PROTON – M COMPOSITE INTERSTAGE STRUCTURES: DESIGN, MANUFACTURING AND PERFORMANCE

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The paper is concerned with the development of composite structures for Russian space launcher Proton-M shown in Fig.1

Fig. 1

In June 2005, forty years have past since the first launching of Russian Proton, originally developed as a two-stage rocket system. Modern three- or four-stage Proton, being in operation since 1967, is now the basic rocket of the Russian State Space Program. In more than 300 shots, Proton has launched into space satellites Kosmos, Ekran, Raduga and Gorizont, probes for Moon, Mars, Venus and Halley comet exploration, space stations Salyut and Mir, International Space Station Modules.

Though Proton efficiency is expected to be on the proper level up to 2010, its mass and energy characteristics are progressively improved, particularly, by application of high-performance and weight-efficient composite structural elements. Proton-M modification of the launcher incorporates, in addition to the traditional carbon-epoxy sandwich fairing, Anisogrid composite interstage structures.

Anisogrid Composite Lattice Structures

Anisogrid composite lattice structures developed at the Central Research Institute for

Special Machinery (CRISM) about 25 years ago [1] and consisting of unidirectional carbon-epoxy ribs and, if necessary, of an external skin made by filament winding demonstrate high weight and cost efficiency in comparison with traditional metal or composite ring-stringer stiffened, Isogrid and sandwich structures.

Lattice structures are made by automatic wet winding during which impregnated carbon tows are placed into helical and circumferential grooves formed on the surface of the mandrel with the aid of

– machining of the foam core covering the mandrel,
– forming grooves in the rubber-type coating that is pulled out of the structure after curing,
– forming grooves in thin metal panels mounted on the mandrel surface.

These processes, each resulting in a specific structure, provide in addition to high load carrying capacity and stiffness, proper damping acoustic attenuation, insolation, sealing, etc.

In general, lattice structures are characterized with six design variables, i.e.,

– the shell thickness (the height of the rib cross section),
– the angle of helical ribs with respect to the shell meridian,
– the widths of the helical and the circumferential (hoop) ribs cross-sections,
– the spacings of the helical and the hoop ribs.

The ribs are the principal load-bearing elements of the structure, whereas the skin, the necessity of which can be caused by design requirements, is not considered as a load-bearing element in design of lattice structures. Moreover, the skin thickness, being treated as a design variable, degenerates in the process of optimization because the skin contribution to the structure mass is higher than that to strength and stiffness of the structure. Thus, the optimal lattice structure has no skin, and if the actual structure needs a skin, its thickness and structure are preassigned to meet the structural and the manufacturing requirements.

Three basic methods have been developed to design cylindrical lattice structures for axial compression, i.e.,

– geometric programming [2],
– minimization of safety factors [3],
– numerical optimization [4].

Designed structures are analyzed with allowance for skin, doors and other structural elements by finite-element method based on discrete models composed of beam-type elements or continuum models simulating the structure with anisotropic laminated shell-type elements.

A specific feature of lattice structures is associated with the fact they cannot be scaled or modeled experimentally. Actual properties of the structure elements can be found only by testing of the full size structure and its fragments. Naturally, it can happen that thus found material properties do not coincide with the values used for design, and the design should be refined. Thus, testing of the actual structure is a necessary step of the design process (in addition to conventional proof tests supporting the design).

Existing and possible applications of lattice structures include

– interstages, intertanks, payload adapters, and fairings of launch vehicles,
– aircraft fuselage sections, wing boxes, and ribs, horizontal and vertical stabilizers,
– helicopter tail beams,
– space telescope bodies,
– submarine bodies,
– masts, columns, pipes and other elements of civil engineering structures.

The following section demonstrate the application of Anisogrid lattice structures to Proton-M launcher.

Payload attach fitting

Payload attach fitting (adapter) is a primary structure of a commercial rocket providing the interface between a rocket and a spacecraft. Because the diameters of attach rings of a rocket and of a spacecraft are usually significantly different and the distance between the rings is relatively small, a typical adapter is a conical shell with rather high angle between its meridian and the rocket axis.

Existing adapters are made in the form of stringer stiffened or sandwich aluminum or carbon-epoxy composite shells. Because the adapter is covered with a rocket fairing while launching, its can be also made in the form of a lattice structure consisting of a system of ribs [5].

