Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

NLR-TP-99033

Development and evaluation of a hard patch repair method for composite stiffened wing panels

A.L.P.J. Michielsen, L.C. Ubels and F. Baas

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-99033

Development and evaluation of a hard patch repair method for composite stiffened wing panels

A.L.P.J. Michielsen, L.C. Ubels and F. Baas*

.* Hogeschool Haarlem/Technare, The Netherlands

This report is based on a contribution to EUCLID-CEPA 3-RTP 3.1 Aeronautical Application Technology, Repair Methodology "On Aircraft", contract number E/L41A/NO266/N5260, and represents a presentation held at the JEC/SAMPE Conference, Paris, France, 1999.

Customer: National Aerospace Laboratory NLR
Owner: National Aerospace Laboratory NLR
Division: Structures and Materials
Distribution: Unlimited
Classification title: Unclassified
February 1999

Contents

(9 pages in total)

DEVELOPMENT AND EVALUATION OF A HARD PATCH REPAIR METHOD FOR COMPOSITE STIFFENED WING PANELS

A.L.P.J. Michielsen and L.C. Ubels
National Aerospace Laboratory (NLR)
Structures and Materials department
Voorsterweg 31, 8316 PR, Marknesse, The Netherlands
Tel: +31 527 248672, fax: +31 527 248210, email: michiels@nlr.nl

F. Baas
Hogeschool Haarlem / Techcare
Veldzigtlaan 1, 2015 CD, Haarlem, The Netherlands
Tel: +31 23 5412 802, fax: 31 23 5412 699, email: f.baas@hshaarlem.nl

SUMMARY

Within the framework of European program Euclid RTP 3.1 ‘Repair methodology on-aircraft’, repair methods were developed for composite structures in fighter aircraft. The National Aerospace Laboratory (NLR), in co-operation with Hogeschool Haarlem, developed a hard patch repair method. In this approach, the damaged zone is completely removed and substituted with a pre-cured patch, flush mounted on a flange that is bolted (and bonded) to the interior skin surface.

Two types of repair were studied, which involve either a skin bay between two stiffeners or a stiffener zone. For each case, the method was *developed* on small specimens. After a feasible solution was established in terms of structural performance, its applicability in structures with one-sided access only was *validated* on a full scale panel structure.
It was concluded that the repair method is suited to be performed “on aircraft”, because it is possible to perform the repair with access from the outside only, by field and maintenance personnel and with relatively simple tools. The method used results in an aerodynamic smooth surface: the patches are flush at the outer skin side apart from a number of rivets. The fatigue and residual strength tests showed that the requirements were fulfilled with respect to repair performance for all configurations studied in the development phase and for the configuration tested in the validation phase.

The method is thought to be promising for the future but is still not developed to the extent, that the application in service is possible without further improvements in repair skills, adaptation of repair materials and further validation tests. Additional research has to be performed if the method is selected to become a standard repair procedure for a specific aircraft.

1 INTRODUCTION

An operational aircraft is always at risk of being damaged. Maintenance activities, impact by foreign objects and for a military aircraft, also battle damage are a threat for the aircraft structure. The full restoration of the static strength by a repair allows the aircraft to operate again, assuming that durability is also guaranteed during an extended period of time. Additionally, the aerodynamic quality of a repair has a direct, but not necessarily dramatic, effect on aircraft performance. For metal structures, repair procedures have been developed in the past and are applied for many years now. The increasing use of composites in primary military aircraft structures calls for the development of a repair method for composite structures too.

This paper presents a repair method for a composite wing structure, which is thought to be suitable as field level repair. Field level repair can be defined as a repair, which is performed at a forward operating base with limited facilities. Moreover, the repair method must be suited to be accomplished on aircraft without back-side access. Large disassemblies are not allowed, as these increase downtime and thus serviceability. In the presented approach, the repair is performed by removing the damaged area and by filling the gap with a patch. The pre-cured patch is mounted with a flange that is bolted (and bonded) to the interior skin surface (fig. 1). The method was developed on small panels and validated on a large panel.

