DESIGN AND MANUFACTURING OF A MULTIFUNCTIONAL HIGHLY INTEGRATED SATELLITE PANEL STRUCTURE

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KEYWORDS

Multifunctional satellite panel structure, highly-integrated multi-functional structure, power supply, vibration control, electrical harness, thermal conductivity, insert load introduction.

ABSTRACT

Mass and volume are some of the most important factors to consider in spacecraft design. In order to address these two aspects, a multifunctional highly integrated satellite panel has been developed and built at the Institute of Composite Structures and Adaptive Systems of DLR. By assembling several multifunctional panels to one unit or by combining them with standard satellite structural components, it is possible to build main satellite structures.

Five systems which can be necessary for spacecraft operations have been integrated into the panel: a vibration control system; a system of integrated electric circuits for signal and energy transmission; a thermal control system; multi-functional inserts for load transmission, electrical contacting (for data and energy transfer) and thermal conduction as well as an energy storage system based on supercapacitors. By integrating these systems into the panel and thereby adding extra functionalities, it is possible to save mass and provide extra volume for payload or additional sub-systems.

1. INTRODUCTION

The built prototype panel is a sandwich structure consisting of two skin layers into which all five systems have been integrated. The two layers are mounted at the top and bottom of a foam core to build the sandwich panel itself. The inserts traverse the complete panel, enabling connections both with the main satellite structure as well as with any mounted payloads.

Figure 1 shows a schematic representation of the prototype. The integrated electrical circuits, shown in grey, are made of stainless steel and are distributed in layers throughout the facesheets of the panel. Together with the multifunctional inserts, they allow for energy and data transfer between the panel components, the main satellite structure and any payloads connected to the panel.

The supercapacitors, shown in light blue, are also integrated in the facesheets and are connected to the internal electrical circuits. Through these connections they are able to provide with energy to other systems, such as the vibration control system, or to any payloads.

The vibration control system consists of piezo-actuators, shown in orange, which are integrated in the panel's legs and connected to the energy source via the integrated circuits. For the sandwich prototype, the piezoactuator control system is mounted as a test payload together with a thermal experiment setup. Alternatively, the control system could be integrated in the sandwich structure itself.

The thermal design of the facesheets allows for a controlled transfer of heat from the payload towards the main satellite structure, through the structure itself and through the multifunctional inserts.

The inserts enable the mounting of the panel onto the main satellite's structure, the attachment of different payloads, heat transfer from the panel into the satellite structure as well as electrical connections with the integrated circuits in the facesheets for energy and data transfer.

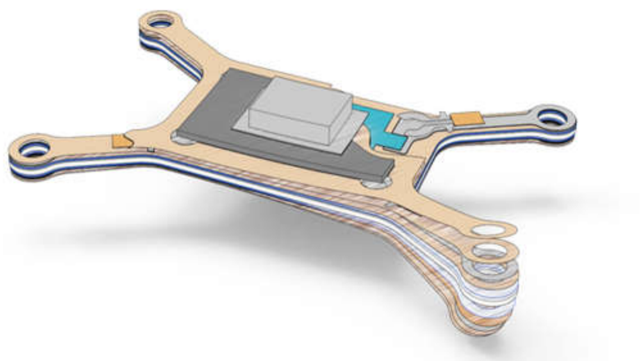


Figure 1: Schematic representation of the Sandwich Panel with Integrated Systems.

2. INTEGRATED SYSTEMS

All five integrated systems strongly interact with each other, guaranteeing their functionality as individual elements but also as a part of the satellite structure and system themselves. The following paragraphs explain the individual integrated functions, the different interactions that are necessary for the system to work and, finally, the integration method.

2.1. Integrated Circuits System

The integrated circuits system represents the wiring harness connecting all systems together and ensuring both the power supply and the data connection between the individual components and control units. To reduce assembly costs and mass, the electrical elements are integrated directly into the fiber layers.

The integration of round cables into the facesheets would disturb the planarity of the laminate surface. In order to ensure an even surface, the geometry, i.e. especially the cross-section shape of the wiring harness, must be adapted. In order to avoid the undulation of the fibers that occurs when integrating "standard" round conductors, it is reasonable to use conductive tracks that are only as thick as a single CFRP layer. Metal foils have therefore been introduced to meet these requirements. Reference [1] presents the relationship between height and width of a conductor track and the options to provide a constant cross-section. It is shown that the influence of the conductor height on the laminate decreases continuously. For the present case, metal foils with a thickness of 0,125 mm have been selected. The foils are fully integrated into the laminate. Two metal layers, which are electrically insulated, are integrated into each facesheet of the sandwich panel.

Since the conductor tracks are fully integrated into the fiber composite structure, they should also be involved in the load transfer. In order to determine the lightweight potential of different conductive materials, the specific conductivity of the materials is set in relation to their density. This results in the mass-related specific conductivity, illustrated in Figure 2.

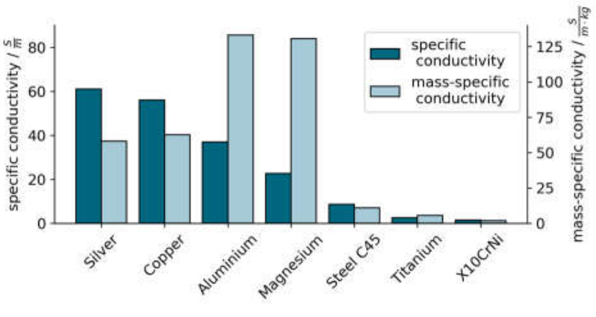


Figure 2: Specific Conductivity and Mass Specific Conductivity for different materials.

As it can be seen, aluminum and magnesium stand out as lightweight materials, since they have a significantly higher mass-related specific conductivity than “classic” conductor materials. Regarding strength, aluminum and magnesium clearly outperform copper or silver. Following this scheme, suitable metallic conductor tracks can be selected to stiffen the facesheets of a sandwich structure in the best possible manner.

