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**F-111 Bonded Panel Repair
Status**

Andrew N. Rider

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F-111 Bonded Panel Repair Status

Andrew N. Rider

**Maritime Platforms Division
Aeronautical and Maritime Research Laboratory**

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ABSTRACT

A visit was made to Amberley Airbase between the 6th and 9th of September 1998 to consult with RAAF staff on current procedures and problems involved in the maintenance and repair of F-111 honeycomb panels. In conjunction with these discussions, a review of the current methods being used for honeycomb repair procedures was undertaken. The following report summarises the methods being used for repairs and the relevant reference documents. Also detailed are the major problems being encountered in these repairs and future problems which may arise as a result of the current status being maintained during the service life of the F-111.

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F-111 Bonded Panel Repair Status

Executive Summary

A visit was made to RAAF Base Amberley between the 6th and 9th of September 1998 to consult with Royal Australian Airforce (RAAF) staff on procedure and problems involved in the maintenance and repair of F-111 honeycomb bonded panels.

The objectives of the visit were to establish which procedures were currently being employed for bonded repairs to honeycomb panels and compare these methods with those stipulated in two documents; AAP 7214.003-3 and draft document AAP 7021.016-2. The methods specified in these two documents were reviewed as a preliminary exercise in preparation for the visit, and are described in sections 2.0 to 5.0 of the report.

A survey of the current repair methods also indicated a number of issues causing problems in the maintenance of bonded panels. Section 6.1 of the report details examples of repairs which have experienced difficulties due to the inability of current procedures to remove moisture from the honeycomb panels. During cure of high temperature adhesives the water vapourises and volume expansion causes large areas of the panel to disbond.

Another issue identified with panel repair in section 6.2 is the problem of dealing with injection repairs. Injection repair sites are often sources for moisture ingress and consequent degradation of bonded panel structural integrity through adhesive disbond or corrosion.

Section 6.3 also examines difficulties associated with in-situ repairs of bonded panels over areas larger than those currently stipulated by AAP 7214.003-3 and in areas which have limited accessibility.

The current RAAF strategy aimed at reducing the maintenance problems associated with F-111 bonded panels is examined in section 7.0 of the report. Sources of replacement panels are identified.

A critical review of the replacement panel and repair strategies is undertaken in section 8.0 of the report and problems associated with maintaining this strategy through the service life of the F-111 considered.

Conclusions and recommendations for RAAF consideration are provided in section 11.0 and 12.0 of this report.

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1. Introduction

A visit was made to Amberley Airbase between the 6th and 9th of September 1998 to consult with Royal Australian Airforce (RAAF) staff on procedure and problems involved in the maintenance and repair of F-111 honeycomb bonded panels.

The first F-111 aircraft delivered to Australia were manufactured over 30 years ago. The aircraft is manufactured extensively from sandwich panels of adhesively bonded aluminium skin and phenolic nomex or aluminium honeycomb. The honeycomb panels are both integrated into the structure and used as access panels. The degradation of the bonded sandwich panels in the F-111 is one of the critical issues with the potential to bring forward the current programmed service withdrawal date of 2020. The science underpinning the bonded panels technology is far from mature. In particular, knowledge of the processes and rates of degradation of bonded panels in service is insufficiently developed to make informed accurate predictions of the present state of bonded structure or the likely rates of future decay.

The visit was designed to gain some indication of the present state of bonded panel repairs and maintenance. One objective was to identify issues which need research support to assist RAAF to achieve the 2020 program withdrawal on the F-111 aircraft.

Key issues included:

1. The consequences of inappropriate prior repairs to bonded panels.
2. Progressive damage to honeycomb panels during elevated temperature repair procedures, resulting from water ingress during service.
3. Reliance on repaired or reworked panels from McClellan Airforce Base Sacramento or retired US Aircraft. The McClellan facility closes in March 1999.
4. Deficiencies in the quality control used during the repair or rework of panels in the USA

Areas of essential supporting research were identified.

2. Differences Between AAP 7214.003-3 and AAP 7021.016-2

The current honeycomb panel repair procedures used by the Amberley bonding shop are based on the draft document AAP 7021.016-2. This draft also draws on specifications and procedures detailed in the RAAF *Engineering Standard C5033*. Whilst the procedures detailed in AAP 7214.003-3 are not relevant to most current repairs some procedures still utilise the techniques specified in this manual. Similarly, current repairs will have to deal with panels previously repaired using the older methods

detailed in AAP 7214.003-3. Table 1.0 provides a generalised summary of the repair methods detailed in the two documents for the purpose of comparison. This Table is not meant to provide a detailed or specific account of the procedures. If this information is sought the reader is referred to the original documents.

Table 1.0 Common repair procedures used for F-111 honeycomb panels. In most cases AAP 7021.016-2 is used. However, repairs will also have to be performed on panels previously repaired in accordance with AAP 7214.003-3.

Repair Type	AAP 7021.016-2 Method	AAP 7214.003-3 Method
A. Injection Repair	Only allowed for short-term repairs when defect between skin and core exists. Patch must be placed over injection repair as part of temporary repair. Must be replaced at next scheduled maintenance.	0.06" holes were drilled through skin in damaged area using template. Potting compound injected, cured, sanded back. Metallic patch may have been applied over repair area depending on location. Several regions do not specify a metallic patch
B. Core Damage $\leq \frac{1}{2}$ " diam.	Refer AAP 7214.003-3 Method	Damaged core is routed out. Potting compound injected, cured, sanded back. Metallic patch applied over repair area according to ENG. STD.C5033
C. Partial Honeycomb core replacement. Damage: $> \frac{1}{2}$ " diam $\leq \frac{1}{2}$ " depth	Route out core to depth of damage. Place film adhesive in cavity followed by metal spacer, film adhesive and foam adhesive. Place foam adhesive around honeycomb plug and insert and cure. Metallic patch applied over repair area according to ENG. STD.C5033	Route out core to depth of damage. Place film adhesive and foam adhesive in cavity. Place foam adhesive around honeycomb plug and insert and cure. Metallic patch applied over repair area according to ENG. STD.C5033
D. Full Honeycomb core replacement. Damage: $> \frac{1}{2}$ " diam $> \frac{1}{2}$ " depth	Route out core leaving adhesive on interior skin intact. Or if adhesive has de-bonded remove. Place film adhesive in cavity floor and foam adhesive around routed edge. Place foam adhesive around honeycomb plug edges and base and insert and cure. Metallic patch applied over repair area according to ENG. STD.C5033	Route out core leaving adhesive on interior skin intact. Or if adhesive has de-bonded remove. Place adhesive in cavity in the order foam adhesive, then film adhesive. Place honeycomb plug in cavity with foam adhesive applied around edges and base then cure. Metallic patch applied over repair area according to ENG. STD.C5033

3. Surface Preparation Procedures for Honeycomb Repairs

The repairs listed in Table 1.0 all have surface pre-treatments specified in the C5033 Engineering Standard or the AAP 7021.016-2. These surface pre-treatments are detailed in Table 2.0. The Table is presented as a general summary of methods used for comparative purposes. For specific details the reader is referred to the original documents.

