

SANDWICH STRUCTURES TECHNOLOGY IN COMMERCIAL AVIATION

Present Applications and Future Trends

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Abstract This paper gives a brief overview of sandwich application history in general and present composite sandwich structures at Airbus. Current R&D developments for sandwich in primary structures are being outlined followed by a discussion of potentials and challenges for composite sandwich structures.

Keywords: cost/weight effectiveness, continuous stiffening, sandwich primary structure, composite adapted architecture.

1. INTRODUCTION

The challenge of making a structure as light as possible without sacrificing strength is fundamental in aircraft design. Inevitably, the requirement leads to the need to stabilize thin surfaces to withstand tensile and compressive loads and the combination of the two, in tension, torsion and bending. Traditional airframe structural design has in the past, and still does to some extent, overcome this difficulty by use of longitudinal stiffeners and stabilizing rings with stringers and ribs or frames. But this is not a very elegant solution in composite design and, in fact, the stabilization of a surface – creating a resistance to deforming forces – can in many cases be more efficiently effected by the use of twin skins with a stabilizing medium between them [1].

2. BRIEF HISTORY OF SANDWICH APPLICATIONS

Sandwich is a common principle in nature and hence the concept is older than mankind itself. The branches of the elder tree are a good example for a foam core sandwich structure. The bones in the skeletons of animals and humans are sandwich structures with foam-like core materials as well. Natural sandwich structures are subjected to complex load cases. The bones in legs have to withstand repetitive, super positioned bending and compression loads. Moreover nature imposes a strict demand for lightweight primary structures (e.g. skeletons of birds). All the mentioned examples show the principle of structural optimisation: minimum use of material for maximum performance.

W. Fairbairn was reported to be the first person to describe the sandwich construction principle in 1849 for the Britannia Tubular Bridge in North Wales. The sandwich comprised iron compression sheets riveted to both sides of a wood core. In 1924 T. von Karman and P. Stock patented a glider plane applying sandwich for fuselage structure. Following his predecessor von Karman, Mautner designed a plane having sandwich elements in the wing structure. The chief designer of De Havilland, E. Bishop, was the first person to use the sandwich principle in a powered aircraft. He used the sandwich concept in the fuselage of the Comet Racer, the Albatross and in the wing and fuselage of their successor, the famous Mosquito (figure 1).

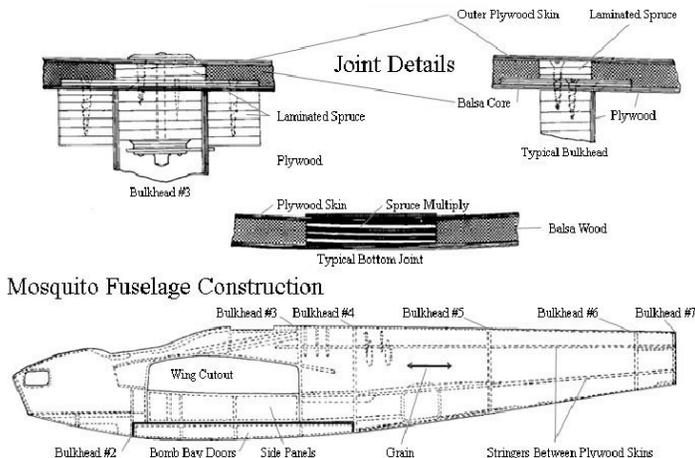


Figure 1. Fuselage of the De Havilland Mosquito, source: Toronto Aerospace Museum.

For these aircraft the sandwich core was balsawood while the facings consisted of birch plywood and were joined to the cores by bonding. The adhesive used for the bonding was based on phenolic resins (Bakelites). However the use of bio-degradable materials like wood is problematic due to their susceptibility to biota like fungi. Metal-wood sandwich was applied in the floor panels of the older Fokker F27. In this case the elements had a core of balsa and facings of aluminium.

The invention of modern honeycomb sandwich structures goes back into 1940's and was the idea of the circus proprietor George May, who showed at Farnborough his invention, that looked like a cross between a book and a concertina. Improvements made through impregnating the paper with phenolic resin led to the honeycomb semi finished products known nowadays [1, 2].

