One-shot fibre-placed grid-stiffened structures with integrated attachment features

Grid-stiffened technology demonstrator panel

Contact details

Company	ATG Europe
Department	SpaceLabs
Website	http://www.atg-europe.com/atg-spacelabs
Name	Leonid Pavlov
Function	Programme Lead - Composites
Phone	+31629721786
E-mail	Leonid.pavlov@atg-europe.com

Introduction

Composite Grid Stiffened Structures (also referred to in literature as lattice, isogrid, anisogrid structures) have long been of interest as a replacement for honeycomb sandwich, aluminium isogrid constructions and skin-stiffened structures for aerospace applications but, for many decades, were not used due to the manufacturing and analysis challenges.

During the past 2 decades, remarkable progress has been made in the manufacturing of these structures at several locations around the United States, Russia and Japan. Programs at CRISMB, The Boeing Company, the US Air Force Research Lab, McDonnell-Douglas (now part of The Boeing Company), Alliant Tech Systems and others have pushed the state of the art in grid-stiffened structures, finally leading to processes and methods of interest to real-world production systems.

As a result of their development, Composite Grid Structures have found their way into the Proton-M launcher interstages, payload adapters and satellites. These structures mostly feature a filament winding manufacturing process. In this particular version of the process (filament winding of lattice structures), the volume fractions used for the composite manufacturing are rather low (in the order of 40% fibre) due to the nodal intersection of the ribs. This limitation has significant implications on the weight and stiffness of the obtained designs, making the possible weight savings rather low.

Composite lattice structures are normally fabricated using a continuous fibre composite material. These structures are defined by a lattice pattern (grid) of stiffeners. In the case that this grid is supporting a shell structure (skin) – the architecture is typically referred to as a grid-stiffened structure. In most cases ribs run in two to four directions forming a regular pattern (Figure 1). In rare cases, a second shell structure (skin) is present at the top of the stiffener pattern, opposite the first skin. Sometimes the cell pattern is made irregular by adding further ribs in specific locations.

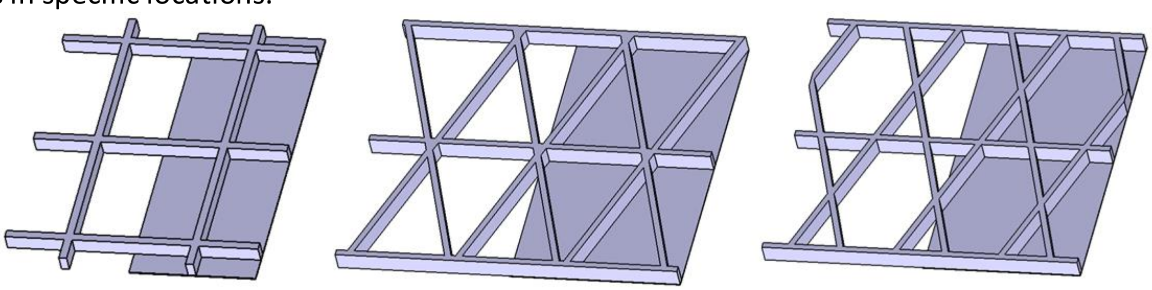

Figure 1. Representations of different grid architectures: left - orthogrid, middle - regular triangular and right - anisogrid grids. Lattice structure types are shown on the left portion of each figure and grid-stiffened structures on the right.

Context

The Projects department of ATG Europe is among others involved in development of technologies and products using composite materials. One of the development directions is in the field of composite grid-stiffened structures. Here, ATG Europe has created a high-quality cost-efficient production process, integrated all necessary realistic structural features into the global architecture and production process and came up with efficient and accurate methodologies for design and analysis of composite (grid-stiffened) structures.

ATG Europe is working towards developing and implementing the grid-stiffened and lattice composite architectures in a number of products across different industries. The industries include: space, aeronautics/helicopters, energy, machine industry, robotics, etc. Examples of targeted products are: aircraft fuselage panels, helicopter panels, wind turbine and pole components, ultra-stiff machine frames, robot arms, interstages, payload adapters and fairings, spacecraft central tubes and shear webs, etc. According to the needs of the product, the manufacturing technology is selected, and it can be: pre-preg fibre/tow placement, vacuum infusion, RTM, filament winding, thermoplastic tow placement, etc.

