Repair and Substantiation of the NH90 Sandwich Composite Bottom Shell

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ABSTRACT

This paper deals with the handling of a severe structural damage on a composite shell of a NH90 Navy Helicopter which occurred in 2011. Aim was to restore the damaged load carrying airframe structure to original type design strength without limiting the contractual defined performance of the helicopter.

Presented will be the complete procedure from damage evaluation using non-destructive-testing (NDT) methods via preparation of repair proposals till finalizing the repair and generating the corresponding strength substantiation.

Since the damaged airframe structure is mainly a carbon fiber sandwich composite, the repair had to comply with the therefore specially qualified materials and processes. The repair approach finally selected was an outside secondary bonded sandwich composite inlay joined by paste adhesive on the original bottom shell and on the inside a wet-laminated patch to join the new with the original inner skin.

Result was a completely restored airframe structure enabling the customer to fulfill all its contractual defined missions without any restrictions.

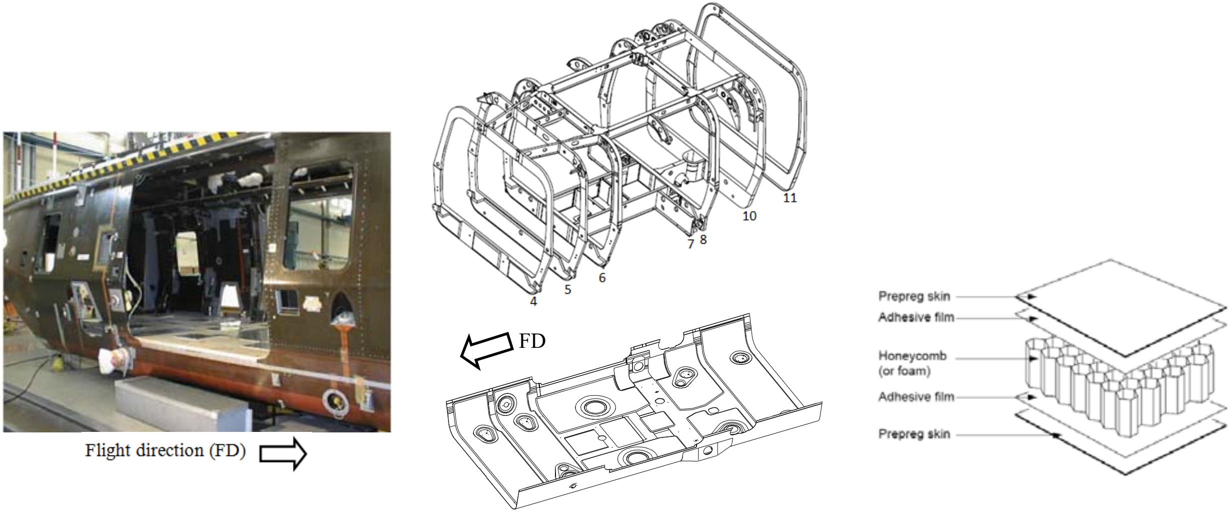
Conclusion is that with the qualified repair materials, therefore specially developed processes together with well-trained personnel such severe damages on load carrying sandwich composite airframe structures can be fixed within reasonable effort and cost.

1.0 THE NH90 AIRFRAME STRUCTURE

The NH90 is a medium-sized, twin engine, multi role transport helicopter with a MTOW of 11 tons. It comes mainly in two variants the Tactical Transport Helicopter (TTH) for army use and the nasalized NATO Frigate Helicopter (NFH).

Figure 1-1: NH90 NFH

This helicopter features mainly a carbon fiber reinforced plastic (CFRP) airframe structure. Almost all frames, beams, shells and panels are made of CFRP. The only metallic exceptions are the cabin floor sandwich panels, local load introduction brackets (e.g. for gear box and landing gear attachment) and some minor sheets. This makes an 85% composite airframe.
The lower illustrations give a rough overview of some center fuselage design elements.