2.2. Thermal Control System & Thermal Experiment

The thermal experiment demonstrates how a CFRP composite structure, such as the panel or a potential CFRP electronic box on top of it, can take over a dedicated (conductive) thermal control functionality in a spacecraft system.

Because the panel does not feature an actual electronic box or payload, the micro controller and amplifiers (TBC) of the vibration control system are considered as a (dummy) heat source. They are mounted onto a CFRP laminate, which mimics a part of an electronic box. The laminate is again mounted onto an aluminum dummy mass (*Figure 3*).

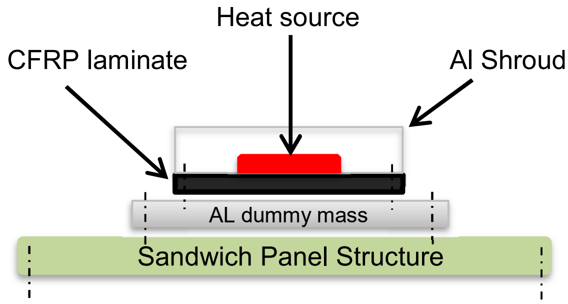


Figure 3. Thermal experiment on top of the SPS.

Hence, on a panel system-level the focus lays on the general design and the multifunctional inserts, which shall allow a dedicated heat transfer between the facesheets (§2.4). On a component-level (E-Box laminate), a FE analysis and a corresponding thermal vacuum test demonstrate how a dedicated CFRP laminate layup can specifically control the conductive heat flux within the laminate.

The CFRP laminate features a completely unidirectional layup of MTM46/M40J (f_{vol}=53%) prepreg with the fibers oriented in the x-direction (cf Figure 4 and Figure 5), id est 45° respective to the laminate’s longer edge. The laminate consists of 12 plies and has a total thickness of 1.5 mm. In each corner, aluminum inserts with radius r_i=5 mm and collars with radius r_c=10 mm inner diameter are glued onto the laminate. These inserts interface to a cold plate, while in the geometrical centre a heat flux is applied to an area of 10x10 mm². The heat flux is generated either by a resistance heater or the electronic components on the circuit board of the vibration control system. However, as the actual measurements require a well-controlled heat flux, these are conducted with the resistance heater. For system tests, four holes with a 2.8 mm diameter, allow to fix the circuit board of the vibration control system.

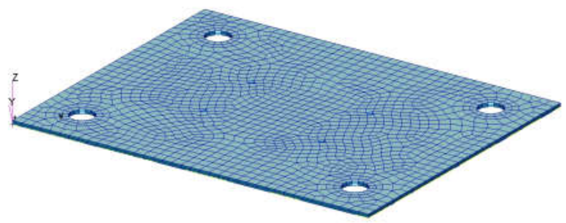


Figure 4: Isometric view of the CFRP laminate FE model.

The corresponding FE model is solely based on two layers of three dimensional CHEXA elements. In order to apply the boundary conditions (BC) and to assign the material properties three separate zones are differentiated: the actual laminate, the central area (between line 13 to16) to apply a heat flux and the inserts (edge 9 to 10) to apply a constant temperature. While all elements have the same property set (unidirectional MTM46/M40J with the fibres in x-direction), the thermal BC need to be different. A heat flux of 0.002 W/mm² is applied to the top side surface of the elements within the central area and a constant temperature of 298.15 K is applied to all midplane nodes along line 9-12. There are no further BC, so neither convection nor radiation can take place.

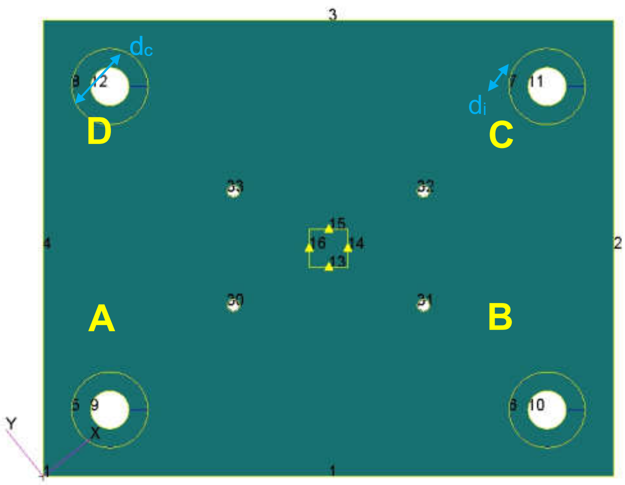


Figure 5: Geometry plot indicating the different sections for BC definition.

Running a quasistatic thermal analysis results in a heat flux distribution as depicted in Figure 6. Clearly the heat flux source is at the centre, where the heat load is applied, and goes towards the interface points A and C. On the other hand, there is almost no heat flux to interface points B and D. This corresponds to the expectation that the heat is predominantly transported in fibre direction.

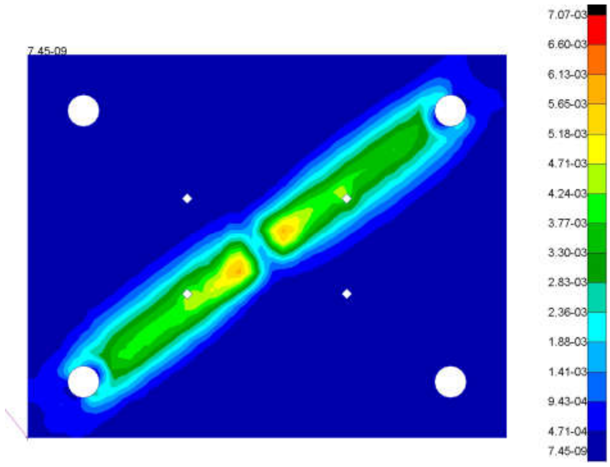


Figure 6. Heat flux distribution when applying 0.2 W at the center and holding a constant temperature of 298.15 K at edges 9-12.