Table 2.0 *Honeycomb repair surface pre-treatment procedures, detailing chemicals used and drying conditions employed.*

Component	Applicable Repairs (Refer Table 1.0)	Surface Pre-Treatment
Partially Routed Core-potted repair	A, B.	MEK flush followed by 2 hour dry at 110°C
Partially Routed Core-Honeycomb replacement	C.	MEK flush followed by 2 hours dry at 110°C
Fully Routed Core-Honeycomb replacement	D.	<i>If skin adhesive intact:</i> MEK flush. Water-break test Dry at 110°C for 2 hours. Grit-blast. <i>If skin adhesive de-bonded:</i> Remove adhesive by sanding. Grit-blast, silane, dry 2 hours
Core Plug Insert	C, D.	MEK flush followed by 2 hour dry at 110°C
Metal Patch/Metal Spacer	A-D	Grit-blast, Silane, dry 1 hour at 110°C
Honeycomb skin-exterior surface for metal patch	A-D	Grit-blast, Silane, dry 2 hours at 110°C

The adhesives typically used depend on the nature and location of the repair, as indicated in Table 3.0.

Table 3.0 The range of adhesives used in honeycomb panel repairs.

Adhesive	Description	Repair Type
PR1750-B (FMS-1044)	Room temperature curing sealant	Application of metal patches for temporary maintenance. (OM)*
EA934	Room temperature potting adhesive	Injection potting. Bonding patches for ferry flights
FM-300	300°F curing film adhesive	Metal to metal and metal to core bonds
Plastilock 654HE	250-350°F curing foam adhesive	Core splice adhesive.

4. Moisture Removal from Damaged Area

One of the critical steps used in the bonded repair procedure is to remove any moisture from the honeycomb panel by vacuum bag drying around the damaged area. This technique is used for all repairs listed in Table 1 and typically involves heating the panel at 85°C for 4 to 6 hours depending on the honeycomb material used.

5. Adhesive Curing

Curing of the film adhesive occurs under the reduced atmosphere of the vacuum bag at temperatures around 150°C when FM-300 is used, refer Table 3.0

6. Problems Associated with Current Repair Methods

6.1 Inadequate moisture removal

Many of the problems associated with bonded repairs arise from the inability to remove water from the repair area of the honeycomb panel during the drying step. Hence, for any subsequent repair procedures in which the panel has to be raised above 100°C at 1 atmosphere of pressure, refer to Table 2.0 and 3.0, the residual water changes from the liquid to vapour phase. The increased internal pressure causes disbonding of large sections of the panel around the damaged area being repaired. This increases the initial repair area significantly.

* Operational Level Maintenance

The first case in which this problem arises is when honeycomb panels with pre-existing injection repairs have a metal patch applied. The Engineering Standard C5033 indicates that a metal patch should be placed over existing injection repairs after NDI inspection and moisture removal. This procedure is conducted to provide environmental protection and structural strength to the honeycomb panel. Typically a tap test identifies the damaged region and skin is removed from this area. If the core is intact then moisture removal is undertaken and a patch is applied. In some instances further damage to the panel occurs during drying of the panel at 110°C. This damage is caused by steam pressurisation. Figures 1 and 2, however, provide a good example of the extent of the damage that occurs during the vacuum bag curing of the FM-300 adhesive when the structural metal patch is bonded.

In the second example a potted repair was performed on an F-111 fuel tank. The initial repair involved riveting and potting a partially debonded patch as shown in figure 3. The damaged area was initially only 2cm in diameter. Subsequently, a series of holes were drilled for injection repairs to rebond the partially debonded patch, as shown in figure 4. A second patch to repair the rivet and potted repair in figure 3 was cut around the defective patch, thus reducing the required overlap length of the repair patch. The moisture removal procedure, refer section 4, extended the damage, leading to a full skin and core removal of approximately 25cm x 25cm. The repair shown is in figure 5. The repair requires a request for disposition/request for waiver(RFD/RFW).

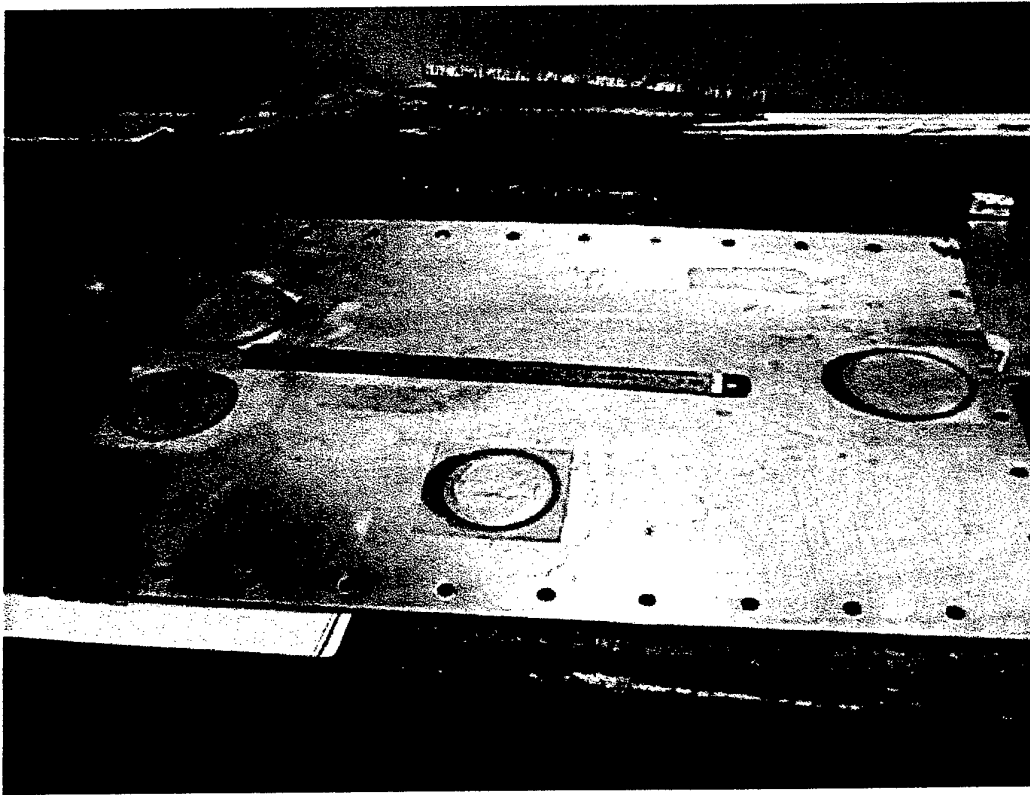


Figure 1.0 Structural metal patches bonded over injection repair areas of a honeycomb panel. Patches bonded at 160°C using FM-300. The ruler is 350mm long.