The list of products where this technology shows great promise in terms of cost, lead time, functionality and mechanical performance is much broader that the one provided. In order to advance and market the technology, it is important, however, to demonstrate the feasibility of certain technological aspects that are often regarded as critical in product realization. The demonstrator panel serves the purpose of showcasing the advances in grid-stiffened structures made by ATG Europe. These advances are bridging the gap between the theoretical concept behind the architecture and the practical requirements and needs of real structures.

The design of the demonstrator and its main integrated features is based on the feasibility study conducted by ATG Europe for the Ariane 6 launcher interstage 2/3 structure and EDRS-C satellite central cylinder. Some combination of these integrated features however is applicable to any of the above-mentioned products and hence its demonstration in one integrated panel proves the capability to handle design, analysis and manufacturing challenges associated with such features.

The design of the demonstrator has been largely based on the Ariane 6 (PPH) Interstage 2/3 structure. Its performance has been verified by FEM calculations using analysis methods developed by ATG. For most dimensions a scaling of 1:2 was used, the demonstrator is representing part of the structure circumference, see Figure 2. The next step is to manufacture a full cylindrical/conical structure of considerable dimensions using automated fibre and tape pre-preg placement processes.

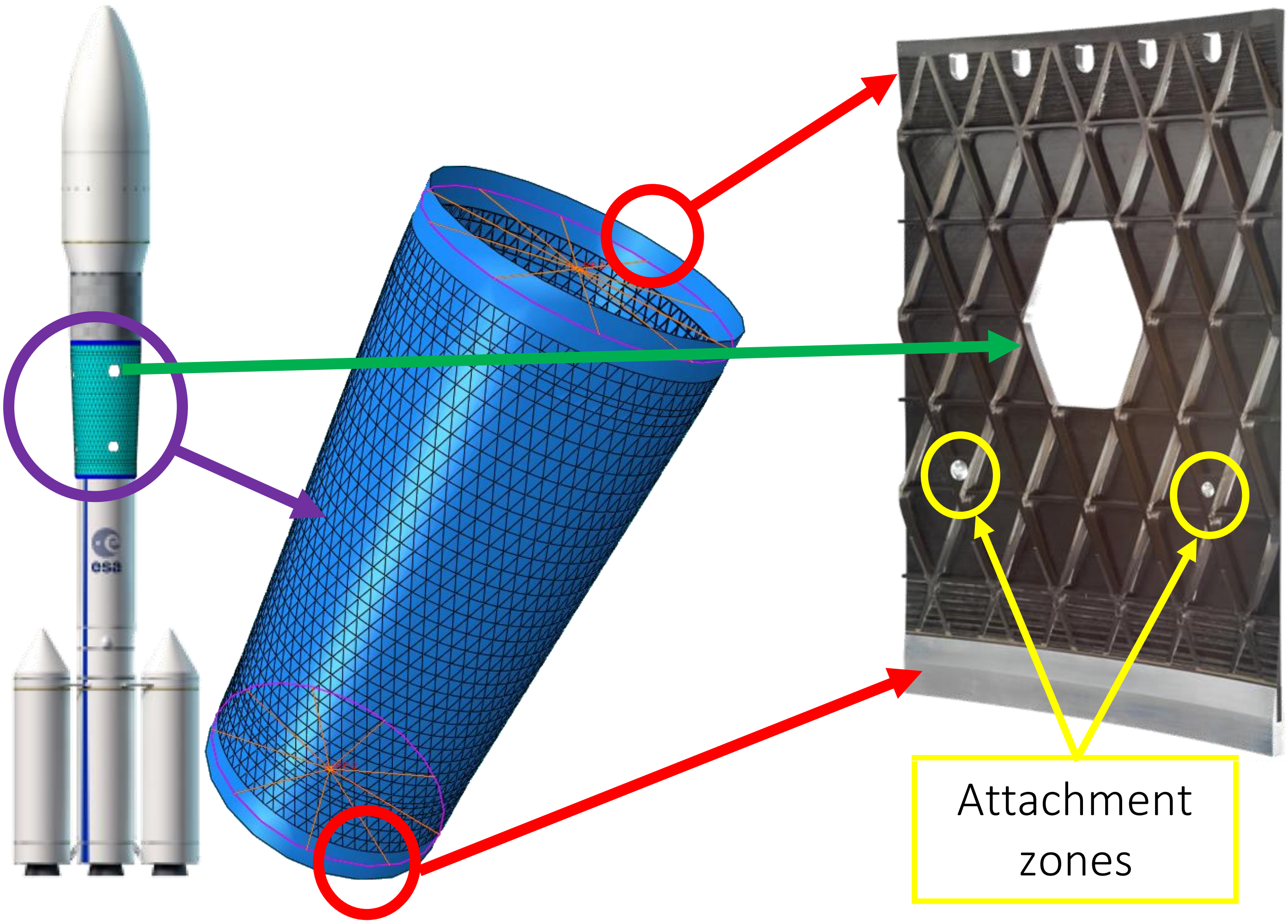

Figure 2. Demonstrator definition logic. Right – Ariane 6 (PPH) with the highlighted representation of the grid-stiffened interstage. Middle – magnified grid-stiffened interstage. Left – Technology demonstrator, with load introduction zones, attachments and a cut-out.

Demonstrator and manufacturing technology

ATG Europe has developed a unique fibre placement manufacturing method for lattice and grid-stiffened composite structures (patent pending) that allows laying up and curing the structure (including all additional realistic structural composite details) in a true one-shot process. The demonstrator features practical structural aspects and has been manufactured using the developed one-shot manufacturing method. These practical aspects of the demonstrator include:

- An end zone with a metallic interface
- An end zone with a composite interface
- Curvature
- Cut-out with a skin reinforcement around it
- Realistic grid angle and height (representative for highly loaded structures)
- Two different integrated equipment attachment zones