The repair method was developed within a joint European program called EUCLID RTP 3.1. (Ref. 1). The program was funded by the MOD's (Ministry of Defence) of several countries. In the part of the program described here, the repair method was developed in co-operation with Techcare (Netherlands) and OGMA (Portugal). The results of the program are reported in more detail in references 2 and 3.

2 STRUCTURAL CONFIGURATION AND TYPE OF REPAIRS

Basically, the damage situations that must be considered can be categorised as:

- damage requiring a skin repair only
- damage involving a stiffener repair also.

In case of a skin repair, a simple patch with flanges can be used. In case of a skin and stiffener repair, a number of separate parts are needed to restore the strength of the structure. In that case, the components used are strongly dependent on the structural configurations. Therefore, the repair methods were developed for configurations typical for two load levels:

- lightly loaded (500 N/mm) blade- and J-stiffened panels
- intermediately loaded (2000 N/mm) I-stiffened panels

Four combinations of damage situation and structural configuration were selected, resulting in four types of repair as indicated in table 1.

structural configuration	type of repair	
lightly loaded J-stiffened	skin	
lightly loaded blade-stiffened		skin-stiffener
intermediately loaded I-stiffened	skin	skin-stiffener

Table 1: Combination of structural configurations and type of repairs

3 DEVELOPMENT OF REPAIR METHODS

For each configuration and type of repair, a repair method was developed, applied and tested for strength and durability.

3.1 Skin repairs

Figure 2 presents the developed skin repair method which can be applied on J-, blade- and I-stiffened configurations. The 'imaginary' damage was positioned mid-bay between the stiffeners in the centre of the panel. The damage was removed by cutting an elliptical hole around the damage. This shape was chosen to allow easy access for repair. The direction of the major axis of the ellipse is in the direction of the forces on the panel. Two different pre-cured patches were made from the same material as the panel. The first patch was made of two flat parts which were bonded together: an elliptical plate which fills up the hole in the skin and a rectangular plate which forms the flanges of the patch. An alternative patch consisted of a single piece and had the same external dimensions, except that the centre of this part was elevated (dimpled). With the chosen geometries, it was still possible to insert the patch from the outside through the hole of the panel. The patch was bonded with a cold curing adhesive and riveted with blind fasteners. Bolted repairs are the most common for battle damage repairs because of reliability and relatively fast application to a damaged part. They are to be preferred over bonded repairs. Therefore, one configuration was tested with rivets only, the bond layer was omitted (specimen J-skin-4). For each configuration a repair manual was written with detailed information how to perform the repair [Refs. 4,5,6 and 7]

3.2 Skin-stiffener repairs

Figure 3 presents a skin-stiffener repair in a blade-stiffened panel. The imaginary damage was located directly above one of the stiffeners. To restore the required strength, both the skin and the stiffener had to be repaired. The repair of the stiffener was performed with two carbon/epoxy angle-sections. These angle-sections were attached to both sides of the stiffener. A small flat part was used to fill the gap of the removed web between the angles. The repair of the skin was performed with a skin patch. The skin patch consisted of an elliptical plate bonded to a rectangular plate both made from carbon/epoxy. The rectangular part of the skin patch was attached underneath the skin between the stiffeners. Again, small plates were used to fill the gap between the substitute stiffener and the skin. Both rivets and adhesive were used to attach the replacement parts.

A more complicated repair was developed for the skin-stiffener repair of the intermediately loaded I-stiffened configuration, where besides the stringer, also a doubler was repaired. This is not discussed in detail in this paper.

In the repairs presented, the aerodynamic smoothness is maintained: the patches are flush at the outer skin side besides a number of rivets. Students without experience accomplished the repairs, no backside access was allowed and only simple tooling was used. The stiffener repair was found to be difficult to perform due to the limited access when riveting the stiffener angles. The quality of the repairs was controlled by C-scan and no major anomalies were found.