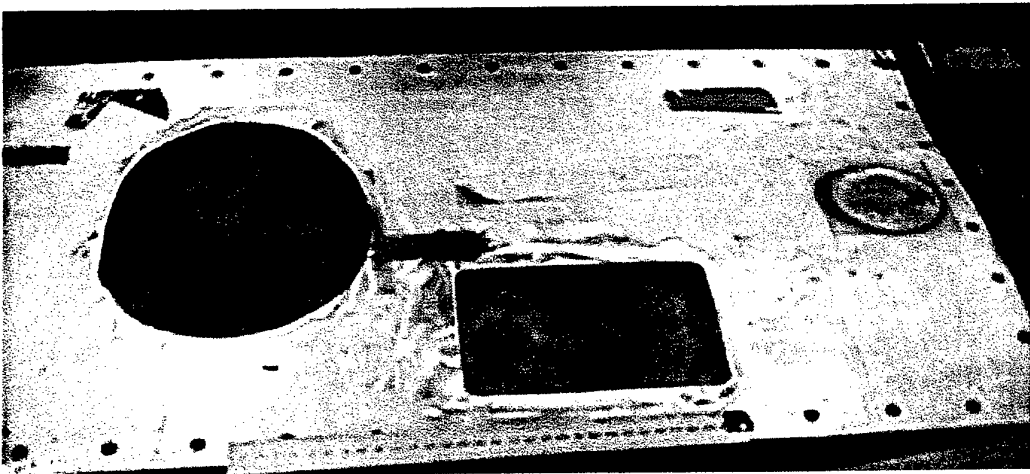


Figure 2.0. The areas that had to be routed from the panel in Figure 1.0 as a result of disbond failure occurring during the cure cycle of the adhesive required for the patch application to the pre-existing injection repairs. The ruler is 350mm long.

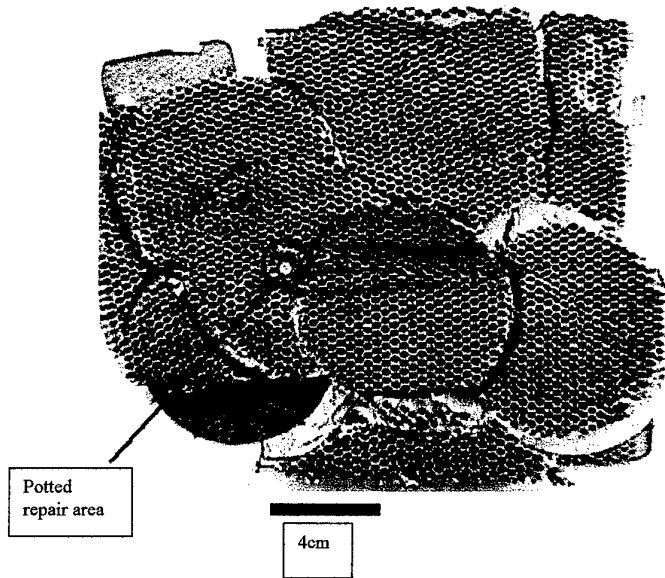


Figure 3.0 The initial repair of an F-111 fuel tank. This involved riveting and potting a partially debonded patch. This area was initially only 2cm in diameter.

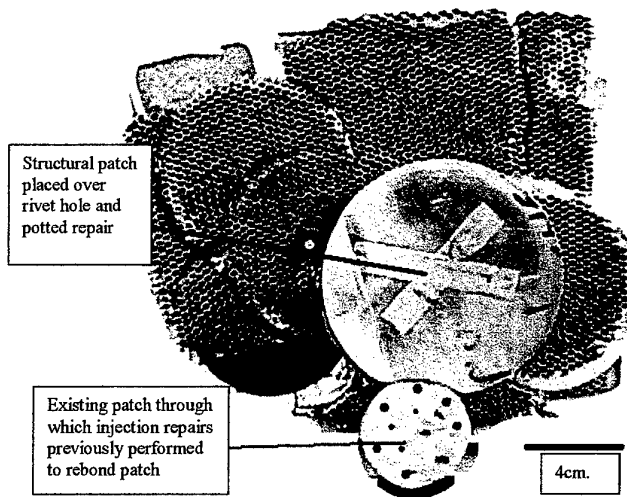


Figure 4.0 The second stage of the F-111 fuel tank repair. Injection repairs attempted to rebond the partially debonded patch. A second patch to repair the rivet and potted repair in Figure 3 was cut to fit around the defective patch, reducing the required overlap specified by the repair document.



Figure 5.0. The area of honeycomb that was eventually removed from the F-111 fuel tank panel in-situ. This resulted from applying the structural patch in Figure 4.0. Complete skin and core removal was necessary. The hole is approximately 25cm x 25cm. The repair now requires an RFD/RFW. Pictures taken from the interior and exterior view. Interior view indicates the relative inaccessibility for repair.

The previous examples of honeycomb repair dealt with honeycomb core material constructed from aluminium and core splice adhesive. However, some panels present on the F-111 were constructed from a phenolic core material. This honeycomb material is very susceptible to moisture absorption. Figure 6.0 displays a large honeycomb panel constructed from phenolic core material that was repaired by core removal followed by application of a metallic patch. The picture clearly indicates the size of the repair patch and the area of disbond as a result of applying the patch using FM-300 adhesive at a cure temperature of 160°C.

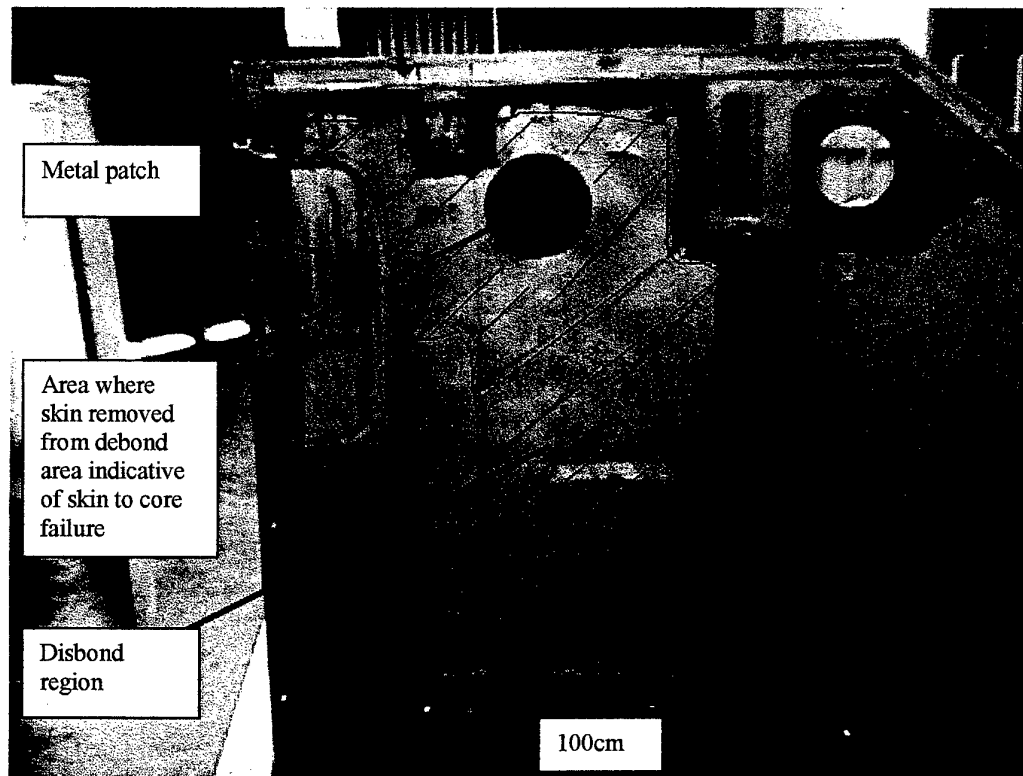


Figure 6.0 *Damage to a phenolic honeycomb core panel resulting from the application of a structural metallic patch. Nearly half the panel is disbonded as a result of the internal pressure generated as moisture trapped in the panel vaporises during the adhesive cure cycle.*

6.2 Repairing Pre-Existing Injection Repairs.

The problem associated with moisture removal is particularly acute in the case of repairs being performed on pre-existing injection repairs, as demonstrated in Figures 1.0 to 4.0. However, many of the panels that are repaired have an extensive number of injection repairs, as shown in Figure 7.0. Rectifying the damage induced in these multiple injection repair sites is exacerbated by the difficulty of moisture removal from the whole panel. The manpower overhead is a major consideration.