Right hand side view on the CFRP (center) fuselage

center fuselage CFRP airframe structure (frames numbered) and below the sandwich bottom shell

General structure of the all NH90 sandwich compostite parts

Figure 1-2: NH90 CFRP Airframe Structure Elements

Basic structural materials are:

- Laminates: Bidirectional carbon (& aramid) and unidirectional carbon fiber fabrics pre-impregnated with an epoxy matrix system (180°C curing class).
- Sandwich core: Polyamide paper honeycomb cores (Nomex) wrapped in epoxy film adhesive for adhesion improvement to the prepreg skins.
- Paste adhesives: Two component epoxy paste adhesives (room temperature & 65°C curing).
- Wet-laminate: Bidirectional and unidirectional dry carbon fiber fabrics impregnated with two component epoxy resins (room temperature & 65/80°C curing).

The CFRP parts are generally joined by fasteners. Used are titanium lock bolts and blind bolts or steel blind rivets. Detachable joints are mostly realized by screws together with riveted or bonded nuts.

2.0 DAMAGE ASSESSMENT

During jacking operation for the purpose of weighing an incident happened on the NH90, NNLN 003 (NFH). While lifting up the helicopter, load cells which were installed between the helicopter jacking brackets and the lifting device, slipped out of their mounting from the front lifting devices.
As a result, the two front lifting devices slipped to the front and penetrated the CFRP sandwich composite structure of the bottom shell in the area of the front tank bladder in front of the second center fuselage frame #5.

Figure 2-1 (left hand side) shows the lifting device (orange) penetrating the bottom shell structure between the first and second center fuselage frames (frame #4 and frame #5).
Figure 2-1 (right hand side) shows the damaged composite structure on the left hand side after removal of the lifting device. Looking through the cracks, the ripped and broken Nomex honeycomb core of the sandwich composite structure can be seen.

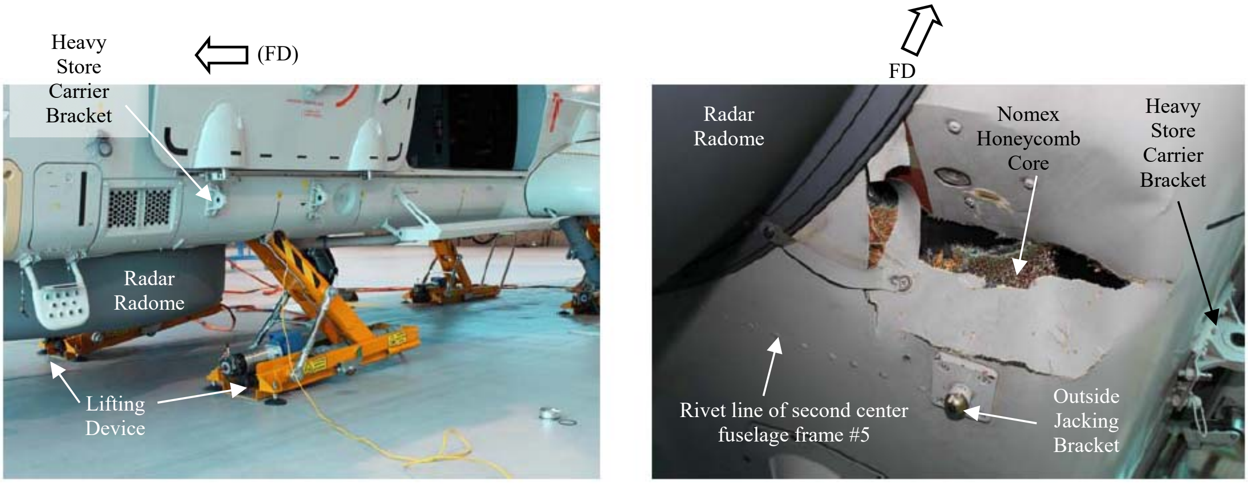
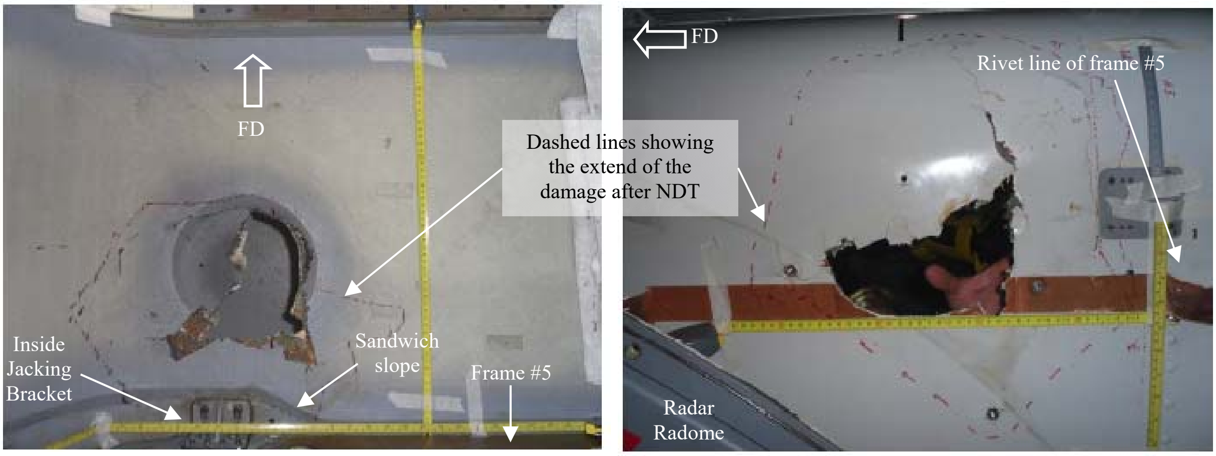