The use of sandwich structure in the Apollo project, that successfully landed on the moon in 1969, showed the high potential of sandwich structure in the field of aerospace. With the help of this unique technology, it was possible to construct the Apollo capsule and its heat shield, which was light and yet strong enough to sustain the stresses of acceleration during the start and re-entry phase [4].

Application of composites for large structures at AIRBUS started in 1983 when the A310 was the first aircraft in the AIRBUS fleet to be equipped with a composite honeycomb sandwich rudder. The composite Vertical Tail Plane for the A310 was soon to follow in 1985. Ever since, the experience with large composite structures was extended. Current developments are being outlined later in this paper.

Today a large variety of sandwich cores are being applied in structural engineering (see figure 2) [7, 8].

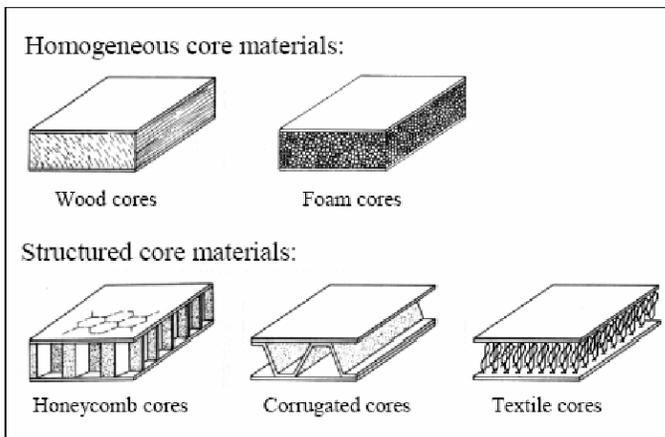


Figure 2. Different sandwich core types.

This short review of the implementation of sandwich structures in nature and in the past of aviation summarizes the concept of sandwich structures. They are very efficient with respect to their integral structural behaviour, weight and manufacturing costs. Validation of new calculation methods and tools, better understanding of effects of defects, improved and more economic Non Destructive Testing (NDT) capabilities (also for large area inspection), advanced core materials, novel manufacturing methods and integration of structural and non-structural functions are some areas of current research work being conducted in the composite sandwich R&D community. The development of sandwich structures and their application does advance and has great potential in the near and mid-term future of commercial aviation [5, 12, 13, 14, 16, 17, 18].

3. STATE OF THE ART COMPOSITE SANDWICH STRUCTURES AT AIRBUS

There is a broad range of composite sandwich structures application in Airbus aircraft. Typical external structures are aerodynamic fairings, covers and doors. Examples are radomes, belly fairings, leading and trailing edge fairings, engine cowlings and landing gear doors. Moreover there is a variety of composite sandwich control surfaces throughout the Airbus fleet (e.g. rudder, aileron, spoiler). Examples for the application of composite sandwiches inside the aircraft are fairings and floor panels in the passenger compartment. Figure 3 gives an overview of composite sandwich applications in the A380 aircraft.

The requirements for composite sandwich structures in commercial aviation aircraft are very diverse. External structures face a wide range of operational temperatures and high aerodynamic loads. Radomes and leading edge fairings are exposed to impacts due to bird strike and hail, lightning strikes and abrasion caused by rain and dust. Moreover electromagnetic transmissibility for radar and avionics is required. Foreign object damage (FOD) caused by runway debris is a characteristic threat for all surfaces on the lower side of the aircraft. Floor panels in the passenger compartment must withstand transverse, discrete loads caused by passengers (e.g. high heel shoes). These examples underline the diversity of operational and environmental requirements for the different sandwich applications. It is crucial to be aware of the different requirements early in the design process in order to develop an appropriate structure accordingly.