Figure 7.0 An example of the potential number of injection repairs, which may be associated with one F-111 honeycomb bonded component. Injection repair hole numbers are indicated. None of these repairs had been protected with a structural patch.

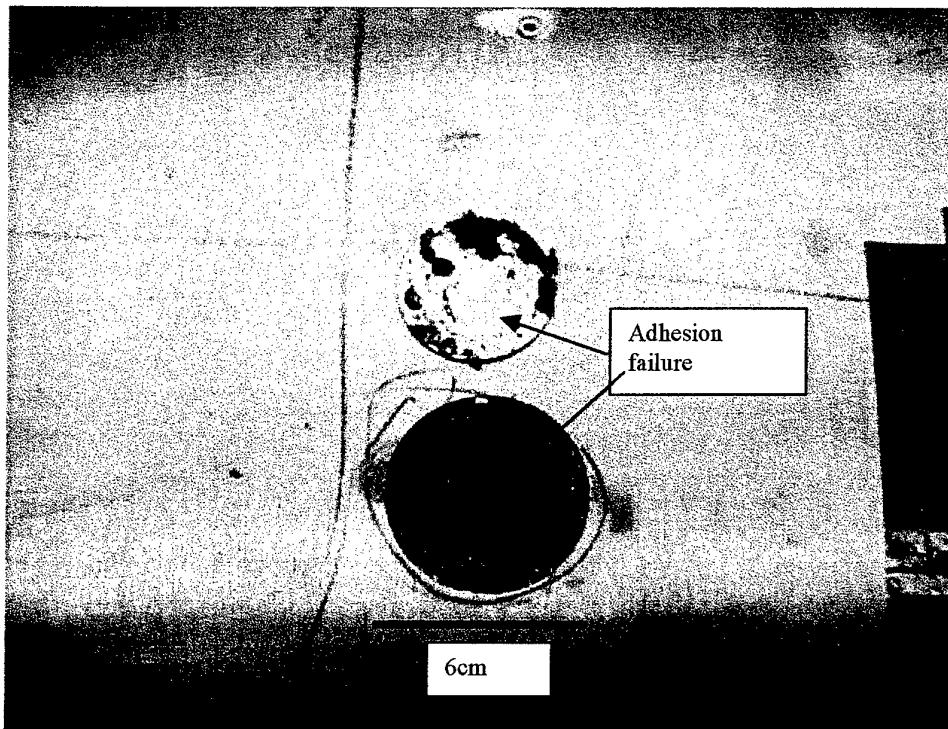


Figure 8.0 Adhesion failure surrounding an injection repair

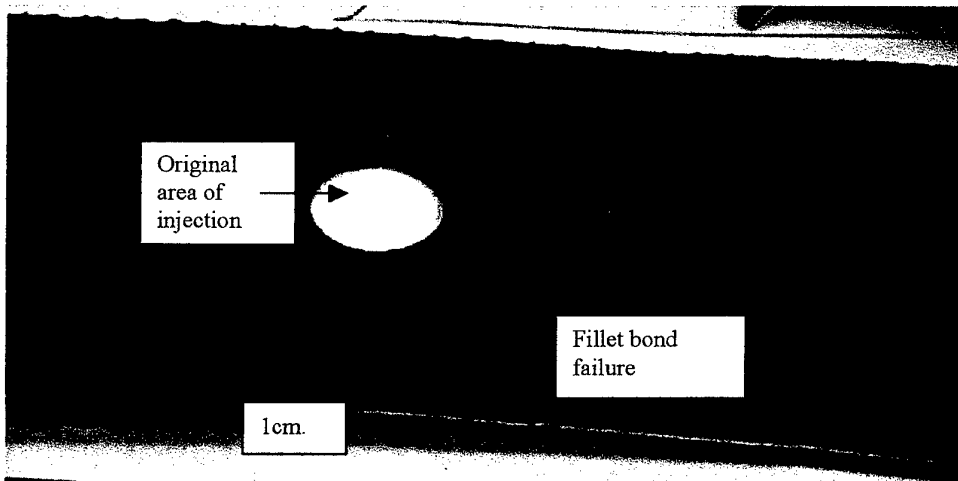


Figure 9.0 Fillet bond failure surrounding the site of an initial injection repair

The current NDI used to evaluate the injection repair areas is also inadequate. The tap test may indicate if contact is made between the skin and injected adhesive. However, the test does not provide any indication of how well the region was rebonded. Contact between the adhesive and skin does not necessarily indicate the presence of a viable adhesive bond. Figures 8.0 and 9.0 provide clear examples where skin removed from

regions around an injection repair have experienced obvious environmental degradation. In Figure 8 adhesion failure between the core and skin has occurred around an injection repair. In Figure 9.0 the adhesive-core fillet bonds have failed over an extensive area around the injection repair site as a result of penetration of water through the injection repair between the adhesive and core bond.

6.3 Performing Repairs on Large Areas In-Situ

Figure 5.0 provides a good example of difficulties associated with performing repairs on large areas of honeycomb panels in-situ. Some of the problems that arise are due to the inaccessibility of the areas for both personal and their equipment and constraints being placed on the procedures due to the location of the repair. For example repairs in fuel tanks or near avionics equipment require containment systems to prevent escape of grit used during the grit-blast stage of surface preparation, refer Table 2.0. The difficulties associated with an area of poor accessibility may result in repair workers avoiding the use of grit-blasting.

Figure 10 shows a region of the F-111 where honeycomb panel damage has a high probability of occurring. The large panels in the vicinity of the mid-air re-fuelling pod often will experience damage as the re-fuelling arm approaches the aircraft. These panels are riveted in place and require in-situ repair. Attempting to repair large panel areas has the problem of designing repairs outside repair manual specification together with the problem of moisture removal. Large repairs in-situ will also encounter difficulties in distributing a uniform heat over the entire repair region due to heat-sinks in the structure. Figure 11 also shows a difficult to access region of the F-111 weapons bay where a repair has to be undertaken. This is also a region where panel replacement would not be a viable option.