Figure 2-1: Damaged Bottom Shell Sandwich Composite Structure

2.1 Damage Inspection

The complete damaged areas were good accessible for inspection on inside and outside. The inspection was carried out

- First, by visual inspection for cracks and scratches
- Second, by tapping test with tapping hammer to detect delamination in the sandwich area and
- Third, by ultra-sonic pulse echo to detect delamination in laminate areas.



Inside view, downward

Outside view, upward

Figure 2-2: Damages on Bottom Shell (only left hand side shown)

The penetration of the jacking device caused cracks in the laminate parallel to the sandwich slope with further cracks reaching widely forward into the sandwich region. The bending inwards of the structure caused also a shear failure of the laminate at the sandwich slope directly in front of the jacking bracket which is installed in front of frame #5.

The extent of the damage on the bottom shell, after NDT was completed, is shown in Figure 2-2 by the dashed lines. The frame #5 showed no defects.

2.2 Damage Evaluation

Not to mention that this large damage, not repaired, would have negative effects on the basic operational capabilities of the helicopter affecting the certification basis, requirements, aspects of compliance demonstration, substantiation data, and other functions of the helicopter.

Nevertheless, in a war time mission scenario it could be thinkable to let a helicopter operate with this kind of damage but with a reduced spectrum for a limited time. Precondition would be that the tank bladder suffered no serious damage and the damaged composite areas have been flattened and stabilized by tape.

In a peace time scenario, as it is the case for this H/C, this damage has to be fixed before further operations.

3.0 REPAIR PROPOSAL

Several procedures have been discussed to fix the damaged area: from sheet metal applications via local extensive wet-laminate restorations till exchange of the complete bottom shell.
According to AHD experience the best compromise between feasibility and effort to handle this damage is the one which was then realized and is roughly shown in the section-cut sketches below.