3.3 Strength and durability test

The requirements with respect to testing were:

- A full restoration of the static strength (100% Design Ultimate Load, DUL) at temperatures of –85°C, –50°C and room temperature (RT).
- A residual strength of 70% DUL after 5.10^5 compressive load cycles with an amplitude of 50% of DUL at RT.

Of each type of repair, several panels were tested. An overview of the tests and the results is shown in table 2. Most tests were performed in compression, a single test on a skin-stiffener repair (specimen blade-stiff-5) was performed in tension. The panels were not instrumented, only the end-shortening was measured in combination with the applied force.

- Static compression tests were performed at room temperature and at a temperature of –85°C or –50°C. The required strength of 100% DUL was obtained for all configurations. Figure 4 presents the deformation of an intermediately loaded I-stiffened panel with a skin repair subjected to 120% DUL (specimen I-skin-2). Figure 5 presents failure of an intermediately loaded panel with a skin-stiffener repair (specimen I-stiff-1). In this case, panel failure originated from the parent structure and was not initiated by the repair.
- Several panels were fatigue loaded at 50% DUL following a residual strength test up to 70% DUL. Figure 6 presents a panel (specimen I-stiff-4) in which several rivets failed during fatigue loading. Even with these failed rivets, sufficient residual strength was obtained.

For the lightly loaded blade- and J-stiffened configurations, significantly higher load levels were obtained than required, as both types of repairs resulted in thickening of the skin, preventing the skin from buckling. In case of the intermediately loaded I-stiffened panels, failure of the panels was obtained at a load level only slightly above the required load level. The tests showed that the repair methods developed, fulfilled the requirements with respect to the structural strength.

Due to the eccentricity of the added patch, out-of-plane displacements were observed during loading, which could cause some additional turbulence in the airflow. The influence of the eccentricity in a large panel was subject of investigation in the validation phase.

4 VALIDATION OF REPAIR METHODS

In the validation phase, the influence of the repairs was studied on the global behaviour of a structure. A skin and a skin-stiffener repair were applied on a large panel with five I-stiffeners. Subsequently, the panel was aged and fatigue loaded. Finally, the panel was tested up to its design load.

4.1 Repair

The positions of the repairs in the 5-stiffener panel are indicated in figure 7. The repairs were performed by OGMA, based on the repair manuals [Refs. 5,6] written by Techcare. Some of the prescribed tools of the repair manual were not available at OGMA so the repairs were accomplished with tools that were available. It was found that the geometry described in the repair manuals did not correspond with the actual geometry of the structure to be repaired. At ‘field level’ several modifications to the geometry were applied and the repair was accomplished. The repairs were inspected by C-scans, and indicated a good quality.

4.2 Ageing

The panel was aged for a period of 1000 hours at a temperature of 60°C where the area to be aged was completely submerged in a bath with demineralised water. Severe corrosion of the steel rivets was observed. It is therefore recommended to use corrosion resistant Monel rivets in future repairs. Additionally, the type of adhesive used - ARALDIT AW106 - degraded during ageing. Therefore an alternative adhesive is proposed - ARALDIT 2014 - which maintains its strength up to 100°C and has a good chemical resistance.

4.3 Fatigue loading

Subsequently, the panel was tested in fatigue cycling in tension up to 50% DUL corresponding to 611 kN and with R=10. During fatigue cycling it was observed that the patches moved with respect to the parent material. This indicated failure of the adhesive between the patch and the parent material. Only the rivets transferred the loads and no rivet failure was observed. Fatigue cycling was stopped prematurely after 200000 cycles, because fatigue damage was found in the clamping of the panel. No fatigue damage was found in the composite panels itself.

4.4 Residual strength test

A residual strength test was performed after fatigue loading. The panel was instrumented with strain gauges near the clamping to determine the load distribution resulting from the load introduction at the panel ends. Gauges around the repair zone and on the repair patches were used to determine the load distribution in the repaired area. LVDT’s were used to record the end-shortening between the clamped edges of the panel and to record out-of-plane displacements of the repaired zones. The panel was loaded in tension up to DUL (1221 kN).

