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# An Innovation and Development System for a New Hybrid Composite Technology in Aerospace Industry

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***Abstract*—**Lightweight design represents an important key to successful implementation of energy-saving, fuel-efficient and environmentally friendly means of transport in the aerospace and automotive industry. In this context the use of carbon fibre reinforced plastics (CFRP) which are distinguished by their outstanding mechanical properties at relatively low weight, promise significant improvements. Due to the reduction of the total mass, with the resulting lowered fuel or energy consumption and $CO_2$ emissions during the operational phase, commercial aircraft will increasingly be made of CFRP. An auspicious technology for the efficient and economic production of high performance thermoset composites and hybrid structures for future lightweight applications is the combination of carbon fibre sheet moulding compound, tailored continuous carbon fibre reinforcements and metallic components in a one-shot pressing and curing process. This paper deals with a hybrid composite technology for aerospace industries, which was developed with the help of a special innovation and development system.

***Keywords*—**Composite, development, hybrid, innovation, system.

## I. Introduction

INNOVATIVE lightweight solutions have led to economical and environmentally friendly aircraft and vehicles in recent years. In this regard, composites such as carbon fibre reinforced plastics (CFRP) are becoming increasingly important compared to the known metallic lightweight materials such as aluminium and titanium. The importance of these comparatively expensive reinforced plastics increases due to their optimum, tailored mechanical properties in combination with a low density. Consequently, aircraft or vehicles with higher fuel efficiency can be developed and the increasingly tough environmental regulations can be fulfilled. However, it is difficult to realise lightweight solutions through the use of fibre reinforced plastics alone, because of economic reasons and other requirements such as an unfavourable.

However, it is difficult to realise lightweight solutions through the use of fibre reinforced plastics alone, because of economic reasons and other requirements such as an unfavourable geometry of the components or high temperatures. Therefore, composite components have to be fitted or bonded to metal components for the realisation of complex structures, such parts can already be found in aircraft. Joining and assembly processes, such as gluing, riveting or screwing, are in industrial use by now. For an even more integral approach, multi-material constructions have to be produced in a direct way. These hybrid materials combine the properties of both material groups in an optimum manner and according to the respective component requirements. This fact also has a positive impact on the potential for lightweight construction. However, there are also some disadvantages which affect the resulting components, such as high residual stresses, due to dissimilar thermal expansion coefficients, a lack of bending stiffness or various problems with the mechanical finishing. In relation to the production of such multi-material constructions a number of technical obstacles have to be overcome, especially in regard to the industrialisation of the corresponding processes. Current composite production processes in the automotive or aerospace industry generate comparatively high component and process costs at low production rates and poor material utilisation. These circumstances lead to an immense demand for efficient, economic and environmentally sustainable processes and the corresponding production systems for the manufacturing of metal and composite multi-material systems. These facts are quite important due to the required increase of resource and energy efficiency in production and the increasing complexity as a result of the rising number of variants. The demand for innovation in this field has to be managed systematically and methodically from the idea, through the development of new technologies and up to the industrialisation. A holistic innovation and development system for such complex lightweight technologies can lead to a more economical and time efficient development process. Furthermore such a system can ensure a subsequent use in an industrial environment, especially in the aviation industry.

## II. State of the Art

In the field of thermoplastic composite-metal hybridisations there already are some promising development projects and technology approaches. They especially deal with the combination of injection moulding and press forming of continuous fibre reinforced thermoplastics, also called organic sheets. Metal inserts and other metallic components are provided for appropriate tools. They are inserted and directly moulded into the parts at the correct position [1].