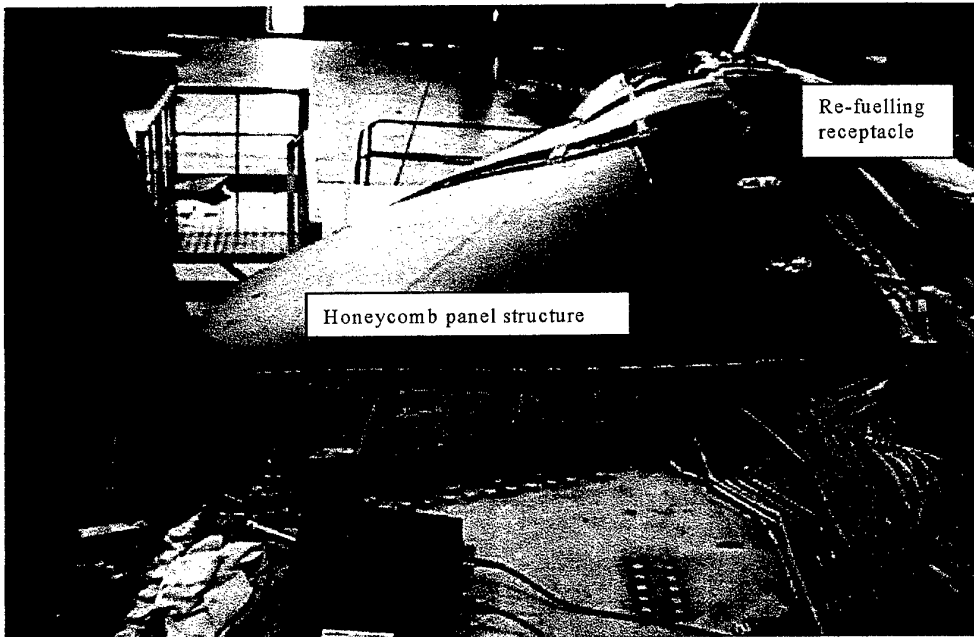


Figure 10. The large honeycomb panels in the vicinity of the re-fuelling area on top of the F-111. These panels must be repaired in situ and are susceptible to damage during the mid-air re-fuelling procedure.

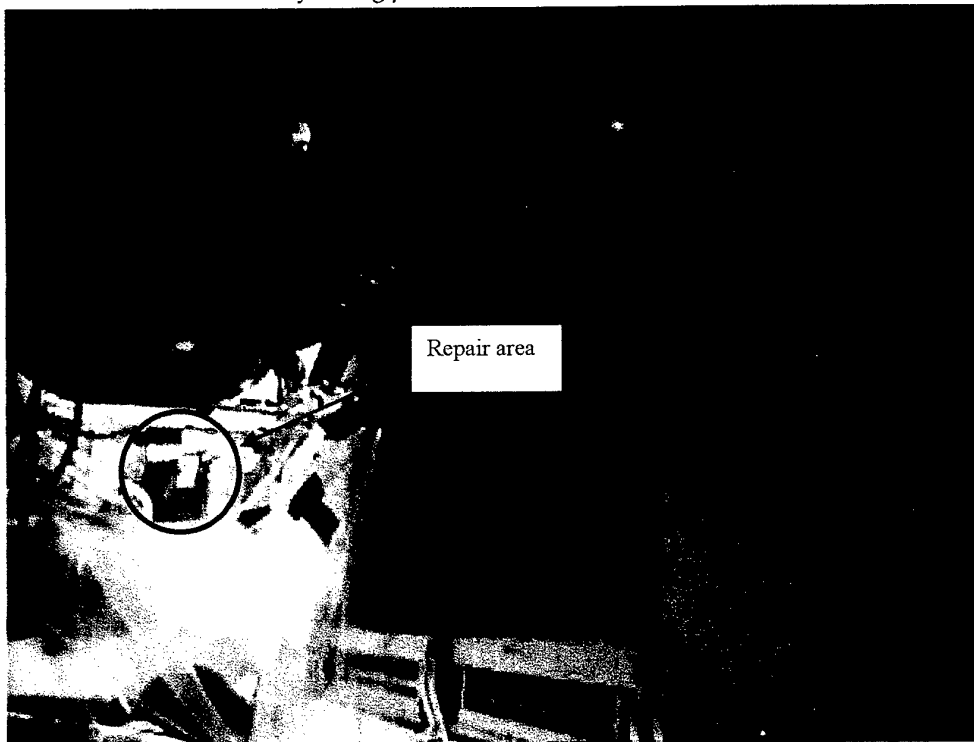


Figure 11 Repair required in weapons bay area of F-111 indicating an accessibility problem associated with replacing a panel in this location.

7. Current Actions Aimed at Reducing the Honeycomb Problem

The RAAF has procured a large number of panels from the McClellan U.S. Air Force Base in Sacramento, California. There are 1,060 panels that have been repaired (ca. 30%) or re-built (ca. 60%) from Sacramento. These comprise the panels that are prone to damage and are repaired on a regular basis such as the STABS, overwing fairings, and engine doors. Repairs involve NDI inspection of the panel and replacement of damaged core sections. Rebuilds involve using the old skins and completely replacing the core and fittings if possible. The saddle tank covers and the glove panels, which are prone to damage in the air to air re-fuelling, refer Figure 10, are not being re-manufactured as they contain rivet holes which are specific to the individual aircraft. A large number of old panels from retired F-111 U.S. military aircraft have also been procured.

8. Potential Problems Developing from the Current Honeycomb Repair Strategy

8.1 Patching Existing Injection Repair Areas with Structural Patches

The examples provided in Figures 1.0 to 6.0 indicate the problems associated with current methods where patches are placed over injection repairs. The injection repairs may have been exposed to high humidity for up to 20 years and the resultant moisture uptake of the honeycomb panel may be significant. Figure 12 indicates two pieces of honeycomb that had been injection repaired. The ability to remove moisture from this region of the repair and surrounding areas is clearly very difficult. The vacuum heating will be unable to remove moisture from the dense potted adhesive. Similarly, the potted adhesive will act as a barrier for the removal of moisture from surrounding areas.



Figure 12 Two pieces of honeycomb core material that had previously received an injection or potted repair.

Two potential solutions are considered:

1) One of the potential solutions offered to this problem is to use room temperature curing adhesives instead of the high temperature curing structural adhesives that are currently used for the environmental patch application. It is believed that this will prevent steam evolution during cure and minimise the extent of disbond damage. There are potential difficulties inherent with this solution. Initially, the current NDI is inadequate to identify the real extent of the honeycomb degradation around an injection repair, as indicated in Figures 8.0 and 9.0. Hence, a room temperature cure patch may be applied over a structurally defective area. Secondly, the room temperature cured adhesive may not be rated for the repair location. Thirdly, the current C5033 Engineering Standard surface preparation procedure, refer Table 2.0, requires heating the honeycomb panel above 100°C to dry the panel after surface preparation. These conditions are sufficient to cause disbonding of the panel as a result of internal pressures generated by steam production. Finally, if a repair such as a honeycomb core replacement is then required in the vicinity of a panel with these room temperature adhesive patches, then the potential for larger disbonds to occur will result, as exemplified in Figure 6.0.