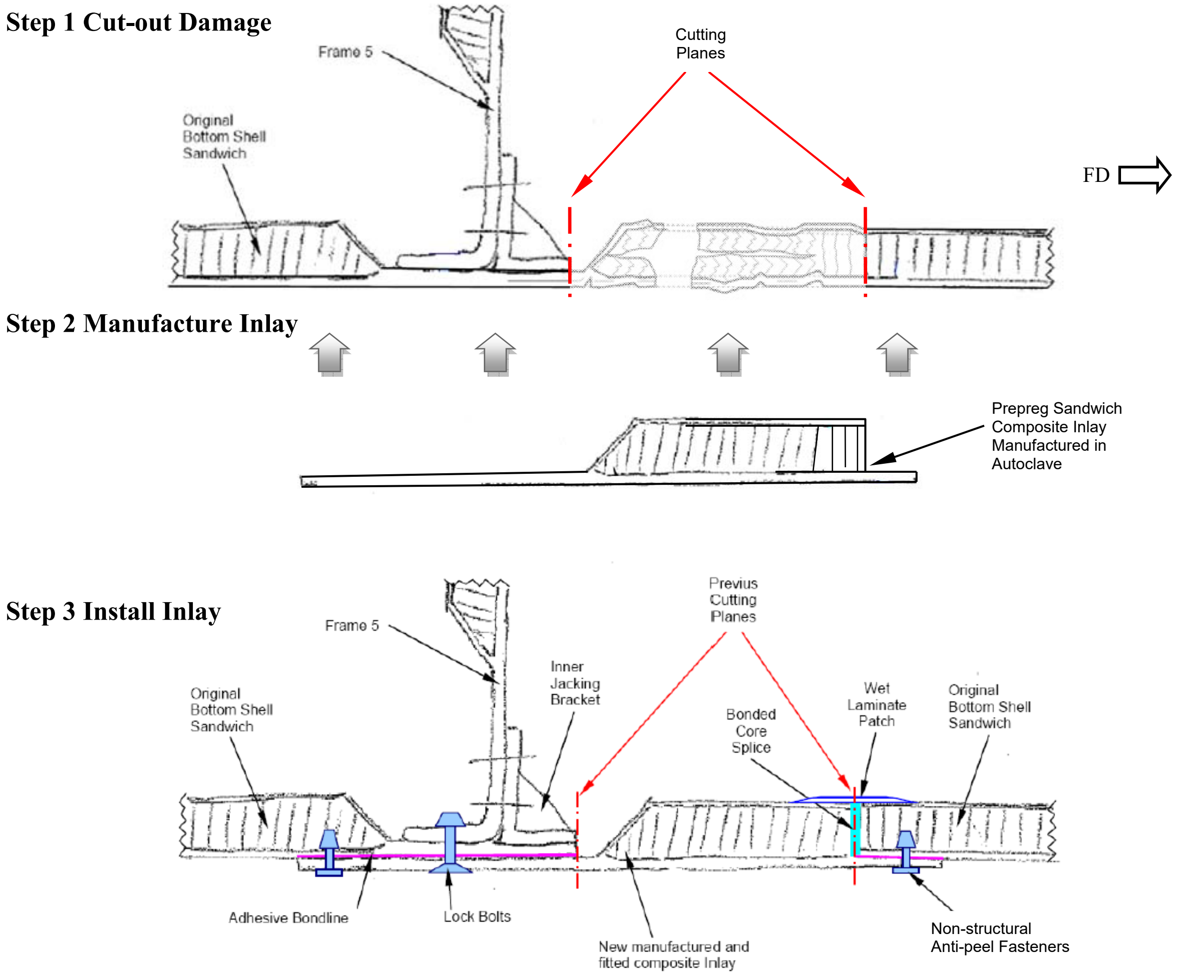


Figure 3-1: Sketch of Repair Approach

The repaired structure will have the following minor impacts.

- The thickness of the overlapping part of the composite inlay will be approximately 3 mm which is protruding downwards.
- Due to the additional patch on the outside, longer bolts have to be used to fasten the outside jacking bracket.
- An additional 3mm shim has to be installed to get an even interface plane for the radar radome.
- The additionally installed weight in total will be less than 4 kg.