The residual strength test showed that the repairs hardly influenced the global behaviour of the panel. In case of the skin repair, strain gauge readings indicated that the load was not distributed to the surrounding structure or transferred to the skin patch itself. The load was mainly carried around the hole by the flanges of the skin patch. In case of the stiffener repair, some additional bending was introduced due to the eccentricity of the repair. The additional bending did not result in exceeding the strain limits of the repair patch or the parent material. DUL was obtained without failure of the panel or the patches.

5 CONCLUSIONS AND RECOMMENDATIONS

The hard patch repair method is suited to be performed at ‘field level’ conditions. The patches can be maintained in storage and relatively simple tools can be used to accomplish the repair. ‘Field level’ modifications to the geometry were incorporated indicating the flexibility of the method. The repair could be performed without backside access, reducing the time needed. To increase the durability of the repair, alternative rivets and a different type of adhesive were proposed.
The aerodynamic smoothness was maintained. Some out-of-plane displacement occurred during loading of the panels, as the repairs introduced some eccentricity. However, the displacements were small and were thought to be negligible for the aerodynamic performance of the aircraft. The tests showed that the repair method fulfilled the requirements: full restoration of the static strength and proven durability.

The method is promising for the future but is still not developed to the extent, that application in service is possible without further improvements in repair skills, adaptation of repair materials and further qualification tests. Additional research has to be performed when the method is selected to become a standard repair procedure for a specific aircraft.

6 ACKNOWLEDGEMENT

The presented work was funded by the Dutch Ministry of Defence and was monitored by Major J.H.J. Verhulst. The work was conducted in part under guidance of Dr. ir. G. Bartelds, former head of the Structures and Materials Division at NLR, and project supervisor from 1993 to 1996.

7 REFERENCES

[1] EUCLID - CEPA 3 - RTP 3.1, Repair Methodology On aircraft, Volume 1, Technical part, Deutsche Aerospace AG, Military Aircraft, 1993.

[2] MICHIELSEN A.L.P.J., Development and validation of the hard patch repair method for skin, skin-doubler and skin-stiffener repairs in composite panels, NLR TR 98619, 1998.

[3] EUC-DOC-3000-01, Final report, Repair methodology On aircraft, 1997.

[4] EUC-DOC-3340-03-NLR, Manual for repairing a skin damage in a blade- or J-stiffened carbon fibre reinforced epoxy resin panel, July 1996.

[5] EUC-DOC-3340-04-NLR, Manual for repairing stiffener damage in a blade- or J-stiffened carbon fibre reinforced epoxy resin panel, July 1996.

[6] EUC-DOC-3340-05-NLR, Manual for repairing a skin damage in an I-stiffened carbon fibre reinforced epoxy resin panel., July 1996.

[7] EUC-DOC-3340-06-NLR, Manual for repairing damage above the stiffener in an I-stiffened carbon fibre reinforced epoxy resin panel, July 1996.