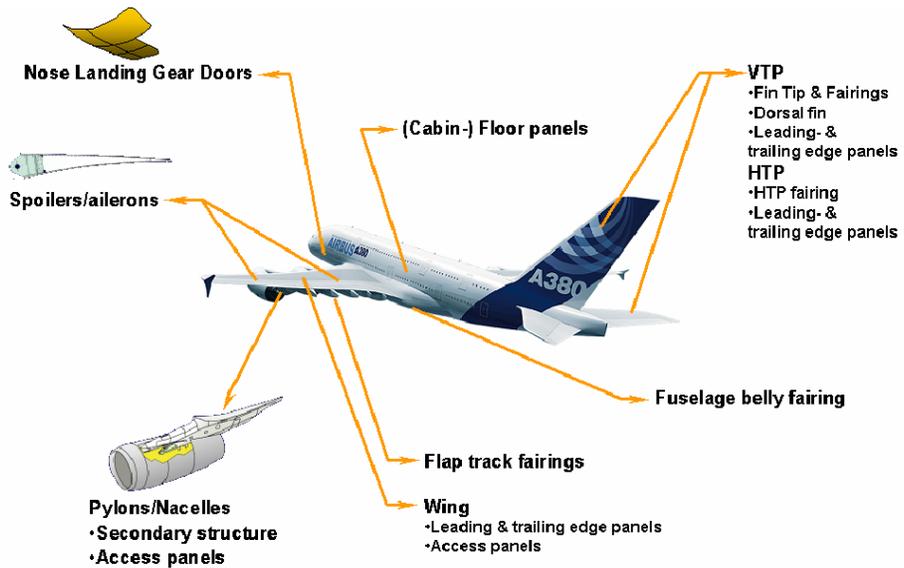


Figure 3. Examples for sandwich applications A380.

To fulfill the different requirements a variety of material combinations can be found in the current composite sandwich structures. Predominate skin materials are glass fiber and carbon fiber reinforced prepreps with epoxy resin matrices. The predominate core material for sandwiches is NOMEX[®] honeycomb. Due to fire, smoke and toxicity requirements (FST) less hazardous phenolic resins are being applied in the manufacture of surface layers of cabin interiors. ROHACELL[®] PMI hard foam is being applied as a manufacturing aid (lost tool; e.g. hat profiles for A340 and A380 rear pressure bulkhead).

4. VERTICAL TAIL PLANE (VTP)

Vertical tail planes of Airbus aircraft consist of 5 major structural assemblies (see figure 4):

1. Leading edge fairings (including tip and dorsal fin)
2. Center box structure (including the interface to the fuselage)
3. Trailing edge fairings
4. Rudder
5. Fin – fuselage fairing

For the A340 VTP the leading edge, trailing edge, dorsal fin, tip, the fin-fuselage fairing and the rudder are produced with composite sandwiches.



Figure 4. VTP major structural assemblies (example A380).

The leading edge fairings (including tip and dorsal fin) have to withstand aerodynamic loads, abrasion and hail-, bird- and lightning strike. Antennas are mounted behind the leading edge and the tip, therefore they have to allow for electromagnetic transmission. The Material combination for these areas is glass fibre reinforced prepreg and NOMEX[®] honeycomb.

The largest sandwich structure in the A340 VTP is the rudder. It consists of the following major components:

- Left and right hand skin panel (NOMEX[®] honeycomb and carbon fibre prepreg; layers of glass fibre prepreg in specific areas for corrosion protection)
- Front spar (monolithic carbon fibre prepreg)
- Root rib (monolithic carbon fibre prepreg)
- Diverse fittings (aluminium parts)
- Diverse small parts

The dimensions of the rudder are:

- Length at front spar: ~9,9m
- Length at trailing edge: ~9,3m
- Width at tip: ~0,9m
- Width at root rib: ~2,6m
- Overall surface: ~15,3m²

Sandwich is the ideal structure for this large component as stiffness to weight ratio is a critical requirement for control surfaces.

5. FUSELAGE

A full composite fuselage is one focus of current R&D and development activities ongoing in commercial aviation. Boeing intends to build its new airplane, the 787, with a full composite fuselage [21]. Although it seems that the first generation full composite fuselage for commercial airliners will be monolithic, several sandwich concepts were investigated by different companies within the last years.

The “Deutsches Zentrum für Luft und Raumfahrt” (DLR) proposed a sandwich fuselage concept in which the outer skin is only intended to be an aerodynamic fairing. Frames can be attached to the uninterrupted (no stringers) surface of the inner skin [3, 13].

An evaluation of a composite sandwich fuselage concept done by NASA/Boeing suggests that the tested structure with twice the original frame spacing is capable of sustaining design ultimate load conditions without damage and of sustaining design limit load conditions with a 1-inch-long notch [22].