2) A second solution to this problem is to place panels in a moisture free 50°C storage environment prior to repair. Currently it is not clear to what extent moisture can be successfully removed from moisture laden honeycomb panels or the time frame required to remove enough moisture from the panel to prevent the disbonding problem.

Both potential solutions need research to evaluate their viability.

The preferred method for dealing with the injection repair according to AAP 7021.016-2 is to route out the injection repaired area and to repair the area in accordance with Table 1.0. In the repair of metallic honeycomb panels the disbond problems created during patch application, as a result of inadequate moisture removal, appear to be localised to several tens of centimetres around injection sites. However, the problems observed with phenolic honeycomb core panels are more extensive as shown in figure 6. Due to manpower limitations, the removal of all injection repairs and subsequent repair in accordance with AAP 7021.016-2 is currently not favoured by 501 WG. However, the removal of all injection repair areas is the preferred option of ASI-SRS.

A more serious aspect of not dealing with the problems associated with injection repairs and ignoring the potential environmental degradation is exemplified in Figure 12.0.

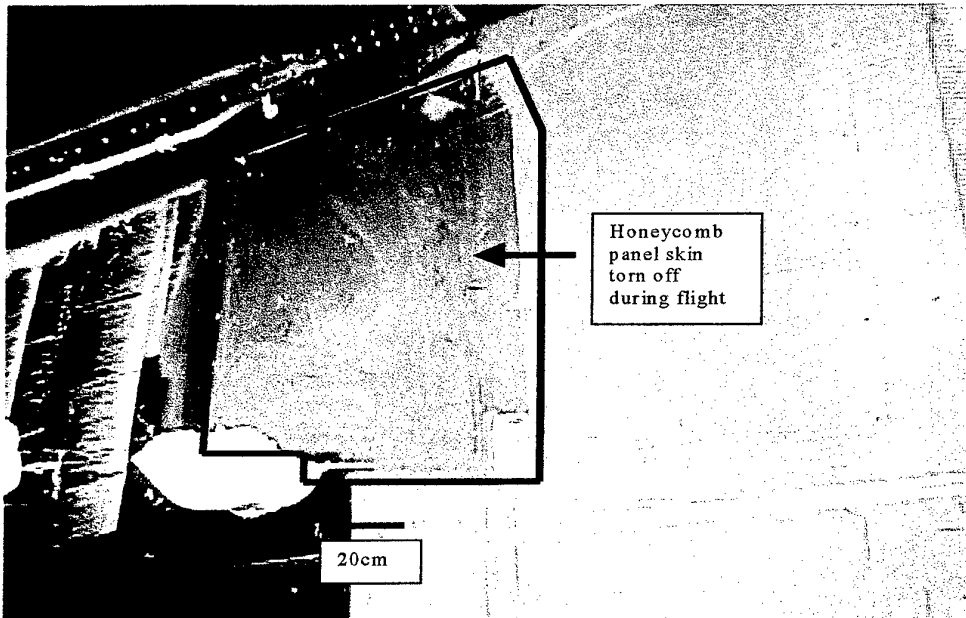


Figure 13 The exterior skin of a honeycomb panel that was removed during flight. The scale marker indicates the size of the panel. The location is just forward of the engine air-intake.

Here, the exterior skin from a large honeycomb panel was torn off the aircraft during flight just forward of the engine intake. Whilst it is unlikely that the skin would have entered the engine it would not have been impossible for some parts of the panel to have been sucked through the air-intake and cause significant engine damage. Clearly, not dealing with the problems of honeycomb panel structural integrity has the potential to lead to serious damage to the aircraft structure during flight and in a worse case scenario to loss of the aircraft.

A second example is the loss of an over-wing faring panel from an F-111 leading to secondary damage to the fuselage, fin and rudder. This failure is discussed in the conference paper entitled "The Role of Materials Processes in Defective Aircraft Bonded Structural Repairs" by M.J.Davis (ASI-SRS) presented at the 41st International Symposium and Exhibition of SAMPE, Anaheim, March 1996.

8.2 Reliance on Replacement Panels

Figures 5, 10 and 11 provide clear examples where reliance on replacement honeycomb panels from McClellan Airforce Base Sacramento California or old U.S. military aircraft will not provide a solution. In the case of Figures 5 and 11 there is inadequate accessibility to replace a panel. In the case of Figure 10 the glove panels once riveted in place are then specific to that aircraft and cannot be replaced from other aircraft panels. Sacramento has not repaired any of these panels.

The source of Sacramento panels, both repaired and re-worked, will cease as of the 18th of March 1999 when the factory is closed down. At this stage the repaired and reworked panels will be the only replacement panels available for the service life of the aircraft. These reworked panels have not been manufactured to the same standards expected of those for the original aircraft. No capability currently exists in Australia to manufacture the F-111 honeycomb panels or to re-work the larger honeycomb panels.

The quality of the re-worked or repaired honeycomb panels from Sacramento needs to be considered seriously. A memorandum from Wayne Plack, SM-ALC/LAFME, the U.S. Airforce F-111 structural engineer overseeing bonding operations at the Sacramento factory, addressed to the RAAF-LA on 29/5/97 clearly indicates that the quality control of bonded repairs performed at Sacramento are not guaranteed by Boeing Wedge durability tests. These tests are specified by the process order. Similarly, the surface preparation of aluminium surfaces for some bonded repairs are performed by an abrade and a solvent wipe. Work at AMRL clearly establishes that finishing a metal adherend surface preparation with a solvent wiping process severely reduces bond durability*.

The capability to rebuild honeycomb panels is available at ASTA and HDH-Sydney, but RAAF will need to review their entire process specifications and quality management systems before they could be considered competent.

The use of honeycomb panels from retired U. S. military aircraft also has the potential to cause similar problems to those existing with the current RAAF panels. These panels will also have received injection repairs and will have been exposed to harsh environmental conditions over a prolonged period. These panels are, thus, likely to

* D. R. Arnott, A. N. Rider "21st Congress of ICAAS-Conference Proceedings", 13-18 September, 1998, Melbourne Australia.

have significant moisture uptake which will lead to the repair problems discussed above.

9. Options to Deal with the Current Honeycomb Situation

The current difficulties associated with honeycomb repairs of panels, which can be repaired ex-situ, stem from the pre-existing injection repairs. In the case of metal honeycomb structures, following the AAP 7021.016-2 procedure of removing the injection repair by routing the damaged area and performing a full moisture evacuation cycle appears to prevent disbonding occurring during the curing of the high temperature film adhesive in the majority of cases. However, some problems have been reported. In the case of the phenolic core the current drying procedures may still be insufficient. Drying the honeycomb panels in low humidity conditions, prior to repair, may assist in alleviating the disbonding problem caused by inadequate moisture removal. However, this will require a research program to investigate each of the moisture removal options together with methods to detect moisture removal in-situ. The option of using a room temperature curing adhesive for repairs may not provide a reliable repair or structurally sound honeycomb panel, as discussed in Section 8.1, based partly on the current inadequacy of NDI techniques used to assess honeycomb damage.