In the field of thermosetting matrix materials only the comparable approaches of the combination of sheet moulding compound (SMC) or bulk moulding compound (BMC) with

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metal inserts exist. Due to the long fibres which are normally not oriented, these composites do not fulfil the mechanical properties and potential for lightweight construction, compared to continuous-fibre reinforced composites [2], [3]. There have already been some efforts and development projects to combine long fibre reinforced extruded masses, in the form of sheet moulding compound, in a closed press and curing process with pre-impregnated continuous fibre semi-finished products (Prepregs). The integration of metallic components in these complex fibre composite materials, by merging these steps into a single stage pressing process, is in this context a new approach. Through the development of such a multi-material system, a new category of high strength, complex and at the same time economically producible metal and thermoset, fibre reinforced plastic hybrid components find their way into the lightweight construction methods [4]-[8].

A wide variety of models exist in the field of innovation management and development methodology, but these often show just partial sections or stringent sequences of how to get from the idea to the application in the industry. In many cases, interaction, feedback and allocation of tasks between parts of the process are only partially or not at all represented. However, the greatest difficulty is to know the appropriate tools and methods for each development stage. A holistic innovation and development system for complex light-weight technologies in the aerospace industry which is described in each stage of the process with a methodological tool box is currently unknown [9]-[12].

## III. Aim and Purpose of the Present Work

The aim of the current research project is the development of a combined, automated pressing and curing process for the direct production of complex hybrid components for the aerospace industry, shown in Fig. 1.

The finished parts consist of carbon fibre sheet moulding compound and pre-impregnated continuous carbon fibre semi-finished products with the involvement of metallic components. Emphasis is put on the holistic approach, design and evaluation of the entire process chain with the purpose of efficiency, flexibility, reliability, part quality, and increasing energy and resource efficiency. These objectives will be achieved through reduced cycle times, automation, better material utilisation, integrated quality assurance elements and by the possibility of using carbon fibre recyclates. All upstream production steps, such as semi-finished product processing, preforming and preheating, the actual pressing and curing process itself, and downstream steps, such as removal from the mould, deburring, finishing and painting are considered in the overall context from the material, handling and automation engineering point of view. This process chain is to be conceptually developed for the aerospace industry and validated using a variety of reference components from this industry, as well as a laboratory production facility. In addition, the industrial integration of this production technology is conceptually developed in the aerospace, checked by simulation for a different number of components and scenarios and finally validated in real life. This is the planned way for the introduction of this industrial production technology and the use of these multi-material systems for cabin, cargo and secondary structure components in future aircraft. Similarly, the transfer into the automotive sector and the transport sector in general is considered which promises an even more substantial increase in productivity and reduction of associated manufacturing costs, due to higher volumes. Numerical optimisation programs and the finite element method (FEM) will be used for the implementation of the lightweight potential. In the application of these programs, short and long-term dynamic loads are applied to the models and the models are optimised in terms of different properties, for example light weight. A particularly high effectiveness of the optimisation tools is demonstrated, when a large number of variables influencing the system behaviour are present, as occurs with the use of smart materials for load-adapted design of components. Part of the research project is to develop a construction and design methodology which allows a higher prediction accuracy of the failure behaviour of the components.

This means that in the current research project new hybrid multi-material systems, the corresponding production processes, the required production technology and a design and interpretation system have to be developed for such complex hybrid structures. The framework for this technology development is an innovation and development system that has been designed for new hybrid composite technologies in aviation, but is applicable to any technology, product or material development. This system simplifies the complexities of the innovation and development process, pointing out a systematic approach and refers in every phase of the development to the appropriate methods to reach the target. The ease of use, applicability and effectiveness of the innovation and development system which establishes a cost- and time-efficient process for the industrialisation of a technology, will be examined and validated by the research project.

## IV. The Innovation and Development System

Innovation, development and utilisation in the industry are mutually dependent. The interaction between these three elements guarantees the efficiency and cost-effectiveness of technologies and products.

There is also a fourth element, the business development which influences the other three elements in a holistic technology or product realisation.A good idea without a sound business model, in the form of implementation, financing or recovery plans, is usually only a good idea and does not create usable innovations. For this reason, the uniform analysis of all four particular important elementary cycles must be performed. The interdependencies of all cycles are shown schematically in Fig. 2.