Airbus initiated a CFRP fuselage project in 1999 supported by the German government. In the first four years of the project, a wide screening of technologies was carried out and several design concepts for a CFRP fuselage were evaluated. In this context the whole fuselage was taken into account, implementing also neighbourhood engineering areas such as cabin, interior, equipment, system installation and insulation. This investigation leads to the integrated double shell design (IDS), which enables the implementation of more functions into fewer parts. Two different double shell concepts, SoFi (Stringers outside, Frames inside) and VeSCo (Ventable Shear Core), are now under investigation and are being optimised through tol 2007.

SoFi aims to provide maximum thermal and noise insulation and impact-protection accompanied by attractive weight savings. The SoFi core material consists of a carbon pin reinforced foam where the reinforcement can be tailored accordingly with the outer skin providing the aerodynamic surface.

The VeSCo concept is shown schematically in figure 5. VeSCo is designed to provide a maximum of weight saving while still offering attractive protection against impact and noise. Again with the outer skin providing the aerodynamic surface. In between the two skins there is a core material that is ventable in order to avoid moisture accumulation.

Compared to an aluminium reference fuselage, SoFi and VeSCo may achieve weight savings of about 24-29% [12, 15].

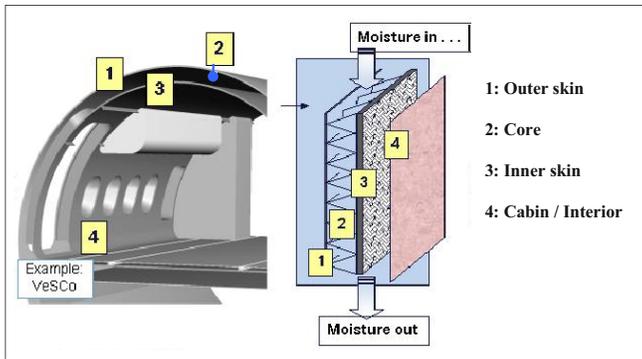


Figure 5. VeSCo concept (schematically shown).

Current R&D shows that there is a high potential for CFRP sandwich applications to save weight and cost in fuselage structures. Metal fuselage structures have been optimised for more than 80 years now and further optimisation becomes more and more difficult. Introduction of a new technology, like composite monolithic or sandwich structures, will lead to a step improvement and a new, steep learning curve.

6. SANDWICH POTENTIALS

Composite sandwich structures offer a wide range of advantages and potentials considering aircraft structural design.

Sandwich structures are very weight effective when it comes to stiffening of skins. The stiffeners are not discrete as in classical stiffened skins resulting in a continuous stiffness distribution in the skin panel. Hence the resulting, non interrupted surface of sandwich skins leads to further advantages, as it is possible to avoid complex cross-overs of stiffening elements (e.g. frames and stringers) which will finally lead to the reduction of analysis-, manufacturing- and maintenance complexity in these areas. Moreover the integral, continuous stiffening permits a reduced parts count for assemblies and therefore less logistics, parts manufacturing- and assembly work. In addition simple skin topography without protruding elements simplifies the vacuum build up (bagging) of the component and reduces manufacturing risk caused by bagging errors (e.g. bridging of vacuum foil, pin holes, strong wrinkling and deformation of foil – see figure 6). The less complex surface geometry allows simple introduction of

technologies for automated vacuum build up can be more easily introduced in order to increase reproducibility and quality.

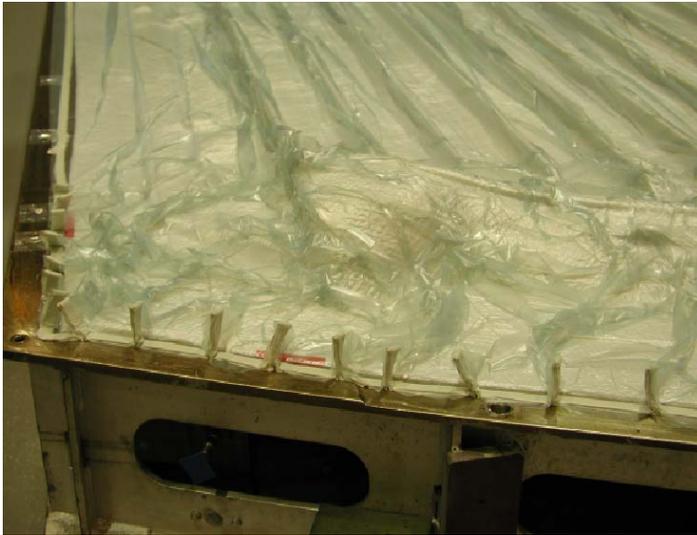


Figure 6. Complex vacuum build up because of protruding elements.

