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DER COMPOSITE-WEG: ENTWICKLUNG VON STRUKTUR- UND FERTIGUNGSKONZEPTEN FÜR HOCHAUFTRIEBSKOMPONENTEN

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Summary

In cooperation between different EADS Business Units, a new advanced composite load introduction rib for high lift devices of future aircraft has been developed to minimize weight and manufacturing costs. The new integrated design of the load introduction rib focuses on the reduction of the complexity and to simplify the Preform manufacturing. The complex loading of the load introduction structure requires a detailed numeric analysis for an accurate calculation of all critical stresses. The static analysis of the new composite load introduction rib and drive fittings show sufficient strength. Based on prior investigations, the composite lugs show satisfying damage tolerance behaviour leading to the conclusion that a second load path is not necessary. A new preform process chain with assembly stitching sub-preforms shows high manufacturing costs saving potential in comparison to current standard composite manufacturing. This is further enhanced by the application of a vacuum infusion process (VAP), outside the autoclave saving additional manufacturing costs. The influence of preform stitching, assembly and structural stitching, on the mechanical properties of the material is investigated in detail as well.

1. INTRODUCTION

Innovative composite structures are increasingly being used in the aircraft industry. A critical point of these new composite parts is the attachment to the surrounding aircraft structure. Current composite high lift structures usually have metal load introduction structures, which have been designed as Fail Safe structures. This leads to high weights, high manufacturing costs and an increased assembly effort. Additional thermal loads may occur due to the different thermal expansion between metals and composites.

The aim of new innovative load introduction structures is to reduce structural complexity by an integrated design reducing weight and costs. The use of composite in load introduction structures permits a damage tolerance design instead of a fail safe structure, since a failure of one ply is compensated by the surrounding intact plies. This further eliminates additional thermal loads, since the high lift structure as the load introduction structure are made of the same material.

2. DESIGN AND ANALYSIS OF THE NEW LOAD INTRODUCTION RIB

The new design focused on the load introduction rib and drive rib with integrated lugs for the attachment of the flap support structure. The aim of the new design was to decrease manufacturing costs by simplifying the component to have one thickness for geometrically complex preforms and allowing significant thickness variances only in areas, which are simple with respect to preforming. The new design consists of a composite load introduction rib being assembled by an Omega-profile and U- and L- profiles respectively, thus minimizing the manufacturing costs by an automatable preform lay-up and industrial concept (Fig. 1).

The calculation of composite load introduction requires the implementation of 3D-elements for an accurate analysis of all stress components. This is achieved by the use of 3D continuum shell elements, which provide all stress components with an enhanced formulation for the transversal shear stresses (Fig. 2). Since delamination is a common type of failure for composite load introduction, the transversal shear and peel stresses are of high interest. The load introduction rib (modelled with 3D-elements) is attached to the surrounding structure (2D-elements) with rivets. These rivets are implemented as elastic connectors in connection with rigid body elements.

The HYPERMESH pre-processor is used for the set-up of the finite element model due to its enhanced capabilities in 3D meshing and extensive support of different solvers. Several load cases are calculated with the ABAQUS implicit solver and post-processed with ABAQUS CAE.

It is shown that the in-plane as well as the transversal stress components are uncritical for the new composite design. Additional extensive analysis of each rivet shows sufficient strength for the connection of the load introduction rib to the surrounding structure. The analytical calculation of the composite lugs [1] show an uncritical loading of the attachments.

3. PREFORM KONZEPT

Zusammen mit der geplanten Preform-Prozesskette ermöglicht das neue Design eine automatisierte Fertigung. Das Preform Konzept beinhaltet die Reduktion von handzuhabenden Einzelteilen und besitzt Potential für die Online Qualitätskontrolle. Ziel ist die Entwicklung einer durchgängigen Prozesskette für eine schnelle und flexible Preformfertigung.

Die Prozesskette besteht aus verschiedenen automatisierten Elementen

- Layup processing
- 2D- and 3D-Nähen
- 2D- and 3D-Schneiden
- Drapieren
- Pick & Place
- Binderaktivierung
- Preformvermessung

Durch die Verwendung eines biaxialen NCF und einen automatisierten, mehrlagigen Lay-Up Prozess (Abb. 3) werden die manuellen Arbeitsschritte reduziert. Die Drapierbarkeit, die Preform-Stabilität und der Binderanteil können nach Bedarf angepasst und mittels Nähtechnik in den ersten Verarbeitungsschritt integriert werden (im Gegensatz zur Verwendung von z.B. quadraxialem NCF). Das Ergebnis des automatisierten Prozesses sind funktionale, „advanced tailored reinforcements“.

Eine weitere Reduzierung der Fertigungskosten kann mit automatisierten Pick & Drape Vorrichtungen oder einem Schneidsystem für die Herstellung von „through-the-thickness“-Verstärkungen (z.B. ein End-Effektor für einen Roboter) erreicht werden. Diese Hilfsmittel (Abb. 3) erlauben die reproduzierbare Herstellung von Sub-Preforms auf Preform-Werkzeugen. Robotergestützte 3D-Näh- und 3D-Schneidprozesse vervollständigen die Preform-Prozesskette. Die Auswirkungen von zusätzlich eingebrachten strukturellen Nähten für „through-the-thickness“-Verstärkungen wird untersucht.