The use of replacement panels from Sacramento in the U.S. (SMALC) should provide a short-term solution to the problem associated with the majority of ex-situ honeycomb repairs, however, the quality of these components may not provide the desired durability. In this case, the current repair problems will re-surface within the projected service life of the aircraft. Panels from old F-111 aircraft are unlikely to reduce the current repair problems given they will have experienced environmental degradation to the same extent as the RAAF panels and will also contain injection repairs.

Repair of panels in-situ appears to be the major short-term problem confronting honeycomb repairs. These repairs are susceptible to the problems associated with inadequate moisture removal. Replacement panels will not offer a solution in inaccessible areas and some panels that are riveted in place cannot be transferred between aircraft. Further, many of these types of panels have not been overhauled at Sacramento and replacement panels do not exist. Repair methods from application to design of patches need to be developed to deal with the problem of large repairs and repairs in difficult to access areas. As the aircraft structure ages further repairs outside the tolerances of the design criteria stipulated in DI (AF) AAP 7214.003-3 will develop.

If the current repair problems associated with honeycomb repairs are not solved then the reduction in the number of serviceable panels may result in the premature retirement of the F-111. An insurance against this event occurring could be achieved by

the development of a capability to manufacture or rework honeycomb panels as the need arises. With the Sacramento (SMALC) operation closing down in March 1999, the RAAF will need to consider the development of this facility in the near future.

10. Update on Current Bonded Repair Status as of February 1999

Recent information from ASI-SRS indicates that the Amberley Bonded Panel Repair shop have developed a method to reduce the incidence of core disbonds occurring as a result of internal pressure generated by trapped moisture vaporising during the cure cycle of the FM-300 adhesive. A large shipping container has been modified to allow the storage of panels under vacuum at approximately 80°C. Storage of panels under these conditions prior to bonded repairs has lead to a significant reduction in the disbond problem, particularly for the Nomex or phenolic honeycomb core panels.

Research is required to establish the minimum storage time required in these conditions for adequate moisture removal from the panels. Research is also required to establish a method to effectively monitor moisture removal during typical drying procedures. This research could be conducted under a milestone in AIR Task 97/121

A recent Interim Amendment (INAM No. 141) to DI(AI) AAP 7214.003-3B5 states that deeper level maintenance D18 injection repairs are prohibited. Injection repairs will only be allowed as a temporary repair and must be replaced at scheduled deeper level maintenance. This amendment will go a long way toward reducing problems associated with injection repairs discussed in this report.

11. Conclusions

From the above report the following conclusions can be drawn:

- 1) The draft document AAP 7021.016-2 for the repair of bonded panels implements a suitable philosophy for improving the reliability of bonded repairs and maintaining the structural integrity of in service bonded panels. However, a more thorough review of the draft document and its procedures would be required before all processes specified in the document could be recommended for adoption by RAAF.
- 2) Pre-existing injection repairs in bonded panels have the ability to cause significant problems for future repair and maintenance. Injected repairs which do not have a structural patch provide zones where moisture can readily penetrate into the bonded panel. Due to the inability to pre-treat the metal surface in any injection repair it is almost impossible to guarantee a successful bond has been formed. The injection repair will be unlikely to recover any loss in mechanical strength of the damaged region of the panel and, in addition, will provide a low resistance path for moisture ingress.

Whilst, INAM No. 141 will go some way towards reducing the occurrence of injection repairs, and their associated problems, pre-existing injection repairs are likely to be one of the sources responsible for the degradation of bonded panel strength. Water ingress will either degrade adhesive bond strength between the aluminium skin and honeycomb or corrode the aluminium or both. Regular occurrences of panels containing water and/or corrosion indicate that this problem can degrade bonded panel strength and hamper adhesive bonded repairs.

- 3) Repairs to bonded panels are complicated by the presence of moisture in the vicinity of the repair region. Current repair procedures use a high temperature curing adhesive, FM-300, which cures at 150⁰C. During cure of the adhesive, residual moisture vapourises and the volume expansion creates a pressure which is often sufficient to cause substantial disbonding of the skin from the honeycomb panel. Significantly larger areas are then in need of repair. Methods to overcome the problems associated with this problem are required.
- 4) Repairs to bonded panels in situ have the potential to cause difficulties in the maintenance of F-111 aircraft. The location of certain panels prevents their

replacement and in situations where these panels are damaged beyond the maximum limits specified in AAP 7214.003-3 new methods for repair must be developed.

- 5) The reliance on rebuilt or reworked panels provides a short term solution for panels which can be replaced and transferred between aircraft. These panels, however, may not provide a long term solution given the question mark over the quality of the bonding operations undertaken at McClellan Airforce Base. Rebuilt and reworked panels cannot provide solutions for panels requiring repairs in situ or to panels which cannot be transferred between aircraft. Panels from retired military aircraft are likely to contain the same problems associated with current F-111 panels and will similarly not provide a long term solution to bonded panel repairs.

13. References

Royal Australian Airforce Engineering Standard C5033, "Composite Materials and Adhesive Bonded Repairs" September 1995, RAAF Headquarters Logistics Command, Melbourne, Vic., Australia.

Royal Australian Airforce Draft Document AAP 7021.016-2, "Composite Materials and Adhesive Bonded Repairs. Repair Fabrication and Application Procedures."

F-111 Repair Manual DI (AF) AAP 7214.003-3B5, Appendix IV, pp D-1 to D-23

SM-ALC/4080/A08/1110 Pt3(63) ; "Use of Improved Materials and Processes in F-111 Bonded Panel Remanufacture (reference to 29/4/97 Minute ASI/4027/2/9 Pt2(23))", 29 May, 1997.

M. J. Davis, Proc. Of 41st Int. SAMPE Symp. And Exhibition, Anaheim, 25-28 March, 1996, pp 936-950.

M. J. Davis, Proc. International Aerospace Cong. 97, Sydney, 24-27 Feb., 1997, pp 215-226.

M. J. Davis, Proc. Int. Symp. On Composite Repair of Aircraft Structure, Vancouver 9-11, August, 1995.

Appendix A: Overseeing a Typical Honeycomb Bonded Repair

A.1. Introduction

The repair of a honeycomb panel performed by a trained RAAF member was observed to examine the quality of repairs and gain insight into the limitations in the application of bonded repairs on honeycomb panels. Specifically a repair was performed on a left-hand pave tack door, in which a dented panel skin produced a crack and damage of the core. The repair involved a partial core replacement followed by the application of a structural patch.

A.2. The Step By Step Repair

The skin is removed around the damaged area and the extent of core damage assessed. The damaged core is then removed by routing and the remaining core is sanded back to provide a level surface for subsequent bonding of a new plug insert.