Advanced manufacturing methods like resin infusion technologies combined with homogeneous cores (e.g. foam) and dry fibre preforming open up further possibilities. The level of structural integrity may be significantly improved by integration of textile preformed lugs and attachment fittings which leads to further parts count reduction. Some infusion processes do not require autoclave technology – an oven and vacuum for curing delivers parts with an acceptable fibre volume content (around 60%) for aircraft components. During part build up there are less health and safety hazards within the infusion technology working environment since there is no direct contact with the resin. Furthermore foam cores can be more easily machined and handled than honeycombs of comparable geometry (less distortion and deformation).

In the area of load introduction a foam core sandwich structure features various possibilities for reinforcements. State of the art reinforcing technologies (e.g. pin reinforcement, stitching, etc.) offer a large variety of tailoring for optimum material behaviour. In addition this tailoring improves key sandwich properties like the compression after impact behaviour.

Besides the mentioned examples other promising concepts exist for load introduction in foam core sandwich. Reinforcements in the foam will also serve as crack stoppers [9, 10].

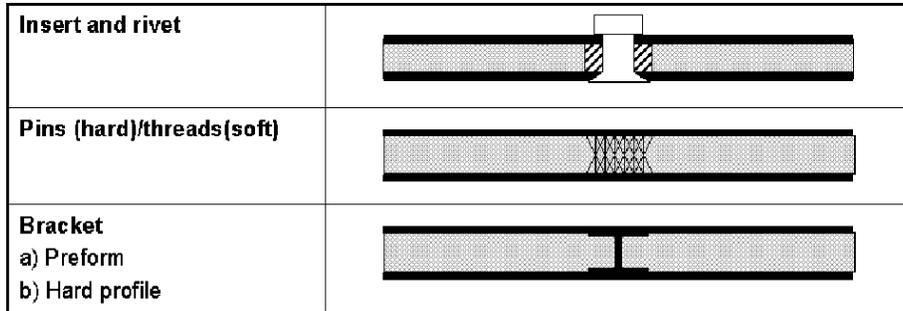


Figure 7. Examples for different sandwich reinforcement concepts.

Sandwich Structures have an excellent damping behaviour and good energy absorption can be achieved by appropriate design [11]. Introduction of sandwich structures in fuselage shells reduces the noise level inside the cabin and thus increases passenger comfort. In this application an integration (at least partial) of thermal isolation of the passenger compartment is also possible.

However, the outlined potentials can not be transferred in to every possible application. For each target application it is the task of engineering in a proper development process to assess the necessary requirements, do trade-off studies for possible concept solutions and validate chosen approaches in simulations and tests to finally show compliance with airworthiness-, customer and company requirements.

This overview is not exhaustive but underlines the large amount of present and future potentials and the multiple possibilities for functional integration in sandwich structures. Because of their inherent properties and qualities advanced sandwich structures represent a composite adapted architecture challenging the quasi metal-derived design and manufacturing of conventional, monolithic composite skins with differentially joined stiffening elements.

At present the potentials of sandwich structures are not fully opened up and applied in commercial aviation. Moreover there are still no primary structure applications of sandwich. For a more widespread application of composite sandwich structures in commercial aviation and to further exploit the benefits of sandwich structures several challenges will have to be mastered in the near and mid-term future.

7. MAJOR CHALLENGES

The application of sandwich structures in commercial aviation is currently restricted to secondary structures. For a more widespread application and in order to introduce sandwich in primary structures several challenges must be met.

For primary structures the possibility of a failure that leads to a catastrophic failure of the aircraft must be prevented. Therefore the structure needs to be evaluated in order to prove that damage occurring during the service life of the aircraft will not lead to failure or excessive structural deformation until the damage is detected. Full compliance to this requirement needs to be shown by simulation and test.