The use of pre-preg materials with 60-65% fibre volume fraction maximizes the stiffness and weight advantages obtained (compared to grid-stiffened structures manufactured using filament winding), also because the fibres at the node are not interrupted (unlike in many other fibre placement methods for grid-stiffened and lattice composites). The integration of all structural components made possible through the one shot manufacturing step allows to also efficiently account for these in the design phase of the structure. Particularly, the manufacturing process developed by ATG Europe is influenced by the design requirements to fully transfer the loads applied in the load introduction points through the lattice architecture into the load introduction structures (end zones). To make this load introduction efficient, such zones must be properly integrated. This integration is achieved by integrating the plies of the load introduction and attachment zones with the plies of the unidirectional grids. The smart tooling design allows for obtaining a continuous surface of the grids, attachment and load introduction zones after this integration during layup. Testing campaigns performed by ATG Europe have shown the outstanding performance of these integrated zones.

Although the lattice or grid-stiffened architecture is not a new architecture per se, the developed implementations and manufacturing methods have significant advantages over existing manufacturing methods. The unique benefits of the developed manufacturing process and process/product design are:

- The fibres crossing at the node are uninterrupted
- High volume fractions (60-65%) are achieved due to the use of pre-preg materials
- Predictable end dimensions of the final product without iterations required to achieve desirable dimensions
- Integration of load introduction zones during the one-shot layup phase (Figure 3)
- Integration of equipment attachment zones during the one-shot layup phase (Figure 4)
- Local reinforcement of the skin and/or grids during the one-shot layup phase (Figure 5)
- Low scrap rate process that makes use of reusable tooling for subsequent layup and curing of further products.
- Suitability for automation – the layup process is highly automatable.

Two distinct types of load introduction zones have been developed: one that has a flat edge and can be integrated with other metallic or composite interfaces through bonding or bolting (Figure 3 left) and one that can be bolted directly to neighbouring structures. (Figure 3 right).
Inside or on any real structure various equipment (i.e. batteries, wire harness, fuel tanks, etc.) needs to be accommodated. Such equipment can have a significant weight and hence adds high and concentrated loads into the structure. For the purpose of attaching internal equipment, attachment zones of two types have been provided: metallic insert protruding through the structure, and metallic insert embedded from one side. One of the attachment zones is shown in more detail in Figure 4.