Anisogrid lattice adapter for Proton-M is shown in Fig. 2. The structure is manufactured by continuous wet filament winding during which carbon fiber tows impregnated with epoxy resin are placed into the grooves formed in elastic coating of the mandrel. The coating is assembled of silicon rubber panels which are fixed on the mandrel before winding and are pulled out of the lattice structure after curing. The winding process is shown in Fig. 3. The structure shown in Fig.2 has the following parameters

- larger and smaller diameters 2500 mm and 1300 mm,
- height 900 mm,
- total mass 50 kg in which the mass of the lattice structure is 28 kg,
- design ultimate axial compressive force 2 MN,
- axial stiffness 440 KN/mm.

Fig.2

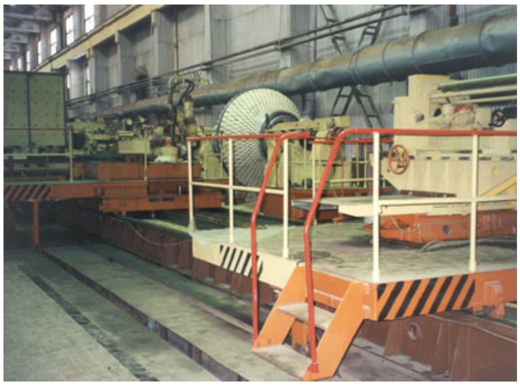

Fig.3

The design strength and stiffness of the structure has been verified experimentally (the testing is shown in Fig.4) and by the finite-element analysis based on the discrete model presented in Fig.5

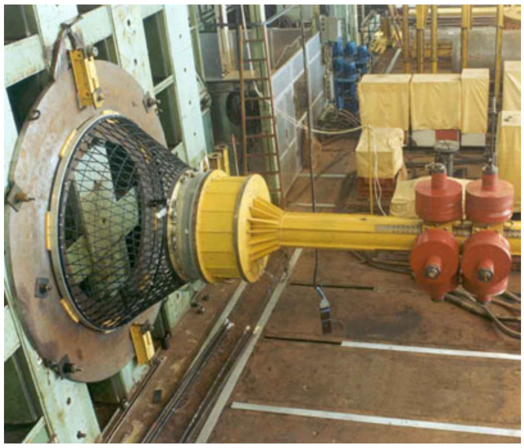

Fig.4

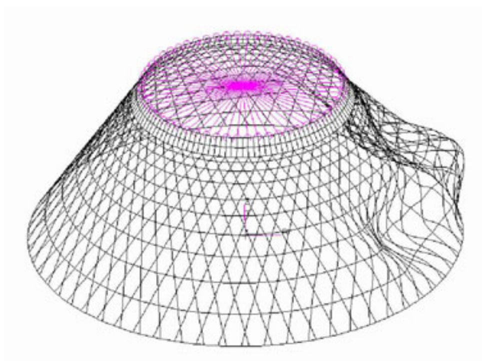

Fig.5

Designed by analytical [6] or numerical [7] methods, lattice composite adapters demonstrate more than 40% weight saving with respect to aluminum prototypes. By now, eight successful launches of Proton-M have been undertaken with lattice adapters. One of them, the 303-th launch of June 17, 2004, has resulted in the record for Proton mass of the geosynchronized satellite – 5575 kg.

Proton-M Composite Fairing

The spacecraft mounted on the launcher with he aid of the adapter discussed above is covered with 15 m long composite fairing presented in Fig.6. The buckling mode of the fairing following from finite-element analysis based on a continuum model of the structure is shown in Fig.7.

Fig.6

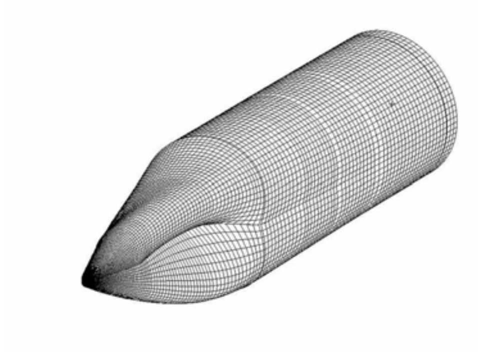

Fig.7

Interstage structures of the second stage

The second stage of Proton-M is 17 meters long and is located between the truss (see Fig.1) and the engine of the third stage. The stage is going to be incorporated into the launche with two Anisogrid composite upper and lower interstages whose diameter is 4.1 m and length is about 3 m each.

The winding process of the upper interstage is shown in Fig.8, whereas its internal (a) and external (b) views are presented in Fig.9. The structure consists of carbon-epoxy helical and hoop ribs and a thin aramid-epoxy skin (Fig.9). The design ultimate axial compressive force which is about 7.5 MN has been verified experimentally and by means of finite-element analysis based on a discrete model shown in Fig.10.