4. INFILTRATION CONCEPT

Concerning the infiltration concept several properties of the basic design have to be highlighted due to their possible impact on the quality of the infiltration procedure. Firstly, the highly integral design principle with diaphragms and angular load introduction elements towards the front and rear side of the rib calls for an appropriate tooling concept. Secondly, the high degree of fabric deformation due to the part's curvature leads to an adequate deployment of caul plate and intensifier modules to assure a good thickness distribution and sufficient surface quality at interface locations. This, of course, affects the complexity of the resin supply concept. And finally, a reasonable amount of industrialisation capabilities have to be considered for the infiltration procedure of the rib and fitting structures. In order to meet all this requirements the Vacuum Assisted Process (VAP®, Fig. 5) is applied together with an innovative tooling concept, which was evaluated during a simplified preliminary manufacturing trial.

The basic process principles are shown in Figure 5 for a simple plate. A dry textile preform is placed on top of the inner mould surface and connected to the resin supply channel by a flow media that allows for the degassing of the resin prior to the preform infiltration. The evacuation of any remaining air out of the preform is managed by a semi permeable membrane all over the parts' surface. Combined with the vacuum bag on top of the whole setup and respective sealing a two chamber system is established.

The respective tooling concept for the rib structure was assessed during a preliminary manufacturing test, which is illustrated in Figure 6. The basic tool for the Omega profile is comprised of a male mould with inserts for the integrated diaphragms and a caul plate module covering all of the part's surface. It has to be stressed that an innovative hybrid tooling concept is applied, since three materials constitute the tooling. The main positive mould is made of ordinary steel (ST-52), whereas the inserts are milled out of Aluminium in a smaller scale, in order to reach the nominal geometry due to thermal expansion during curing at 180° C. Thus it can be assured that also less compressed dry preforms for the diaphragms fit into the main tool. Moreover, the caul plate is manufactured using CFRP materials that assure sufficient stiffness in the radius areas.

To account for the nearly closed mould principle deployed for the rib structure and to address the industrialisation requirements, some features were already embedded into the preliminary tooling devices or will be applied for the final cure tooling. First of all small resin channels were milled into the main steel mould and the aluminium inserts. This accounts for a robust infiltration procedure and can also be referred to as a way to minimize manufacturing cost due to the fact that no resin flow media has to be applied additionally. Moreover, vacuum channels with an optimized shape could be integrated into a serial production main mould, thus providing adequate evacuation time. Due to cost this will not be done within this project.

According to the investigations so far performed for the infiltration procedure it can be concluded that the overall feasibility of the above mentioned concept and the corresponding features is proved (Fig. 7). Additionally, the findings during the first manufacturing trails indicate that also the normally observed spring-back effects could be limited to a negligible amount by applying integrated diaphragms to profile-like structures.

All for the manufacturing of the test parts required toolings have been designed incorporating the results of the trials. Also the manufacturing and delivery of the toolings is completed. After the manufacturing of the test parts the reached qualities and geometrical tolerances will be evaluated.

5. UNIT CELL MODELLING OF STITCHED PRE-FORMS

Within the composite load introduction rip local three-dimensional tension conditions especially in the lug areas can occur. To enhance the poor out-of-plane behavior of the composite load introduction rib in these areas the insertion of local through-thickness reinforcements by structural stitching is intended.

By means of the ANSYS® Parametric Design Language (APDL) a linear finite element model based on a representative unit-cell is developed to predict three-dimensional elastic and in-plane strength properties of structurally stitched NCF CFRP laminates (Fig. 8). The parametric model is built up considering the number, thickness and fiber orientation of the laminate layers, the cross-section area and width of stitching voids, the yarn count, the stitch spacing, pitch length and stitching direction as well as the loading direction. Micrograph analyses in each layer of the laminate provide the numerical data for the void area and width. The unit-cell model also respects local fiber displacement in the vicinity of the stitching yarn and the change of the fiber volume content due to structural stitching. By defining a total of twelve load cases at the surfaces of the unit-cell in form of displacement boundary conditions the coefficients of the global stiffness matrix [ABD] can be determined by means of the resulting nodal forces and moments. Young's moduli, shear moduli and Poisson's ratios are obtained from coefficients of the compliance matrix [ABD] 1.

The continuum mechanics based strength prediction consists of stress and strain analysis, fracture analysis and degradation analysis. The maximum stress criterion is applied to estimate the fiber failure stress exposure. To predict inter-fiber failure Puck's action plane criterion for 3D-stress states is used. By means of a modified Chiu model post-failure behaviour due to partial stiffness degradation is modelled.

With the aid of the developed FE unit-cell model structural stitching configurations which cause small reductions of the in-plane properties only but in turn generate enhanced of the out-of-plane properties shall be identified.