The findings and the performance of the structural concepts (grid architecture, load introduction, attachment zones) have been confirmed through structural test validation campaigns executed by ATG Europe. Cost and lead times estimates indicate that the grid-stiffened architecture offers a lower recurring cost and lead time than most alternative architectures, e.g. the composite honeycomb sandwich architecture.

The innovation is an example of design-process-material trinity: it is an innovative and unique manufacturing method which enables an efficient implementation of a clever design that is only made possible by using unidirectional composite materials. In this respect it is an integral innovation that is part of design-process-material thinking.

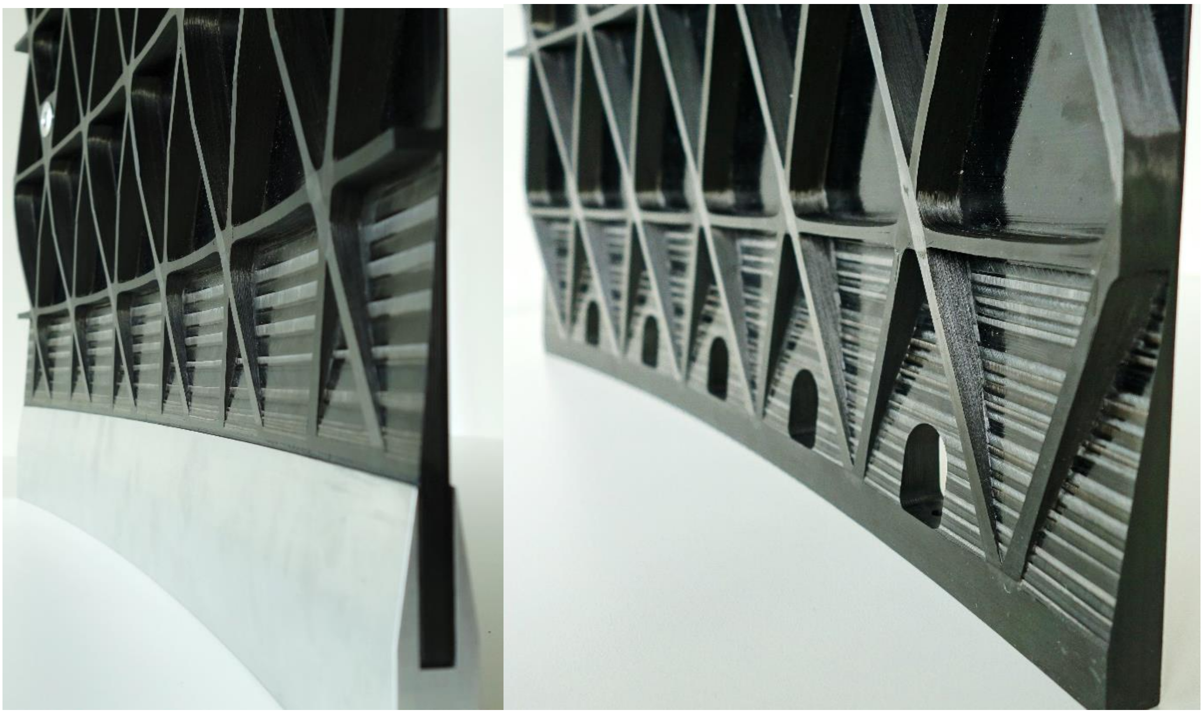

Figure 3. Two different load introduction zones into the part. Left: A long flat laminate section that can be e.g. bolted or bonded to another interface (in this case bonded to a metallic "ring"); Right - A composite interface that can be bolted directly to a neighbouring structure.