One challenge is to understand in detail how different damages influence the structure and what their behavior in-service is. On one hand the combination of tests and simulation will provide the allowed material values for proper sizing of the structure and will prove new design principles. On the other hand the methods and tools for simulation (e.g. impact behavior, crack growth) will need to be developed/adjusted and finally verified according to the new requirements of a primary sandwich structure and the outcome of the tests. Obviously this is an iterative process that usually starts at a generic hardware level (coupons and elements) and proceeds to more and more complex structural components. One result of this process is the definition of maximum allowable damages and their visibility.

With the information of maximum allowable damages at hand one has to understand the detectability of these damages in the service life. It is a disadvantage for sandwich structure that structural failures (especially in the core) cannot always be detected by common methods (e.g. visual inspection, ultrasonic pulse-echo). One sided access only and large area inspection poses further challenges. A number of NDT technologies are available and under development that better fit the needs to inspect sandwich panels [16, 17, 18, 19]. Novel structural health monitoring technologies are another option to facilitate NDT in service [20]. Once a specific sandwich structure is understood with respect to maximum allowable damages an appropriate detection method has to be chosen and a NDT concept needs to be developed taking into account requirements for economic in service behaviour.

Another important issue is the ability to perform fast and effective repairs. Advanced in-service repair methods (e.g. temporary, infield repairs) have to be developed according to the detailed concept of sandwich primary structures. Important factors for repair methods are the required time and complexity, required infrastructure and tools, achievable material strength after repair and other economical advantages and disadvantages compared to state of the art methods [23].

Naturally any approach to introduce sandwich as a primary structure depends heavily on the design, architecture and material selection of the sandwich structure itself. Innovative, crack stopper and load introduction concepts will be one key issue. The ability of the overall structure to behave fail-safe – means the ability of load redistribution after partial, obvious damage/single failure without loss of overall structural load bearing function – is another key issue. Toughness of the chosen material combinations and the ability to withstand impact damages is also a key driver. The aim must be to produce a design that has optimum robustness within the strict weight requirements of commercial aviation.

8. CONCLUSIONS

This paper gives a brief overview of past and present sandwich applications. Several R&D activities in the area of sandwich for commercial aviation primary structures are described followed by a discussion of potentials and challenges for advanced sandwich structures.

Major commercial aviation sandwich potentials outlined in this paper:

- Weight effectiveness
- Continuous stiffness distribution
- Reduced complexity of surfaces – no protruding elements (e.g. stringers)
- Highly integrated structures possible → reduced parts count
- Reduced production effort and logistics
- Tailoring of reinforcements and load introduction areas
- Advanced manufacturing methods will open up further potentials
- Excellent damping properties
- Possibility of functional integration (e.g. thermal insulation)

Major commercial aviation sandwich challenges outlined in this paper:

- Sandwich as primary structure
- Verified simulation methods and tools for simulating the damage behaviour of complex sandwich structures
- Cost effective, in service non-destructive testing (NDT) methods for complex sandwich structures
- Introduction of structural health monitoring (SHM)
- Advanced in-service repair methods for existing and new sandwich concepts
- Novel load introduction and reinforcement concepts
- New material systems with improved toughness and impact behaviour

The ultimate aim of all activities must be a robust design that can be operated economically.

The overview given in this paper is not exhaustive but underlines the large amount of present and future potentials and the multiple possibilities for functional integration in sandwich structures as well as the challenges that need to be overcome to further promote the application of sandwich in commercial aviation. Advanced sandwich structures represent a composite adapted architecture challenging the quasi metal-derived design and manufacturing of conventional, monolithic composite skins with differentially joined stiffening elements.