Figure 7 depicts the corresponding temperature field on the CFRP plate. There is a hot spot in the centre with a low temperature gradient towards points A and C, but a steep temperature gradient towards point B and D. The maximum temperature in the centre is 15 K higher than the one kept constant at the four interface points.

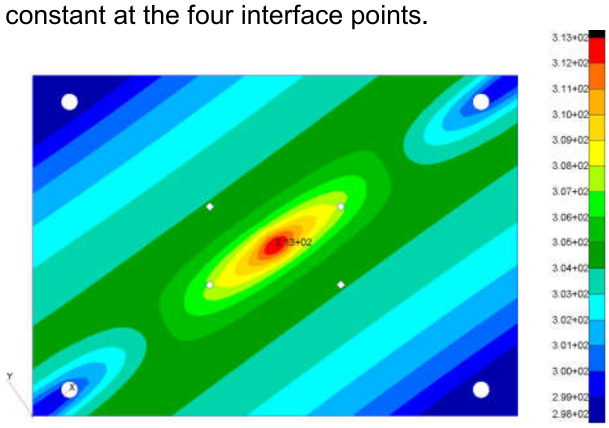


Figure 7. Temperature distribution when applying 0.2 W at the center and holding a constant temperature of 298.15 K at edges 9-12.

Overall, it can be stated that it is well possible to control the heat flux (direction) in a fibre composite structure by adjusting the ply layup. However, in an actual application and on a system-level such as that of the satellite panel structure, it is necessary to find a compromise between thermal and mechanical design optima.

2.3. Multifunctional Inserts

In order to mount the multi-functional sandwich panel to the satellite's structure as well as to attach payloads onto the panel, joining elements are necessary. For adaption and rework measures, these joints must be designed as bolted, detachable connections.

Since the sandwich's core material provides only a low local compression resistance (typical for common lightweight core materials, Figure 8 - left), supporting elements must be integrated to stabilize the core against the clamping force of the bolt as well as to allow the transfer of a proper structural load amount between payload and panel. The herein utilized cylindrical supporting elements with a central screw receptacle are commonly called “inserts”.

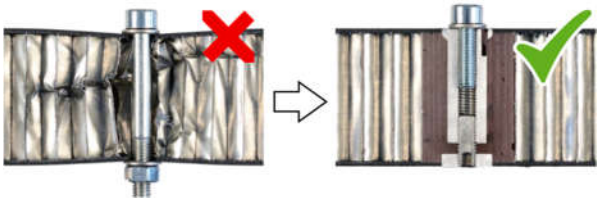
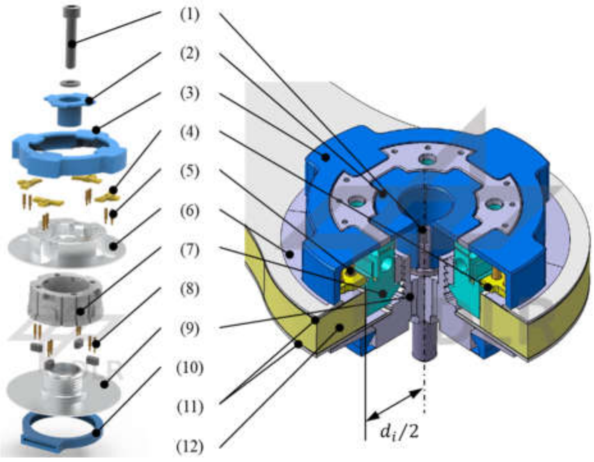


Figure 8: Appropriate core support and load transfer by an insert element added to a bolted load introduction in a sandwich element.

Launching costs of space vehicles easily reach 10 - 50K$/kg [2, 3, 4]. Because of this, strong efforts for mass minimization are vital for every component of the multi-functional sandwich panel. Therefore, core-connected (potted), symmetrically shaped inserts are selected as a basic design, since this variant offers the highest lightweight potential among all insert types [5, 6, 7], Figure 8 - right.

Within the inserts, two mass reduction measures are combined: the minimization of the insert’s core diameter, d_i, and the integration of additional functions. Both together allowing to reduce the overall number of elements needed in the sandwich panel. This leads to the design shown in Figure 9.



No.	Designation of component
(1)	Screw for panel mounting
(2)	Inner cover
(3)	Upper main cover
(4)	Brackets for spring loaded contacting pins
(5)	Spring loaded pins
(6)	Upper structural insert part
(7)	Adhesive distribution ring
(8)	Spring loaded pins
(9)	Lower structural insert part
(10)	Lower main cover
(11)	Sandwich facesheets
(12)	Sandwich foam core

Figure 9: Individual Parts of Insert Concept.

2.3.1. Insert Shape Dimensioning

In a first step, the minimal diameters, $d_{i,min}$, of all insert elements of the sandwich panel are calculated with the help of a DLR-developed analytical dimensioning method [8], which takes the relevant material, geometrical and load conditions into account.

The preliminary damage of an insert load introduction is a shear rupture of the sandwich’s foam core adjacent to the insert, caused by the transversal force $F_{i,t}$ acting on the insert, as shown on Figure 10.

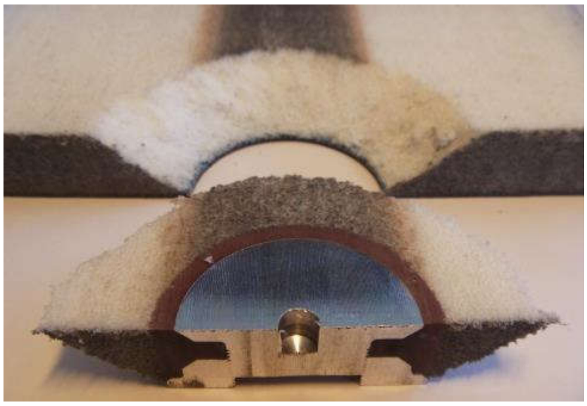


Figure 10: Conic shear rupture of the foam core around an overloaded insert.