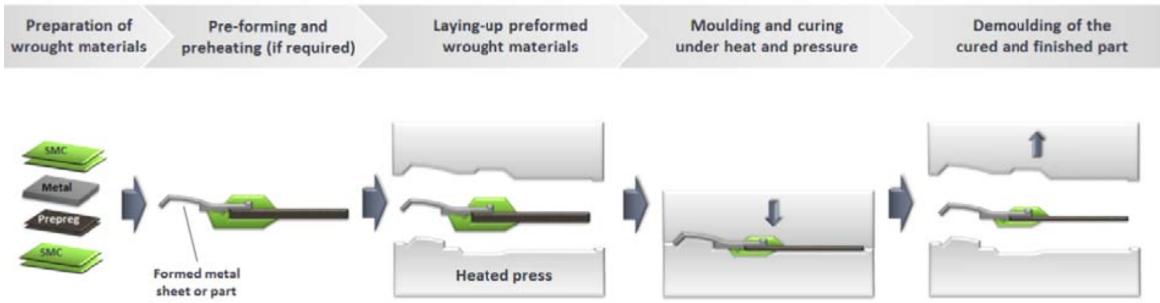


Fig. 1 Process cycle with the combination of pre-impregnated carbon fibre fabrics, carbon fibre SMC and formed metal components

Each cycle and phase of the development is subject to the economic, technical and environmental influences which always have to be observed. All of the four elements are based on the Deming Cycle or PDCA cycle (Plan, Do, Check, Act). This innovation and development system is more than just a sequence of process steps and an illustration of their complex interactions, because at each stage the appropriate methods are stored. This includes creativity techniques, assessment procedures, management tools and other scientific methods. For the development of the new hybrid composite technology, several methods have been adapted to the topic. These adjustments cause a more efficient objective definition and development process. The development errors are minimised, reducing the development costs and accelerating the development process.