4.0 PREPARATIONS

Before starting with the detailed design of the repair, the laminate properties in the affected areas must be known since there are different materials used and different lay-up's present.
For example, the largest area with the same sandwich property has an outer skin with 5 layers, 4 aramid plies and one carbon ply, an inner skin with three carbon layers and a honeycomb core of 12 mm height.

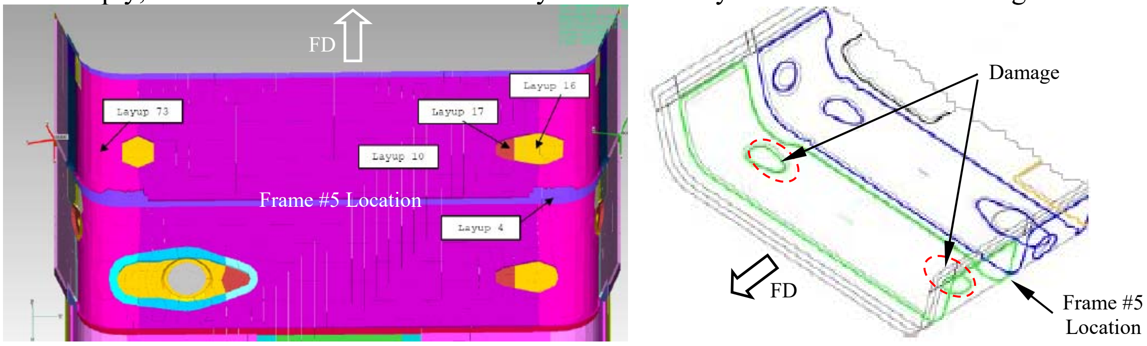


Figure 4-1: Design Environment

Figure 4-1 shows on the left hand side a finite element model (FEM) plot of the front bottom shell where the different properties are shown in different colours. The mainly affected properties are sandwich layup no. 10&73 and laminate layup no. 16&17. The illustration on the right hand side gives the borders of the sandwich areas in the front bottom shell with the damaged areas marked in red.

Also the strength substantiation data needs to be checked to get a view on the criticality of the repair area because the repair materials have based on their processing not exactly the same strength and stiffness properties as the original structure. This must be incorporated in the repair design. Based on this information the detailed design drawings can be established.

Next step is to define approximately the repair work steps in which the complete repair will be accomplished.

- Determine detailed cut-out areas according to damage inspection and geometric constraints and create cut-out drawing
- Determination of dimensions for the composite inlay overlapping, fasteners etc.
- Create manufacturing drawing of new composite inlay
- Create assembly drawing for fitting of new composite inlay
- Create link drawing for installation of composite inlay at the helicopter
- Manufacture the composite inlay
- Cut-out the damaged areas
- Make final fitting of new composite inlay
- Install composite inlay on helicopter by structural bonding with paste adhesive/compound
- Make inside connection of composite inlay and original structure by a wet-laminate patch
- Install structural fasteners
- Install anti-peel fasteners
- Reinstall surface protection

All these work steps were then implemented in a repair design approval sheet (RDAS) which composes together with the repair design drawing set, the detailed process instructions and the strength substantiation report the *repair design dossier*. All parts of the repair design dossier must be approved by the relevant NQO, in case of this NH90 part the LufA-BW / WTD 61.

5.0 REPAIR PROCEDURE

According to instructions and repair drawings the damaged area was cut-out and the autoclave pre-manufactured composite inlay was prepared for installation.

Figure 5-1: Cut-Out, Prepared Inlay, Fitted Inlay

Figure 5-1 from left to right:

- Left – Cut according to drawing data is already done. Black visible are the cutting lines.
- Middle – Prepared but not fitted composite inlay shown next to the cut-out part from bottom shell.
- Right – Fitted composite inlay attached (but not installed) for tolerance check.

After the fitting proved that the inlay is suitably prepared the actual bonding process can start.
Therefore all bonding surfaces must be flattened/streightned/activated and then cleaned. This is done by careful grinding with suitable tools and by hand using sand paper or scotch brite pads. For cleaning usually a cloth wetted with degreasing solvent is used.