As a countermeasure, the insert’s diameter must be extended to $d_{i,min}$, where the declining core shear stress $\tau_{c,zr}(r)$ (Figure 11, blue curve, caused by $F_{i,t}$) around the insert no longer exceeds the shear strength $R_{12,c}$ of the core material, Figure 11, red lines [5,9].

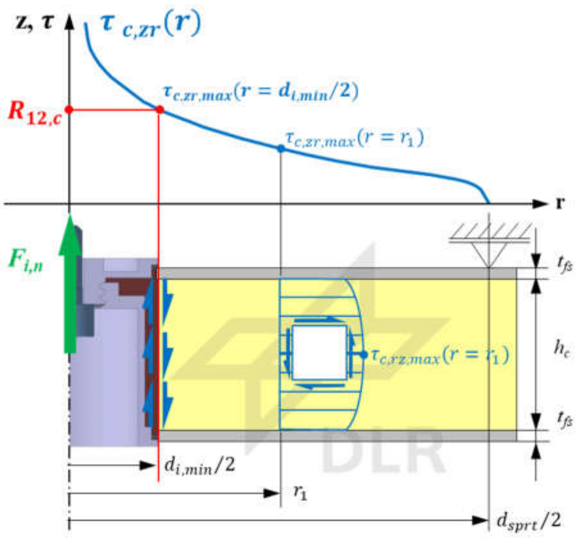


Figure 11: Core shear stress distribution around a transversally loaded insert in a sandwich element with thin facesheets; determination of the insert’s minimal diameter (red lines).

Serving this approach reveals a minimal diameter of $d_{i,min}$ = 36 mm for all inserts in the multifunctional sandwich panel.

2.3.2. Function integration

The calculated minimal insert diameter of 36 mm leaves free space inside the insert for implementing additional elements and functions, Figure 12. An adhesive distribution ring element is integrated, allowing for a fast, reliable potting filling of the hollow space between insert and sandwich. In addition, a shape adaption of the insert for a defined heat transfer from the panel into the satellite structure is a part of the insert's design capabilities. Finally, electrical contacting and conducting elements are integrated.

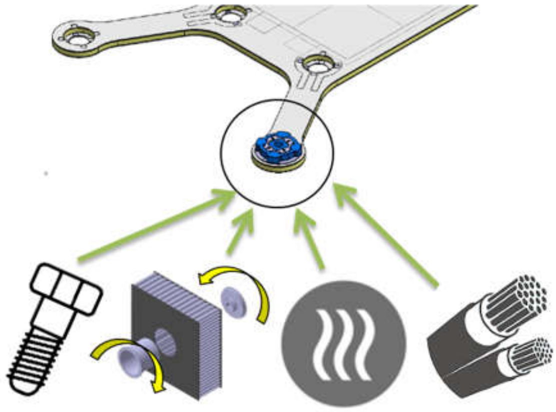


Figure 12: Functional scope of the insert elements: Load transfer, fast and reliable installation process, controlled heat transfer and electrical conductivity.

<u>*Installation features: Tolerance management and simplified potting filling*</u>

Each insert is mounted by firstly inserting its top and bottom pre-assembled components into the mounting hole in the sandwich and screwing them together, Figure 13. This allows for an easy compensation of height tolerances of the sandwich and provides with an optimal thickness between the adhesive layers between the insert's collars and the sandwich facesheets.

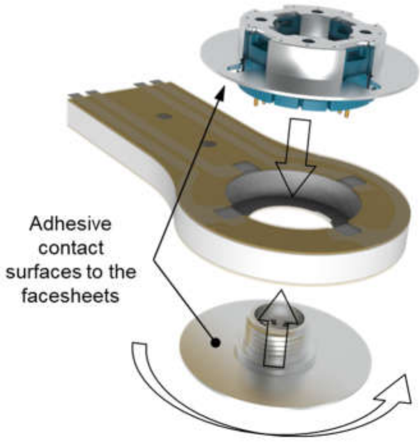


Figure 13: Form locking and tolerance adjustment by two-component design of the insert.

To connect the insert elements with the sandwich's foam core, liquid adhesive is filled in the hollow spaces between them. For ensuring a rapid, reliable and homogeneous adhesive filling, each insert is equipped with a ring-shaped element possessing an internal channel system, Figure 9, No. 7. Viscous adhesive, applied with a cartridge gun into the filling port of the insert, is distributed within the branched channel system and drained through a circular opening near the insert's bottom, Figure 14 and Figure 15 - right. This enables an even fill-up from bottom to top while ensuring the enclosed air can escape via venting ducts. Thus, flaws such as trapped air bubbles or hollow spaces, which would otherwise reduce the insert's strength, are suppressed.

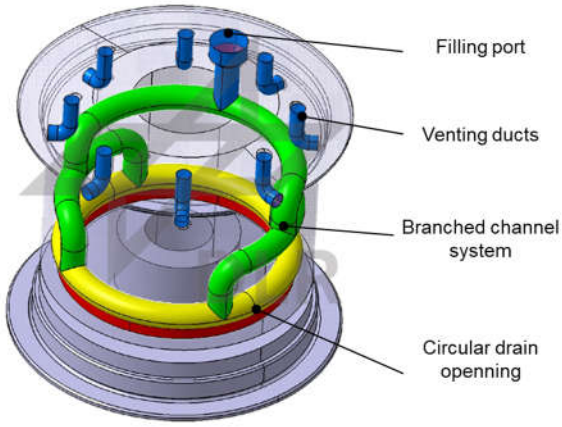


Figure 14: CAD-model showing the internal channel system for adhesive distribution.

Parts with such an internal channel system are very elaborate to produce with common, subtractive manufacturing methods such as milling or drilling. In contrast, with the help of additive manufacturing techniques, a fast and cheap production of such complex geometries is easily feasible, Figure 15 - left. With this in mind, the Fused Deposition Modelling 3D-printing process (FDM) was selected, allowing the use of a wide range of thermoplastic materials. Herein, PEEK was chosen for the adhesive distribution ring because of its outstanding thermal and chemical resistance as well as low degassing tendency, which is ideal for space environment conditions.

