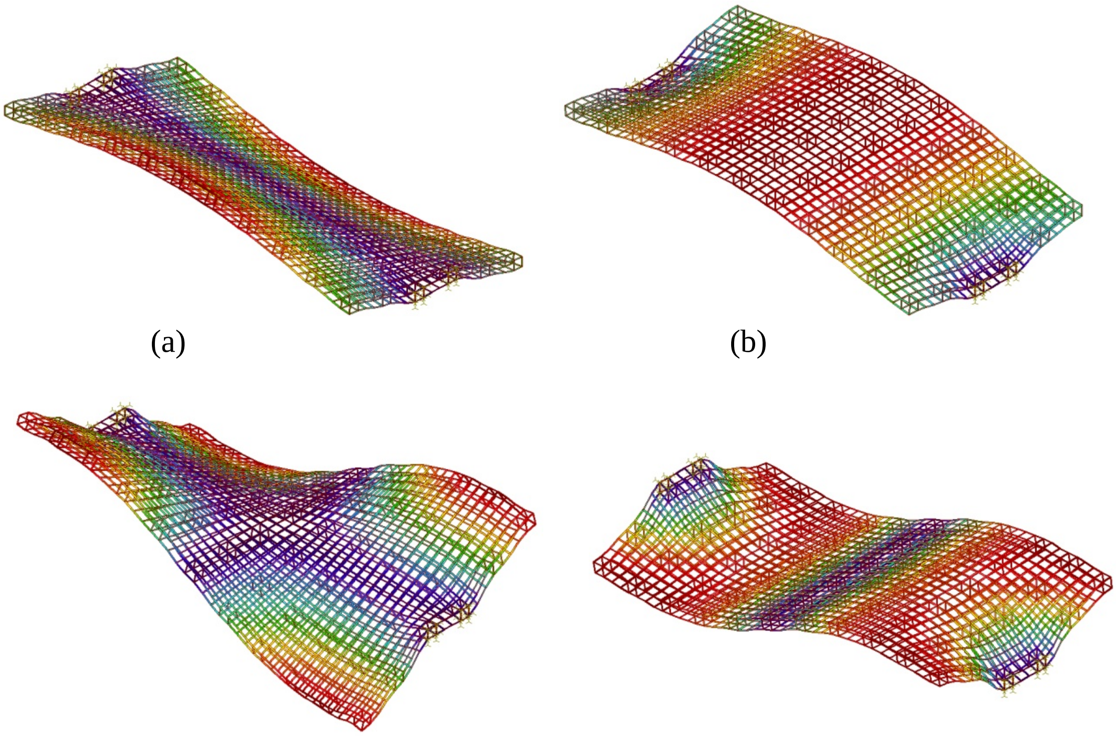
Fig. 12 Vibration modes of the lattice frame fixed at the corners: (a) first; (b) second mode; (c) third; (d) fourth mode.



(a) (b)

(c) (d)

Fig. 13 Vibration modes of the lattice frame fixed at the two points located at the long side: (a) first; (b) second mode; (c) third; (d) fourth mode.



(a) (b)

(c) (d)

Fig. 14 Vibration modes of the lattice frame fixed at the four points located at the short sides: (a) first; (b) second mode; (c) third; (d) fourth mode.

Table 1. First four frequencies of the panels: $f_i \ (i = 1,\ldots,4)$, Hz

Type of frame support	f_1	f_2	f_3	f_4
(a)	10.116	13.596	18.936	27.347
(b)	4.055	5.924	12.874	15.443
(c)	10.066	10.734	19.072	20.830

The data obtained can be used for the panel frame design subject to the specified natural frequency constraints.

CONCLUSIONS

The paper illustrates the novel design of the composite lattice frame of a spacecraft solar array. The frame assembly consists of two parallel CFRP grid plates joined by the set of the frame-like connectors. The connectors can be placed with the various pitches and layouts. This creates an opportunity for the development of versatile design of the lightweight rigid frameworks suitable for the support of the spacecraft solar arrays. The resulting framework structure has high stiffness-to-mass ratio and can be readily assembled into various configurations. The fabrication techniques are outlined and assembly design aspects are discussed. The results of the modal analyses based on the use of the finite element modelling technique developed in this work are presented for the CFRP panels with various types of the supports.

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