Section cut areas with honeycomb core damages and delaminations must be fixed separately before the inlay will be installed. This is performed by filling potting compound (microballoon thickened laminate resin) into the area were the damaged honeycomb core was removed and injecting heated laminate resin into the delaminated areas by using a syringe.

A therefore created “special process” structural bonding process instruction gives all the detailed steps how to prepare, clean, apply the adhesive and bond the mating parts.

As a matter of course, the bonding process

- must be performed under defined climatic conditions which are at room temperature and at a relative humidity below 60%
- needs qualified vacuum bagging materials and facilities such as peel ply, bleeder and vacuum foil
- must follow the defined curing parameters which are either 24 hours at room temperature or two hours at 65°C for both, the secondary bonding paste adhesive and the here used wet-laminate resin.

The first step of closing the cut-out is to bond the composite inlay from outside on the bottom shell structure.
After the bonding is cured, the gap between original structure and new installed inlay must be filled by potting compound to ensure the connection of the sandwich cores between the parts.

Figure 5-2: Outside bonding with Following Closing of the Gap

Figure 5-2 from left to right:

- Left – Paste adhesive application on composite inlay butt joint prior mounting from outside
- Middle – Installed vacuum bagging for application of uniform pressure during curing
- Right – Inlay bonded on H/C structure with compound filled gaps.

The load transfer of the inner skin will be done by the second step of closing the gap on the inner side. This is done with a wet-laminated carbon fiber fabric patch. Also here, drawings give patch position and ply layup with overlapping lengths. A “special process” wet-laminating process instruction gives all the other parameters necessary for achieving a suitable and reproducible laminate quality.

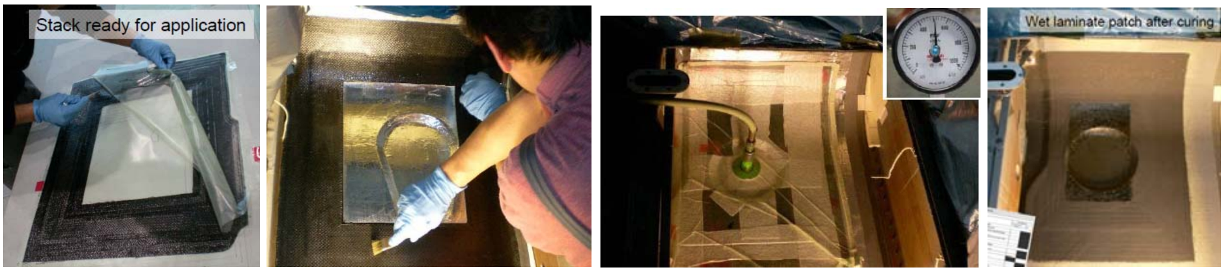


Figure 5-3: Inside Wet-Laminate Patch

Figure 5-3 shows the main steps of the wet-laminate procedure: preparation of hand-impregnated stack, application of stack on inside repair area and wet-laminate under vacuum bagging. On the right, the finished cured wet-laminate.

Further steps after the bonding and wet-laminating, is the reinstallation of electrical bonding paths, installation of structural fasteners to the frame #5, installation of anti-peel rivets at the outer edges of the composite inlay and finally the restoration of paint outside and sealant inside.
This is shown for outside and inside in figure 5-4.

Figure 5-4: Repair Finished except Top Coat

6.0 STRENGTH SUBSTANTIATION

The strength substantiation of this repair was done using approved hand calculation methods whereas loads stresses and strains are derived from FEM's created respectively modified for that purpose.
The concept for strength substantiation goes along the following points.