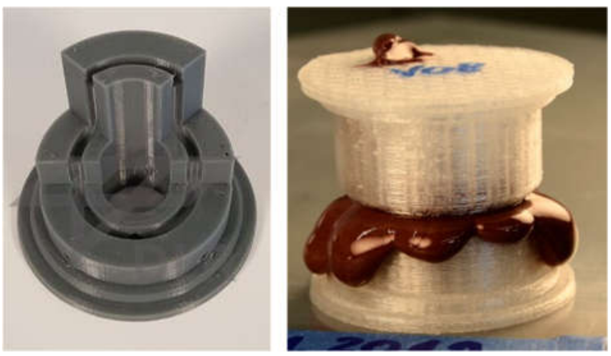


Figure 15: 3D-printed prototypes. Left: Section model with internal channel system. Right: Evenly distributed adhesive bleed.

Shape-controlled thermal conductivity

In order to ensure a defined heat transfer, the insert's two main components are made of aluminum and the size and shape of the relevant contact surfaces is designed specifically for better heat conduction, Figure 9, No. (6) and (9) and Figure 16.

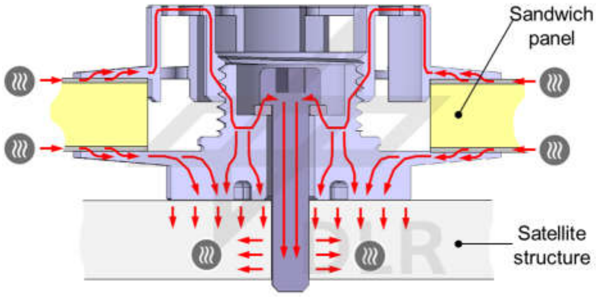


Figure 16: Head routing from the sandwich panel into the satellite's structure through the metallic insert components.

Electrical energy and signal transfer

In order to guarantee electrical signal and energy transfer between the systems integrated in the facesheets, any payloads attached to the panel and the satellite's main control unit outside of the sandwich, conducting elements are integrated into the insert: The insert is equipped with spring loaded pins, Figure 9 – numbers (5) and (8), contacting the integrated wiring harnesses of both facesheets.

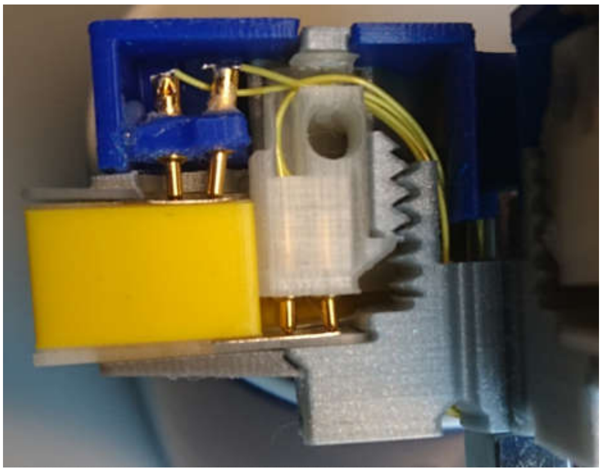


Figure 17: Spring-loaded pins and conductors inside of the inserts.

The pins are positioned in the inserts upper flange cover as well as in the adhesive distribution ring. Attached conductors (Figure 17, yellow) end in a multi-connector located in the insert's bottom flange cover and allow connections with the satellite's main electrical system or potential payloads, Figure 18.

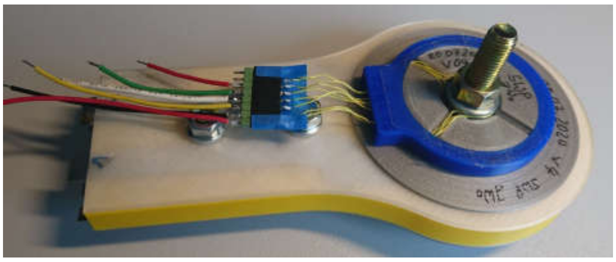


Figure 18: Multi-connector (extracted from the lower, blue flange cover).

2.4. Energy Storage System

The electrical energy needed for the vibration control system is stored in two integrated thin film supercapacitors (ITFC). The supercapacitors are respectively integrated within the outer composite layers of the sandwich. Thanks to their physical, reversible storage mechanism of electrostatic indicated ion diffusion, supercapacitors are maintenance-free and therefore ideal for integration in structural components. This approach has the potential to reduce volume and weight significantly which plays an important role for expensive space applications such as a multifunctional satellite panel.

Capacitors typically consist of two oppositely charged electrodes. The performance of capacitors depends on the distance between those electrodes and their area. In terms of a supercapacitor, the collectors are equipped with electrodes of high specific surface area. A liquid electrolyte between the electrodes provides ions for charge transport. These ions diffuse into the oppositely charged electrode reducing the distance to the nanoscopic scale. Ions form a double layer (Helmholtz layer) with a distance between ions and electrode of approximately one Ångstrom ($1e^{-7}$mm).

Furthermore, the specific area of the electrode is increased enormously by using nanoscale electrically conductive carbon structures as electrodes. In this way, there is more space to diffuse for the electrolyte's ions. The material of the two collectors, the anode and the cathode, is the same and the build-up is very simple and environmentally friendly, since carbon structures can be produced from regenerative sources. The diffusion and approximation of ions into the electrode improves the performance, so that very high specific energy densities, compared to a common capacitor, or power density compared to a battery are possible. The huge power density is the foundation why supercapacitors can be charged and uncharged up to 100-times faster than a battery. Supercapacitors are ideal components for peak power application with limited operation time.

For the highly integrated satellite panel, the aim is to manufacture a lightweight and compact energy storage system. Since the vibration control system has a limited operation time, the use of integrated supercapacitors is ideal. The supercapacitors consist of two 24 µm thick aluminum collectors which are coated with 116 µm of activated carbon (Figure 19 b)) supplied by Skeleton Technologies GmbH (Germany, Estonia).