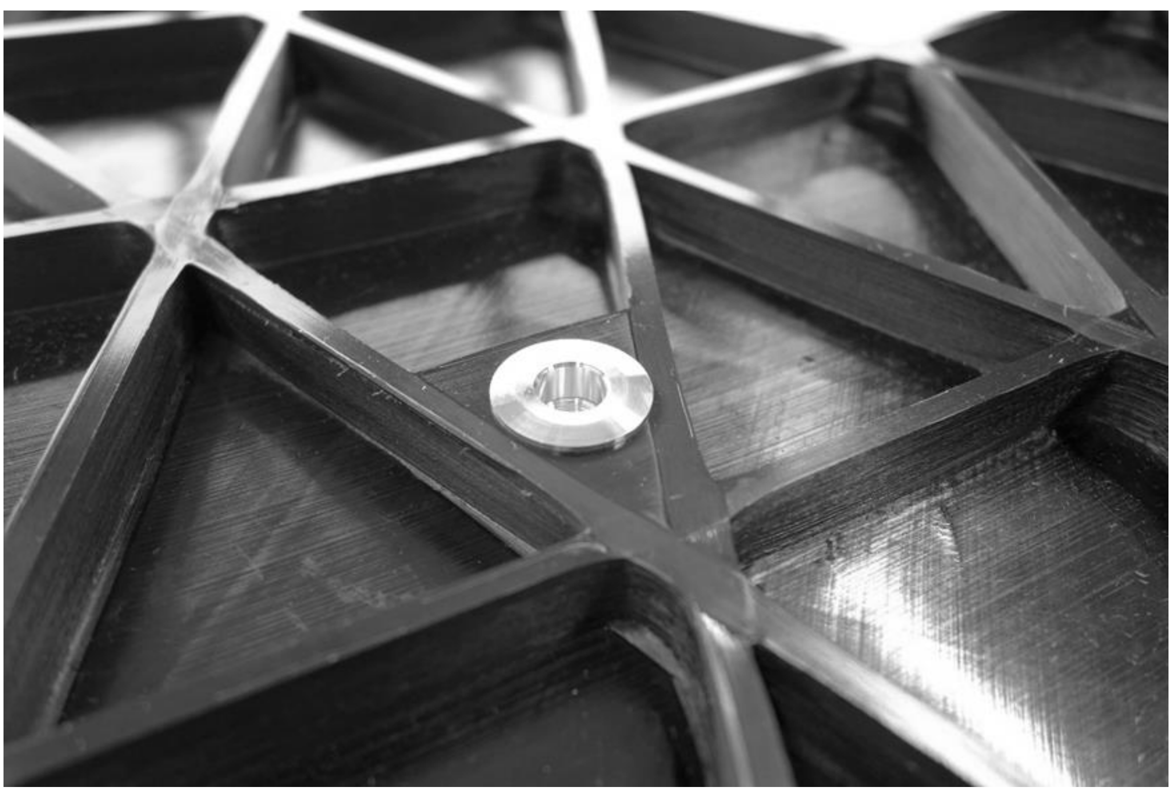

Figure 4. Attachment (or point load introduction) patch integrated into the lattice during the one-shot layup phase. The patch plies are interweaved with the grid for efficient load transfer.

Figure 5. Cut-out with a skin reinforcement, reinforcement integrated during the layup phase.

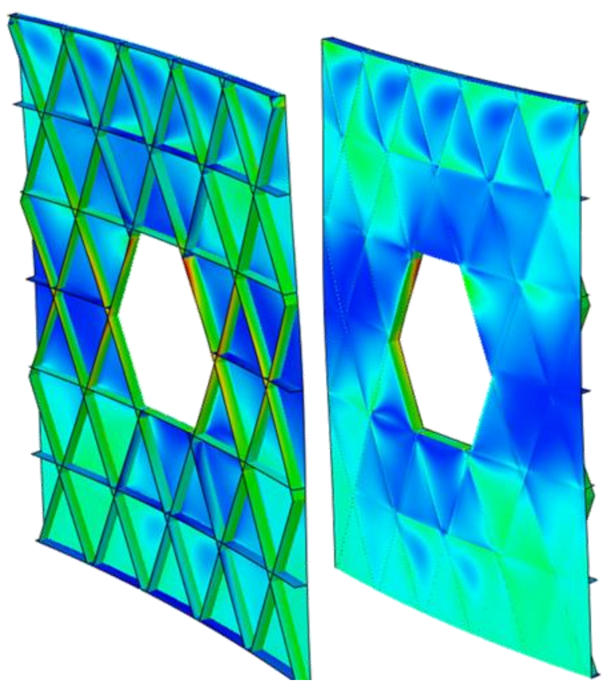

Figure 6. The performance of the demonstrator under uniform compression has been verified by FEM calculations using the analysis procedure developed by ATG Europe.