- The locations of the damaged areas were faced with the critical areas for an evaluation of the general criticality of the damage.
- Finding out the relevant load cases which were responsible for the sizing of the affected areas with respect to the damaged areas.
- For those load cases, investigating in detail the kind of loadings, load levels and strains in the affected areas. This is mainly done by taking the outputs from calculations with FEM of the NH90 helicopter.
- Calculation of the minimum necessary overlapping lengths. Calculation of the margins of safety for shear stress of bonding adhesive and maximum stress and strain level for inner and outer skin in the damaged areas.

The layup of the repair patches consists of more carbon plies for the outer skin than the original bottom shell layup and also more carbon plies for the inner skin as for the original bottom shell layup. The stiffness is at least the same for the repair patch skins as for the original bottom shell skins. Therefore, the stability and strength of the patches themselves was not substantiated. Here the original margins of the bottom shell remain still valid.

It was investigated whether the loads occurring in the affected areas of the bottom shell can be transmitted by the adhesive bonding area into the repair patches and vice versa. As usual for the purpose of stress calculations, the FEM output (element forces and element bending moments) of all selected elements and all calculated load cases were transformed into the material coordinate system.
In case of the bottom shell sandwich areas, these transformed element loads were then recalculated into stresses which are acting in the outer and the inner skin of the sandwich composite. These skin stresses in the outer- and inner skins were then recalculated into principle stresses. The principal stresses acting in the bottom shell skins have to be transferred via the adhesive bonding into the skins of the repair patches.

For the outer skin the allowable lap shear strength value of the used adhesive and the defined overlapping length are used. The highest stress level of these principle stresses has been taken for the shear stress calculation in the bonding adhesive.

The wet-laminate joint of inner skin was substantiated following a similar conservative approach.
Taking into account the fact that a wet-laminate joint will be installed on top of a present prepreg-laminate, this has actually no behaviour which is comparable to a standard lap shear sample with a paste adhesive and a defined bonding gap. The actual limiting value in case of a wet-laminate installed on a prepreg laminate is not the lap shear allowable. Instead, the inter-laminar shear allowable has to be used to determine the necessary overlapping lengths for a load transferring layer. Repeating the above calculation with this limiting allowable, the necessary shear stress can be calculated.

7.0 CONCLUSIONS

Strength substantiation:
The resulting margins from the strength calculations were all positive. This means that the repair does not lead to any impact on the load carrying capability of the Bottom Shell structure.

Long term performance of repair and its used materials:
All structural materials (original prepregs, dry fabrics, laminating resin and paste adhesives) were qualified according to CMH-17 guidelines (namely the building block approach testing pyramid) and approved according to FAA FAR-29 regulations. This means that all relevant long term performance influencing factors such as humidity, service temperature and contamination fluids on the materials, design elements and components were tested and approved. As well damage tolerance testing over several levels of the testing pyramid was a pillar of the qualification.
Talking about fiber reinforced composites; the material itself cannot be separately regarded from the manufacturing process. Material and process are an inseparably unit. All desired and defined material properties are established only when the correct process will be applied. A deviation either in the material (resin mixture, fiber orientation...) or in the process (handling, curing temperature, vacuum pressure…) may show undesired effects in the composite properties.
That’s why for all qualification activities as well as for the repair activities approved process documents were the basis. Not to forget that without qualified staff trained according to the defined processes such a repair would be hardly successful.

Repair approach:
Since the NH90 features a CFRP airframe structure, the repair of such a structure has to be in line with the therefore qualified materials and processes to be reasonable in effort and cost and certifiable. A repair with metallic sheet metals / stringers riveted on the composite structure would be thinkable but was considered early in the process as less effective in terms of preparation effort, design freedom, installation effort, cost, weight and long term performance (here especially galvanic corrosion might become an issue). Only for smaller temporary (battle) damages riveted metallic patch repairs are considered as an option.
Nevertheless, the here used secondary bonding combined with wet-laminating might not be the most effective way to fix such damages. Other possibilities such as use of out-of-autoclave prepregs or tailored dry preforms attached via resin infusion might be a more comfortable way but for these cases, at least at AHD, some R&D investments are still required to achieve the required level of maturity.