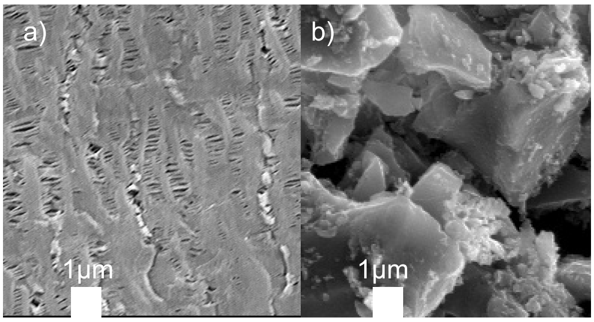


Figure 19: SEM-pictures a) separator micro structure b) activated carbon electrode.

As electrolyte the ionic liquid (IL) 1-ethyl-3-methylimidazolium bis (trifluoromethylsulfonyl)imide is used supplied by Iolitec, Ionic Liquid Technologies (Germany). The electrical insulation between the electrodes is ensured by a 20µm thin separator film (Celgard 3500) supplied by Celgard LLC (Figure 19, a)). The ITFC-stack has a total thickness of 300 µm. This corresponds to nearly 2,4 layers of the used fiberglass prepreg Hexply 913 (Hexcel Corporation, USA). Due to compression during the vacuum process the ITFC-stack can be compensated by two fiberglass prepreg layers.

The contamination of the surrounding composite can be avoided by an optimized amount of electrolyte stored in the electrode and separator. The optimization of IL is important on the one hand to cover the whole electrode's surfaces and, on the other hand, to connect the anode ionically via the IL wetted separator with the cathode. Leakages due to excessive IL must be avoided, because on the other hand the mechanical performance of the composite will be drastically reduced. If resin is contaminated with IL, as shown on Figure 20 [10], composites suffer from weak polymer bonds and separating effects between resin and fibers.

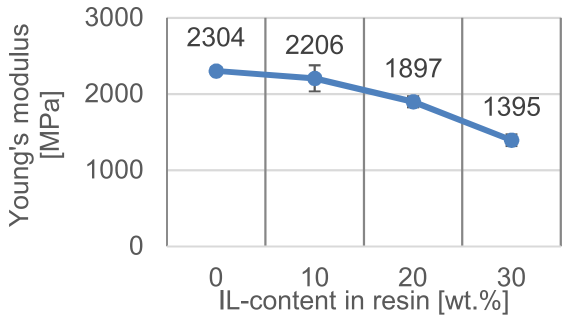


Figure 20: Mechanical performance vs ionic content.

In the case of the multifunctional satellite panel structure, two ITFCs with an electrode area of 593 cm^2 each are integrated. The developed ITFC reaches 106.47F (discharge capacity) using a scan rate of 20 mV/s within the voltage range of 0V-1V (Figure 21).

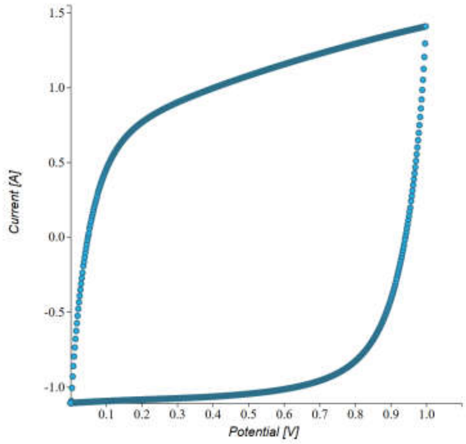


Figure 21: Cyclovoltammetric analysis of the electrophysical properties of the ITFC at 20mV/s.

Tests showed that the electrolyte can be treated up to 3.5V without showing any irreversible electrochemical reactions. According to Adam's [11] classification of integration levels (degree of integration, DoI) this approach of integrated power components achieves a DoI II. However, due to comparable literature [12] parasitic housing materials can be avoided. Thanks to electrodes, which are ideally saturated with IL, the ITFC can be directly integrated into the composite. This approach reaches 90% of the mechanical properties of the neat composite.

As a result, this power composite has a comparably good electrochemical and mechanical performance with the potential to save 70-80% weight and volume [13] compared to the integration of an equivalent commercial cell.
Further information about the structural integration of supercapacitors developed at the DLR is presented in a second paper of this conference [14].

2.5. Vibration Control System

Another important part of the multifunctionality in the panel comes with the vibration control system. This system comprises the following components:

1. Actuators
2. Accelerometer
3. Controller
4. Filter
5. Power-supply
6. Cabling

These components are on the one hand integrated into the panel itself and on the other hand placed as part of the payload. Actuators, power-supply (Section 2.4) and cabling (Sections 2.1 & 2.3) are embedded into the structure, while the accelerometer, filter and controller are integrated on a circuit board, which is itself mounted in the payload, i.e. the thermal control system (Section 2.2).

Figure 22: Piezoelectric Actuator.

Eight piezoceramic actuators as the one shown in Figure 22 are embedded into the panel. They are pairwise placed in the upper and lower skin of each of the arms of the panel, as it can be seen in Figure 1 & Figure 25. Overall the vibration control system is designed to act on the first eigenmode of the panel being a fundamental bending mode as shown in Figure 23. This results in a single input single output control system, where one accelerometer is sufficient to detect vibrations deflections in this mode, while four pairs of bending actuators with identical signals have high authority on the first eigenmode.

The integrated circuits system and the multifunctional inserts provide power from the energy storage system to the circuit board as well as the control signal from the circuit board to the actuators. The prototype circuit board, intended to be used in thermal-vacuum tests and shaker tests, is shown in Figure 24. The parts integrated are denominated by their number:

1. Four piezo amplifiers, providing up to 100 V to the piezoceramic actuators. These amplifiers can drive one pair of actuators in bending mode.
2. The filter and analog amplifier are used to filter the sample rate of the digital to analog converter and to adjust the voltage level to the input of the piezo amplifiers.
3. The voltage regulator is used to regulate the voltage coming from the energy storage system to a constant 5 V, needed by all other components.
4. The accelerometer is used to observe the vibration of the payload and thus the panel. It was placed on the circuit board as the board itself is mounted in the payload.
5. A microcontroller with analog to digital converter and digital to analog converter. This part is used to run the control-algorithm.