REFERENCES

1. Widjaja D., Herrmann A. S., Entwurf und Berechnung von Leichtbaustrukturen mit hybriden, räumlichen Netzwerken, DLR Interner Bericht, Braunschweig, Germany, 1993.
2. van Tooren, M. J. L., Sandwich Fuselage Design, Delft University Press, Delft, the Netherlands, 1998.
3. Wilmes H., Kolesnikov B., Fink A., "New Design Concepts for a CFRP Fuselage", Workshop at German Aerospace Centre (DLR) on Final Project of Black Fuselage, Braunschweig, Germany, 2002.
4. Tan J. C., A Brief History of Sandwich Technology, URL: <http://www.msm.cam.ac.uk/mmc/research/steelsheet/sandwichbase/briefhistory.htm>, 2005.
5. Herrmann A. S., "Design and Manufacture of Monolithic Sandwich Structures with Cellular Cores", Sandwich Construction 4, Vol. 2, pp 719-728, 1998.
6. Military Handbook, Structural Sandwich Composite, Washington, USA, 1968.
7. Pflug J., Xinyu F., Vangrimde B., Verpoest I., "Development of a Sandwich Material with Polypropylene/natural Fibre Skins and Paper Honeycomb Core", Proc. of 10th European Conference on Composite Materials (ECCM-10), pp 331, 2002.
8. Pflug J., Vangrimde B., "New Sandwich Material Concepts – Continuously Produced Honeycomb Cores" COMPOSIT Workshop on New Material Concepts for Composite Transportation Structures, Leuven, Belgium, 2003.
9. Lascoup B., Khellil K., Benzeggagh M., Aboura Z., Maquet J., "Stitched Sandwich Panel Materials for Resin Infusion Structures", SAMPE Journal, Vol. 41, No. 1, pp 42-48, 2005.
10. Cartié D. D., Fleck N. A., "The Effect of Pin Reinforcement upon the Through-Thickness Compressive Strength of Foam-cored Sandwich Panels", Composites Science and Technology 63, pp 2401-2409, 2003.
11. Majamäki J., "Impact Simulations of a Composite Helicopter Structure with MSC.Dytran" (URL: <http://www.mssoftware.com/events/aero2002/abstracts/pdf/p00701a.pdf>) MSC - Worldwide Aerospace Conference & Technology Showcase, Toulouse, France, 2002.
12. Kolax M., "Advanced Composite Fuselage Structures", JEC Composites, No. 10, pp 31-33, 2004.

13. Kleineberg M., Wenner U., Hanke M., "Cost Effective CFRP-Fuselage Manufacturing with Liquid Resin Infusion (LRI) – Technologies", Workshop at German Aerospace Centre (DLR) on Final Project of Black Fuselage, Braunschweig, Germany, 2002.
14. Ley R. P., Lin W., Mbanefo U., Facesheet Wrinkling in Sandwich Structures, NASA/CR-1999-208994, Virginia, USA, 1999.
15. Kupke M., Kolax M., "CFRP-Fuselage – Ensuring Future Competitiveness", SAMPE Conference, Paris, 2004.
16. Hilger W., Meier R. Henrich R., "Inspection of CFRP Components by Ultrasonic Imaging with Air-coupling", InSight Vol. 46 No. 3 pp 147-150, 2004.
17. Andersson J., van den Bos B., "NDI on Bonded Sandwich Structures with Foam Cores and Stiff Skins – Shearography the Answer?", Application Report No. 02. 01 of Attemeyer AG, http://www.dantec-ettmeyer.com/pdf/shearography_ndt_2_01.pdf.
18. Gustafsson J., "Nondestructive Large Area Testing Using Shearography", Application Report No. 01. 02 of Attemeyer AG, http://www.dantec-ettmeyer.com/pdf/shearography_ndt_01_02.pdf
19. Anastasi R. F., Zalameda J. N., Madaras E. I., "Damage Detection in Rotorcraft Composite Structures Using Thermography and Laser-Based Ultrasound", SEM X International Congress and Exposition on Experimental and Applied Mechanics, Costa Mesa, CA, 2004.
20. Bois C., Hochard C., "Monitoring of Laminated Composites Delamination Based on Electro-Mechanical Impedance Measurement", Journal of Intelligent Material Systems and Structures Vol. 15 pp 59-67, 2004.
21. Boeing, "Boeing Completes First 7E7 Composite Fuselage Section", http://www.boeing.com/news/releases/2005/q1/nr_050111g.html, 2005.
22. Rouse M., Ambur D. R., Bodine J., Dopker B., "Evaluation of a Composite Sandwich Fuselage Side Panel with Damage and Subjected to Internal Pressure", NASA Technical Memorandum 110309, Virginia, USA, 1997.
23. Armstrong K. B., Barrett R. T., Care and repair of Advanced Composites, Society of Automotive Engineers (SAE), PA, USA, 1997.