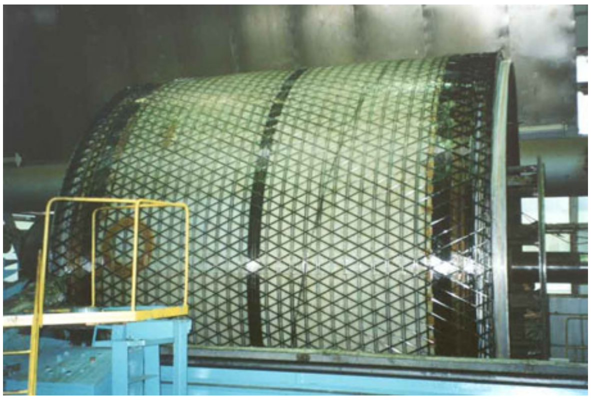

Fig.8

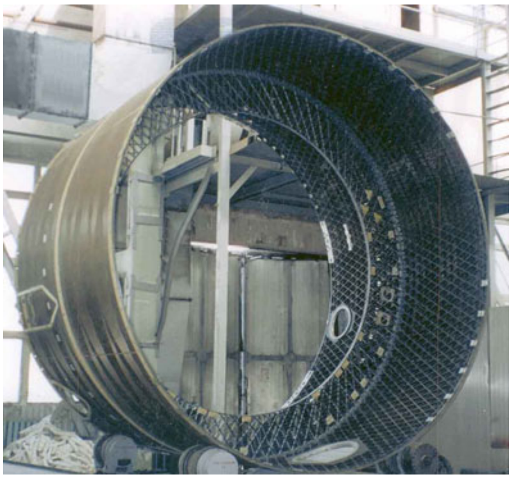

Fig.9 (a)

Fig.9 (b)

The interstage has a load-bearing transportation lattice ring made by winding and mechanically joined to the shell (Fig.9 (a)).

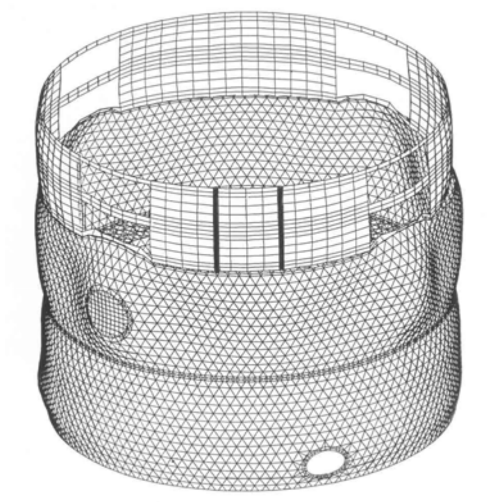

Fig.10

The lower interstage has a similar structure. The winding process is shown in Fig.11, whereas the general view of the structure is presented in Fig.12. The lower interstage is a highly loaded structure – the ultimate design axial compressive force is about 14 MN.

At the lower cross section the interstage is loaded with 20 axial forces transferred from the truss (Fig.1). To take these forces, aluminum stringers are incorporated into the composite lattice structure (Fig.12).

Fig.11

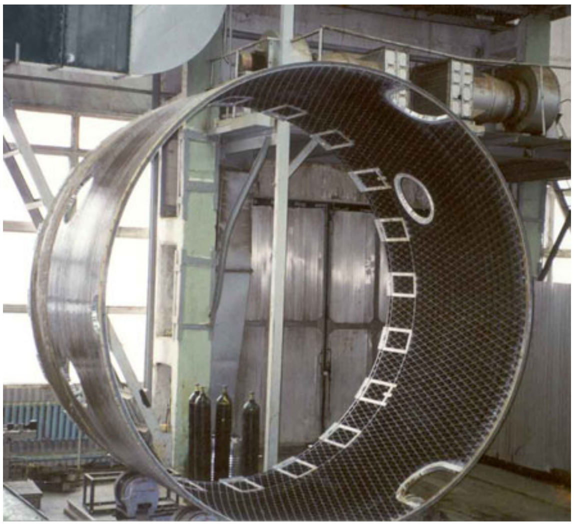

Fig.12

Substitution of Inisogrid composite lattice interstages for traditional ring-stringer stiffened aluminum structures results in 500 kg mass reduction for Proton-M second stage.

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ATTACHMENT

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