The hardware is to be tested to be able to drive a vibration control with an upper limit of frequencies to 1.5 kHz, which is sufficient for controlling the first eigenmode of this panel.

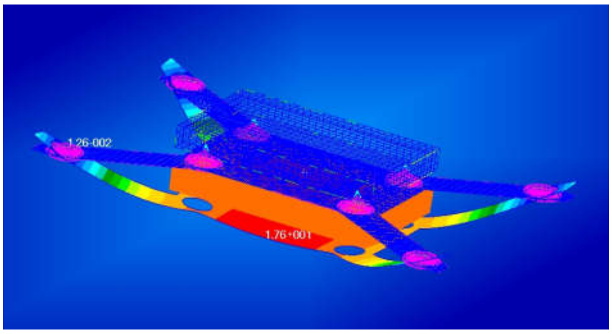


Figure 23: First Eigenmode, with colors indicating displacements.

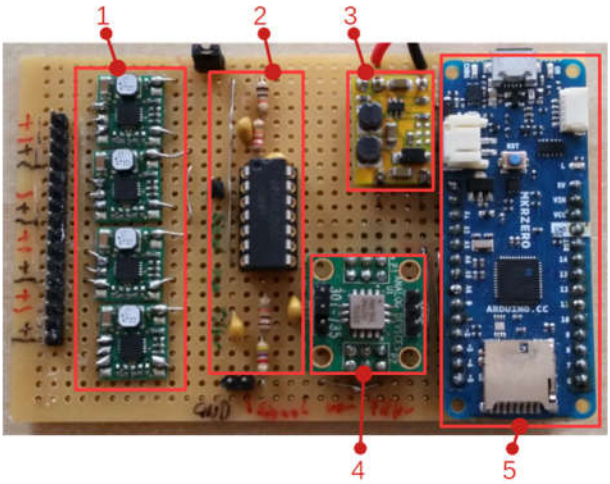


Figure 24: Circuit Board.

3. PROTOTYPE MANUFACTURING

The developed sandwich structure consists of composite top and bottom facesheets and a foam core.

All previously mentioned sub-systems (actuators, supercapacitors and electrical conductors) are integral parts of both facesheets, except for the inserts, which are mounted afterwards and encased throughout the whole sandwich's thickness.

The integration of all sub-systems generates certain manufacturing challenges, especially for the production of the facesheets. To meet these challenges, special measures were implemented in the production process as follows:

1. For a reliable function of all integrated elements, a very accurate positioning of the

facesheets in relation to each other is crucial. Therefore, specially designed, removable positioning cones as well as the molding tool's edges are used for aligning all elements properly, Figure 25, No. (8) and (9).

2. The complex contour of the sandwich panel makes end trimming complex and time-consuming. As countermeasure, the molding tool is designed to allow a near-net-shape manufacturing without the need of machining the final contour, Figure 25, No. (9).

3. The limited heat resistance of the integral actuators and capacitors severely restricts the choice of GFRP prepreg systems. For this purpose, a special GFRP prepreg system with a low curing temperature was procured and qualified.

4. For reliable electrical contacting between inserts and the integrated conductors, its exposed contact points must remain clean and blank, despite the liquefaction of the matrix during the curing process. For preventing contamination with matrix resin, the contacting surfaces were covered with both, removable, special protective layers as well as silicone pressure caps, Figure 25, No. (1).

To minimize the risk of malfunctions of the integrated sub-systems, the facesheets are manufactured in separate processes and added to the core afterwards to generate the sandwich panel. For series production, however, in-situ production of the entire sandwich, including all integral elements, is aspired in order to reduce manufacturing time and effort.

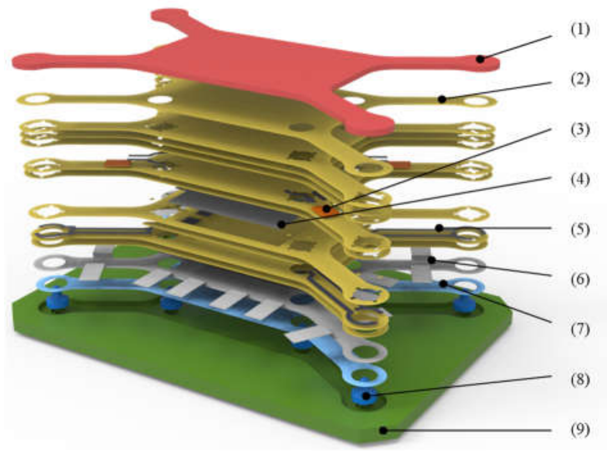
3.1. Panel manufacturing

The panel manufacturing process is divided in two main steps. During the first, the facesheets are manufactured and all the systems, except the inserts, are integrated into them. In the second step, the sandwich itself is mounted together and the inserts are as well integrated.

3.1.1. Facesheet manufacturing

An ureol female molding tool was used to manufacture both facesheets. This form is shown in green in Figure 25, No. (9).

In a first step, GFRP prepreg layers, capacitor, actuators, metal electrical conductor tracks as well as additional production aids were inserted into the molding tool, Figure 25 No. (9). In order to align all layers correctly, positioning cones were used for stacking, Figure 25, No. (8) as well as Figure 27 - Figure 29.



No.	Designation of components
(1)	Silicon pressure cap
(2)	GFR-Prepreg-Layer
(3)	Piezo actuator element
(4)	Supercapacitor
(5)	Steel conductor, wiring harness
(6)	Peel ply
(7)	Release film
(8)	Positioning cone
(9)	Molding tool

Figure 25: Exploded view of the stacking of the top facesheet with integrated capacitor, conductors and actuators.