specimen number	type of test	strength required	strength obtained		condition after test	strain obtained P/EA [µ]
		[% DUL]	[% DUL]	[kN]		
Lightly loaded J-stiffened panels with a skin repair, DUL = 74 kN						
J-skin-1	compression	100%	156%	115	failure	4390
J-skin-2	compression at T = -50°C	100%	242%	178	failure	6795
J-skin-3	compression after fatigue at T = -85°C	70%	217%	160	failure	6107
J-skin-4, no bonding	compression after fatigue	70%	>136%	>100	no failure	3817
J-skin-5	compression after fatigue	70%	>136%	>100	no failure	3817
Lightly loaded blade stiffened panels with skin-stiffener repair, DUL = 89 kN						
Blade-stiff-1	compression	100%	124%	110	failure	5523
Blade-stiff-2	compression after fatigue	70%	>147%	>130	no failure	6527
Blade-stiff-3	compression after fatigue at T = -50°C	70%	205%	182	failure	9138
Blade-stiff-4	compression after fatigue at T = -85°C	70%	174%	154	failure	7732
Blade-stiff-5	tension	100%	>124%	>110	no failure	5523
Intermediately loaded I-stiffened panel with skin repair, DUL 577 kN						
I-skin-1	compression	100%	>120%	>692	no failure	6161
I-skin-2, dimpled patch	compression	100%	>120%	>692	no failure	6161
I-skin-3	compression after fatigue	70%	>84%	>484	no failure	4309
Intermediately loaded I-stiffened panel with skin-stiffener repair, DUL $_{\text{I-stiff-2}}$ = 553 kN for all others DUL = 577 kN						
I-stiff-1	compression	100%	114%	655	failure	5832
I-stiff-2, reduced width	compression	100%	109%	600	failure	5591
I-stiff-3, lengthened patch	compression	100%	108%	624	failure	5555
I-stiff-4	compression after fatigue	70%	>84%	>484	no failure	4309
I-stiff-5	compression after ageing	70%	83%	478	failure	4256