6. REFERENCES

[1] Kassapoglou, Townsend, Failure Prediciton of Composite Lugs under axial Loads. AIAA Journal Vol 41, No. 11, November 2003.

7. PICTURES

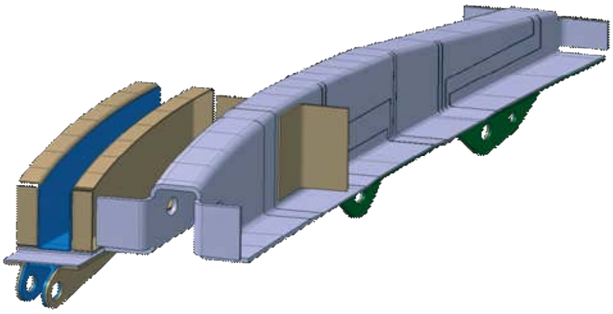

BILD 1. Design of Composite Load Introduction Rib and Drive Strut Fitting

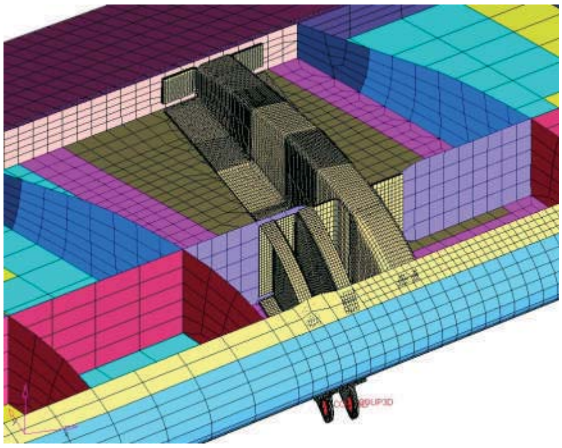

BILD 2. Analysis model of Composite Load Introduction Rib and Drive Strut Fitting

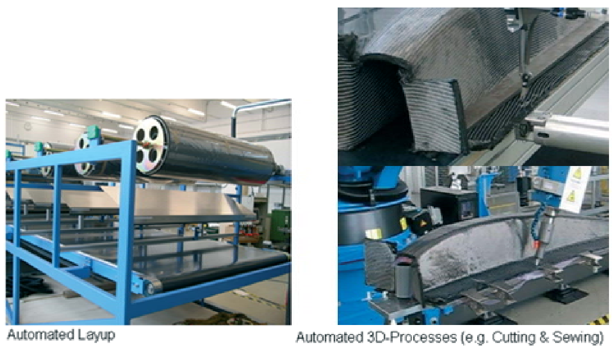

BILD 3. Functional advanced tailored reinforcements

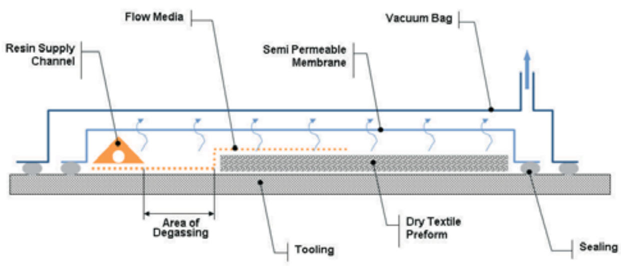

BILD 4. Principle of Vacuum Assisted Process (VAP®)

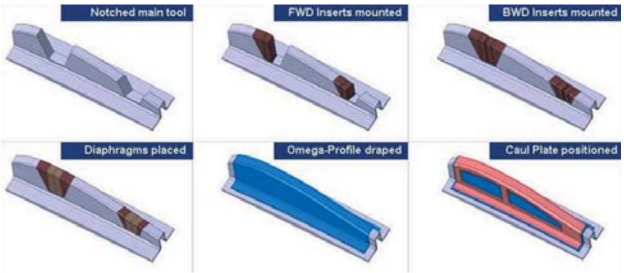

BILD 5. Schematic manufacturing and tooling concept for integrally formed diaphragms

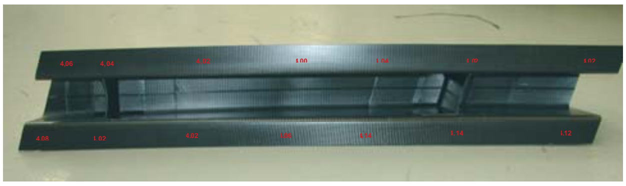

BILD 6. Result of first manufacturing trails with integrated diaphragms

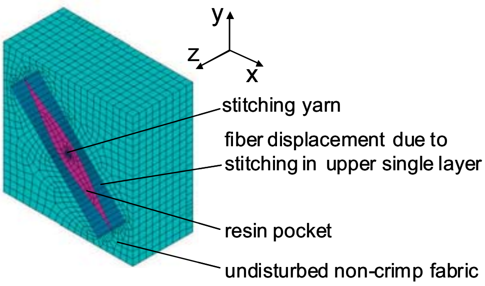

BILD 7. Finite Element unit-cell model of structurally stitched NCF CFRP