The stacking was compacted with a silicone pressure cap and a vacuum build-up, as it can be seen on Figure 26. After compacting and curing in the autoclave, the facesheets can be removed from the molding tool in their final shape, and the tool can be reused for manufacturing the next facesheet.

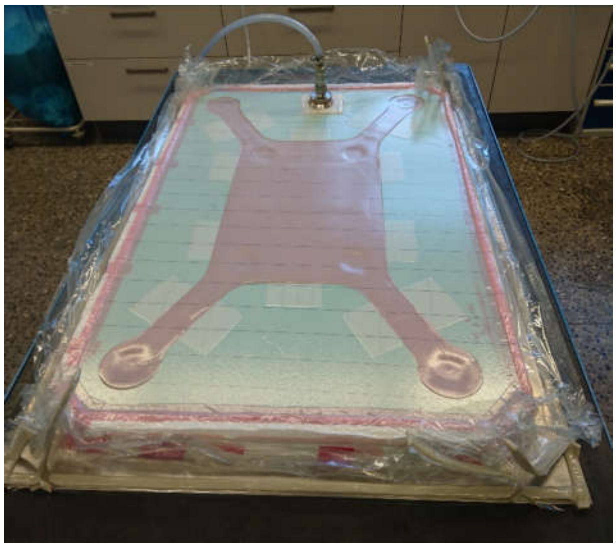


Figure 26: Vacuum build-up of a facesheet in the molding tool.

3.1.2. Sandwich panel assembly

To assemble facesheets and core to the final sandwich prototype, the facesheets were bonded to the foam core with glue film layers. Therefore, these elements were built up on a flat manufacturing tool. The manufacturing tool was equipped with mounting holes, allowing to use the positioning cones to align the sandwich components precisely against one another, Figure 27.

Figure 27: Attachment of top facesheet onto a glue film layer (red), foam core (white) and lower facesheet. Alignment with help of positioning cones (blue).

The adhesive film layers were cured under pressure and heat in an autoclave process analog to the already described curing process of the facesheets. In order to protect the sensitive edges of the sandwich preform during the adhesive curing process, the sandwich preform was placed in a negative mold, Figure 28 and laterally fixed with cork strips, Figure 29.

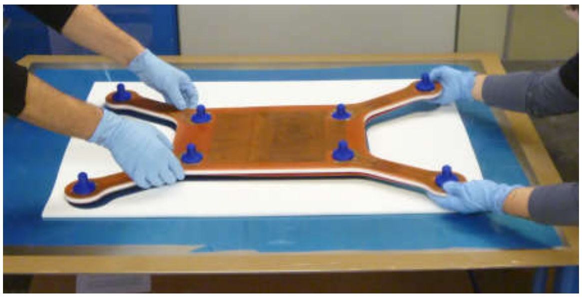


Figure 28: Inserting the sandwich preform into a negative mold.

Figure 29: Insertion of cork strips to fix the workpiece against the mold. Also visible are an actuator (right), electrical conductor tracks inside the facesheet, contact surfaces (protected by cover layers, red).

After the removal from the manufacturing tool, the sandwich edges were cleaned from all cork residues.

3.2. Insert test fitting, future final assembly

For test fitting purposes, the insert elements were mounted into the receptacles of the sandwich and screwed together, Figure 30.

Figure 30: Sandwich panel with test-mounted inserts.

For the prototype sandwich panel, a thermal experiment setup as well as an actuator control circuit board are to be mounted as a test payload onto the panel, Figure 31.

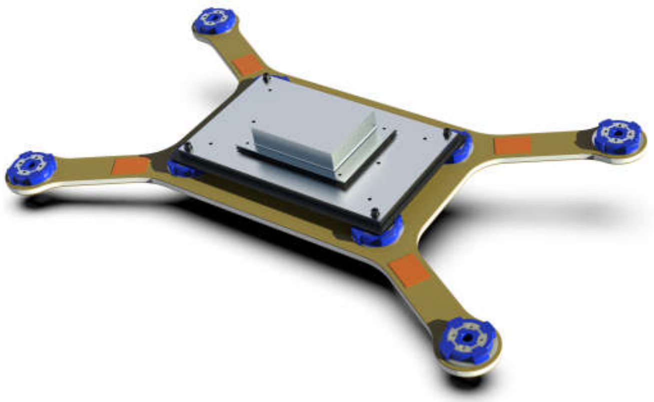


Figure 31: Assembled multi-functional sandwich panel with payload (thermal experiment and control unit inside housing).

4. NEXT STEPS, CONCLUSIONS & OUTLOOK

At the time of writing this paper, a first prototype of the multifunctional sandwich panel has been manufactured and first system component tests have been performed, aiming to prove the functionality of the integrated systems. These tests include the measurement of the mass and inertial properties of the panel to validate the generated theoretical models and the predicted mechanical behavior. In addition, the functionality of the different systems regarding energy saving capabilities, vibration control, thermal transfer and inserts functionality have been realized.
After the theoretical models have been verified and validated and the functioning of the systems has been tested, a second prototype panel will be produced, following any necessary structural or component changes.

Once this second panel prototype has been manufactured, the panel structural tests and the integrated systems functionality tests will be performed again for a first validation of the structure. Once all these tests have been achieved, the multifunctional panel prototype will be subject to thermal-vacuum chamber tests as well as shaker tests, necessary for space qualification.

The inserts, as an integral part of the multifunctional sandwich panel, will also be subjected to thermal-vacuum chamber as well as shaker tests to prove both, the structural integrity as well as the reliability of all integral functions under the environmental conditions in space under all critical load states. For a proof of concept, further tests may be carried out, addressing the potting filling concept, the critical mechanical load capability (Figure 32) as well as electrical contacting and heat flow to qualify the insert concept for utilization in future space structures.

Figure 32: Test rig assembly for insert load capability evaluation.

The goal is to qualify and certify the multifunctional sandwich panel for future implementation in space applications. By doing this not only will the structure itself be qualified as a whole, but also all the integrated sub-systems individually.

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