Table 2: Test results of panels with repairs

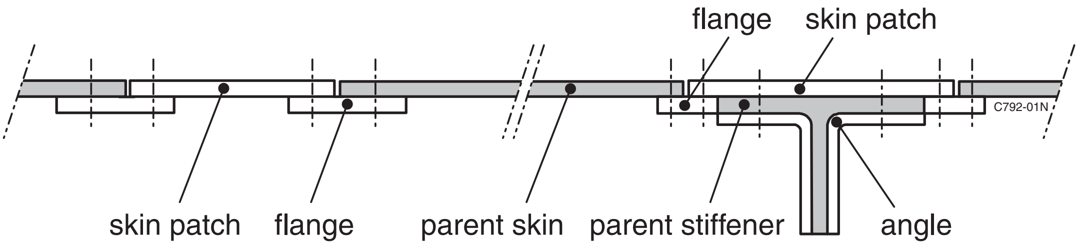

Figure 1: Principle of the hard patch repair method

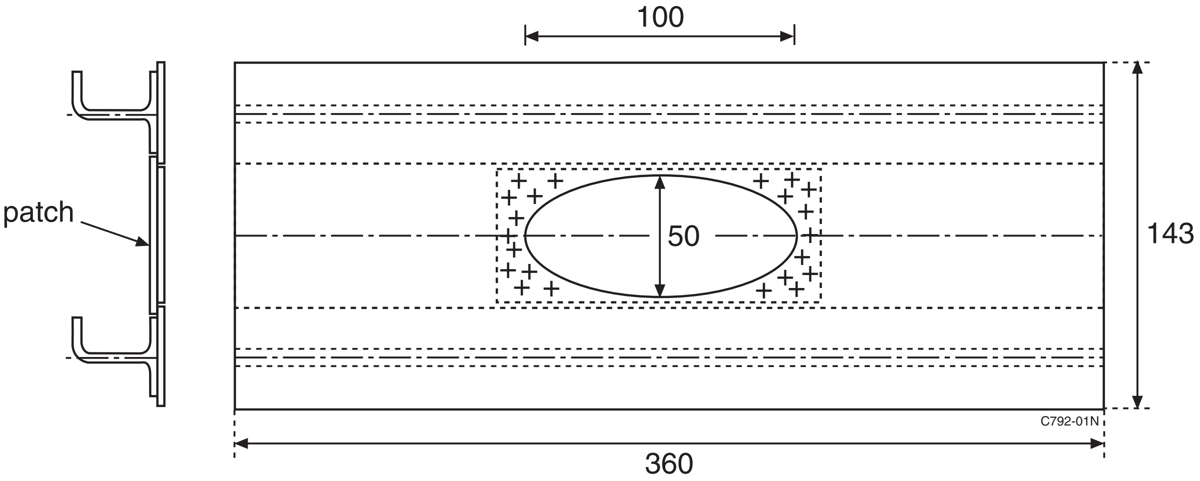

Figure 2: Skin repair patch in a lightly loaded J-stiffened panel

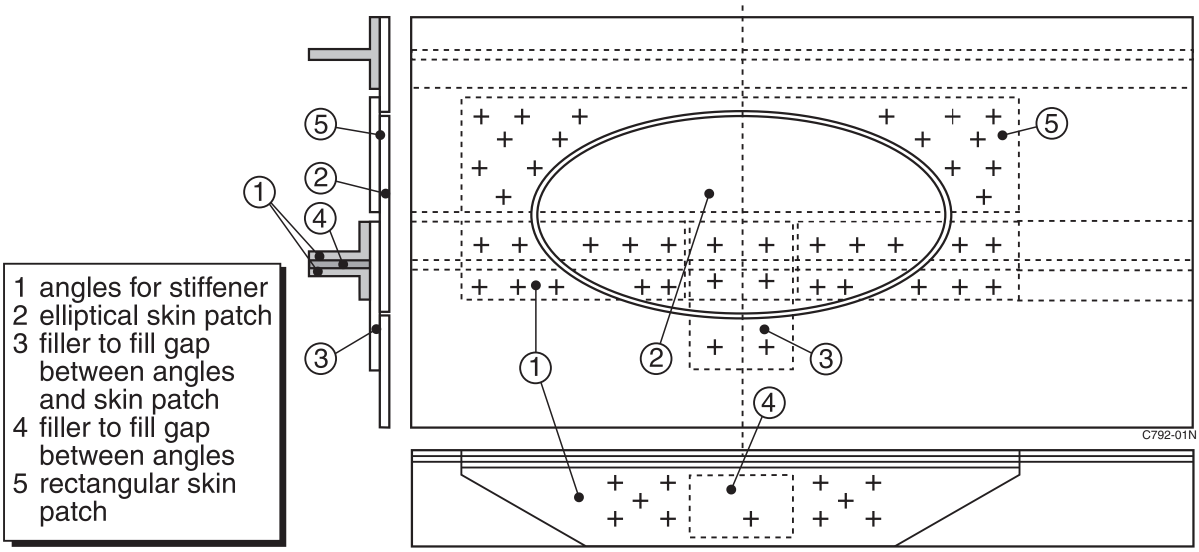

Figure 3: Skin-stiffener repair in a lightly loaded blade-stiffened panel

Figure 4: I-stiffened panel with a skin repair subject to 120% DUL (692 kN) in compression (specimen I-skin-2)

Figure 5: Failed intermediately loaded panel repair (specimen I-stiff-1)

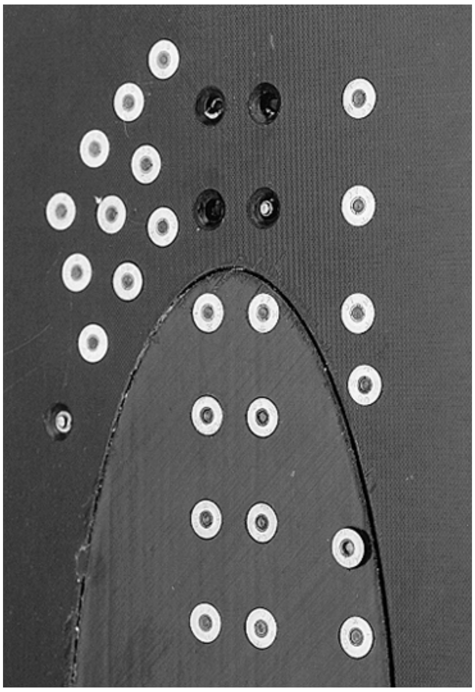

Figure 6: Failed rivets of a skin-stiffener repair in an intermediate loaded panel (specimen I-stiff-4)

Figure 7: Skin repair and skin-doubler repair in I-stiffened panel