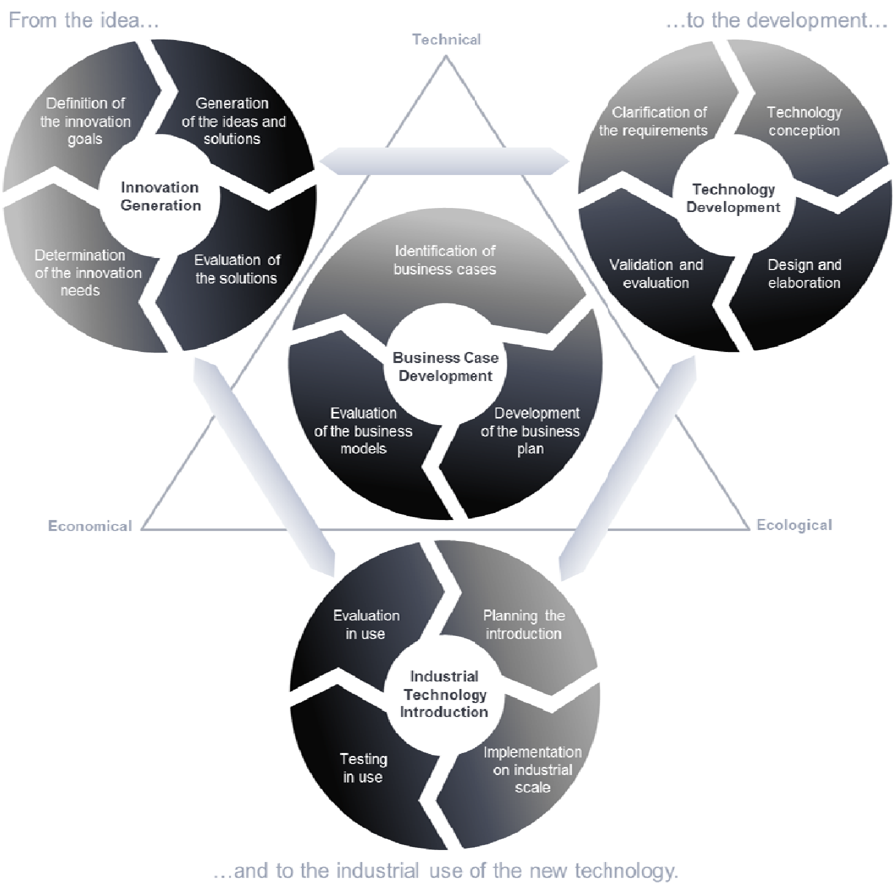


Fig. 2 Innovation and development system for new aerospace technologies

The development process begins with the determination of the need for innovation. Before ideas can be used to generate solutions, the determination of innovation objectives and the definition of possible innovation problems have to be done. Finally, the solutions are evaluated. Innovations with a negative assessment result are either discarded or passed to the innovation generation cycle for further improvement. Promising approaches are handed over to the business case development which consists of the identification of possible business cases, the development of business plans and the evaluation of the business models.

For a positive evaluation of a business model for an innovative technology solution, the innovation is forwarded to the actual technology development cycle. This element consists of the exact clarification of the requirements, the technology conception, the design and preparation phase and the final development review. Business models also have to be generated for promising technology developments. After the successful evaluation of the business case for a developed technology, the requirements for the implementation in an industrial environment are created.

The Technology Readiness Level (TRL) and / or the Manufacturing Readiness Level (MRL) assessment for example can provide a guideline for this phase. Both of these procedures define a rating scheme for the evaluation of the development progress. Before a technology or product is able to advance to the next level, a review is done. Depending on the outcome of this evaluation, the technology or product may advance to the next level, further work within the current level has to be done or it can be discarded. If the evaluated technology was discarded, the innovation generation cycle can be started again with additional information regarding technological or industrial obstacles. When the Manufacturing Readiness Level 8 is reached, the introduction of the technology in the industry, a test under real conditions and the final rating are following.

Afterwards follows the introduction of the technology in the industry, a test under real conditions and the final rating. If this ends with a negative result, a new iteration of this cycle is started. A positive evaluation leads to the final use of the technology. Information is exchanged at any time between the cycles. The results for example which are created in the Industrial Technology Introduction cycle may raise new issues or problems which need to be optimised. This in turn leads to new innovation needs, creating a dynamic cycle. In the innovation and development scheme these circumstances and additional external influences are taken into account. An example provides a more accurate insight into the methodical approach and the methodical tools. For this reason, the development phase of the generation of the ideas and solutions, which is a part the innovation generation cycle, will be considered in detail. The appropriate methods and the methodical approach to generate ideas and solutions referring to the innovation needs in the field of composite technologies for the aerospace industry are shown in Fig. 3.

After the definition of the innovation goals and requirements, the development step of finding ideas and generating solutions follows. This step can be supported by various methods, for example the Political, Economic, Social, Technological, Environmental and Legal (PESTEL) analysis. Other techniques can be the Strengths, Weaknesses, Opportunities and Threats (SWOT) or the Value, Rarity, Imitability and Organization (VRIO) analysis. Different influencing factors regarding the technology development, like the political, economic and ecological environment as well as the structure of the research organization, can be analysed with these tools. [13]

Afterwards the development focuses have to be analysed and the generated goals and requirements have to be weighted. Adequate methods can be the paired comparison or a Pareto Analysis.

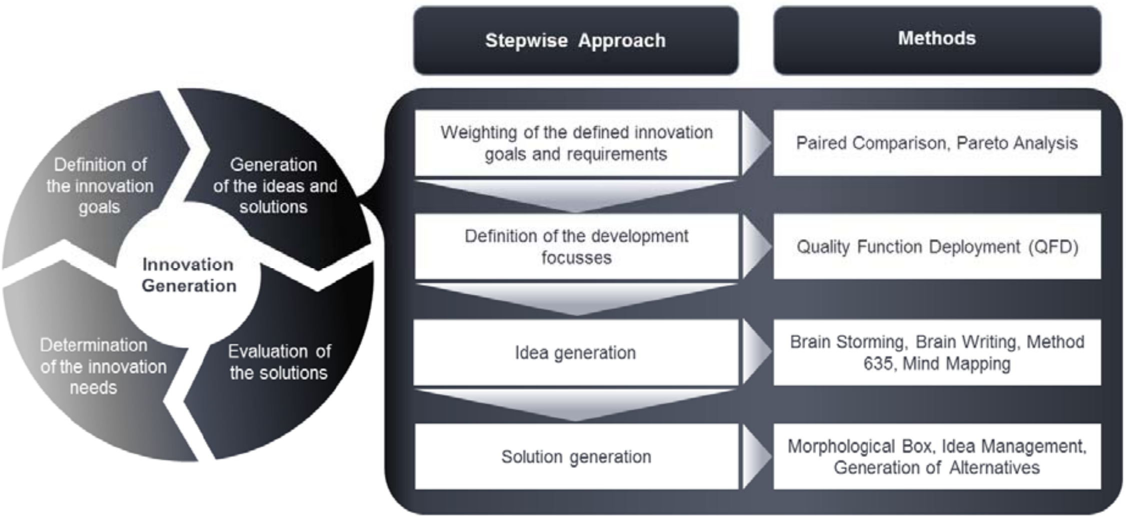


Fig. 3 Methods and methodical approach for the generation of ideas and solutions in the field of new composite technologies

Quality Function Deployment (QFD) can be used to ensure that the innovation goals are correctly defined and adapted to the requirements. A ranking of the diverse technological solutions in regard to the requirements is obtained as a result of the Quality Function Deployment. The assessment of the technological solutions in terms of the expected difficulties will obtain another ranking. These two rankings can be used to create an importance-difficulty plot, where the most critical solutions are situated at the top right corner. [14]

Subsequently, new ideas have to be generated with methods like Brain Storming, Mind Mapping, Brain Writing or Method 635. These ideas are the basis for innovative solutions. In this regard complete solutions can be developed out of the generated ideas. Methods like the Morphological Box, idea management and the generation of alternatives can help to organise all ideas and to find auspicious solutions. Finally the created innovation solutions result in the next development step where they have to be analysed and evaluated. For the analyses and evaluation of the solutions methods like Failure Mode and Effect Analysis (FMEA) and Benefit-Analysis can be used. The Failure Mode and Effects Analysis can be used to detect, evaluate and rank the risk associated with failures within a design, process or system in a structured way. The early and continuous use of this method within this innovation and development system enables potential costs savings. The cost savings are achieved due to the failure detection at an early stage of the development process and they can be rectified or prevented with a relatively small budget. [15]

The presented stepwise approach for the generation of ideas and solutions in combination with the appropriate methods is only an example. The described innovation and development system provides such approaches and methodical tools for every step. For this reason the whole development process for new technologies can be executed in a systematic and methodical way. Moreover, the methodical tools, displayed in the right column of Fig. 3, help to use the adequate methods in an appropriate way and at the right place.

In conclusion the system can ensure the industrial use of innovative technologies and reduce the time to push technological developments into practice.

## V.CONCLUSION

In the field systematic and methodological approach for the complete development of a new technology in the aerospace industry may result in a more efficient, economical and faster progress of innovation. These potentials are investigated in the framework of the development of a new fibre composite and multi-material technology. Here the functionality, applicability and effectiveness of the industrial utilisation of the new multi-material system, the production process of the plant technology and a design and interpretation system are considered. Since this is a universally applicable system which is required for each phase, the development methods have to be partially adapted to the constraints and objectives. In addition, it is important to consider the integrative approach and the interaction of the four elementary cycles at all times. It has to be noted that ongoing processes are always subject to technical, economic and environmental influences. Research leading to the technology development of the combination of sheet moulding compound, continuous carbon fibre reinforcements and metallic components for the aerospace industry can be efficiently and successfully supported through the use of this system. In combination with the suitable methods the Technology Development phase can be achieved. The transfer of this method to other sectors, such as automotive or transportation, is the focus in the future.

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