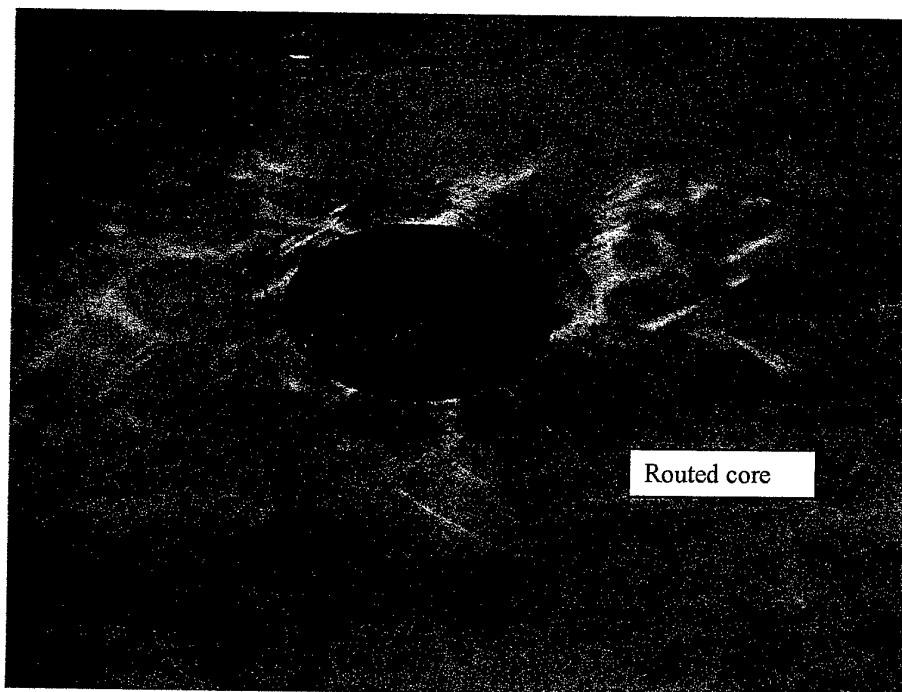


Figure A-1 A typical repair. Step 1: removal of the damaged core by routing

The routed area then has a moisture evacuation performed at 85°C and -75kPa with 6 thermocouples and a heater blanket either side of the repair area, refer figure A-2.0.

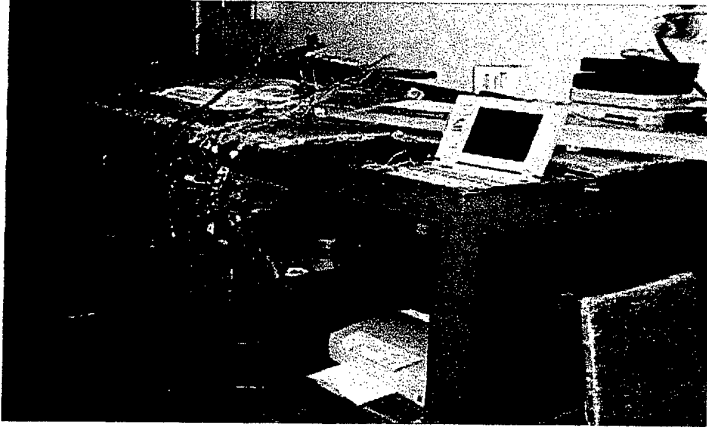


Figure A-2 Moisture evacuation of the repair area using the vacuum bag, heater blanket arrangement, using a hot-bonder unit HBC-43 from Novatech®.

Before moisture evacuation a piece of honeycomb plug is carefully cut to shape which is 10mm thicker than the skin level, as indicated in figure A-3.0.

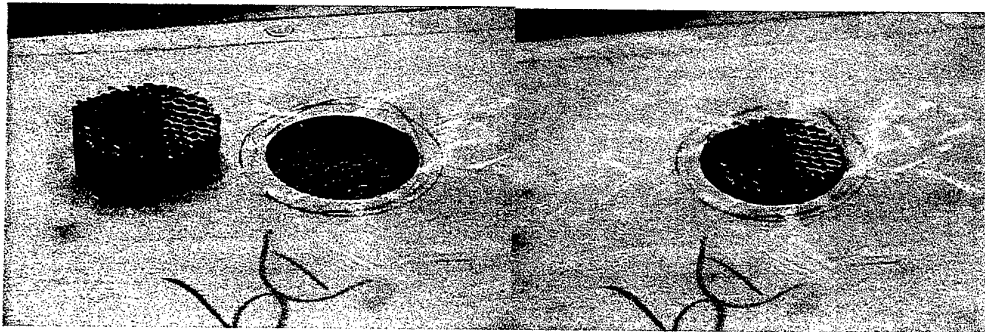


Figure A-3 The core plug insert used to repair the routed core

The core plug is then flushed with methyl ethyl ketone (MEK), analytical reagent and dried at 110°C for 2 hours using an oven. The routed area of core on the panel is also flushed with MEK and an infrared lamp is used to dry the repair area at 110°C for 2 hours.

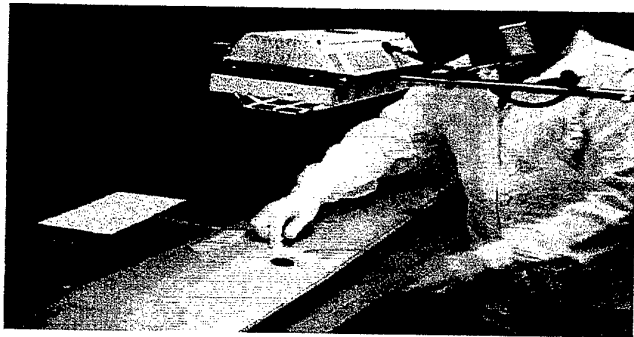


Figure A-4 Infrared heating of core after MEK flush.

After the drying of the plug insert, pre-thawed foaming and film adhesive are cut to shape and applied to the plug insert as shown in figure A-5.0. Once the core area on the panel is dried, the plug and adhesive are applied to the routed core area. The plug insert is cured initially, as shown in figure A-6.0, and the metallic patch is applied as the final step of the repair, figure A-7.0.

Repair Involving Replacement of Honeycomb Core

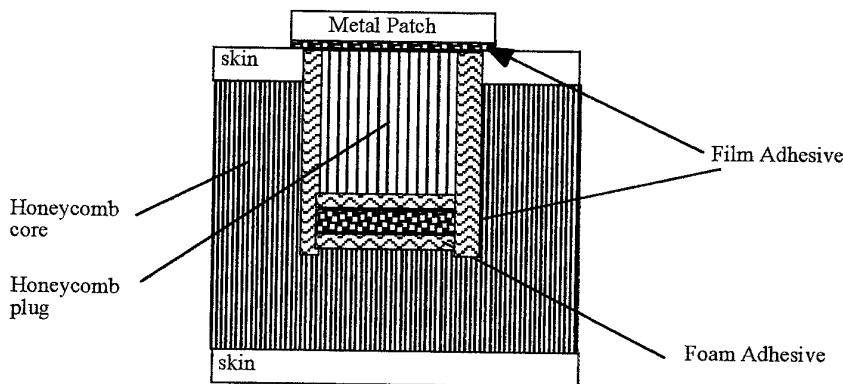


Figure A-5 Diagram indicating the details of the plug adhesion process. Step 1 involves curing the plug in place. Step 2 involves application of the metallic patch.



Figure A-6 The two pictures indicate that the plug bonded in position after the initial adhesive curing step. Note in the left-hand picture the foaming adhesive has not expanded correctly and voids exist between the plug and routed core. In the right hand side picture the foaming adhesive has expanded correctly. The foaming adhesive came from the same batch.

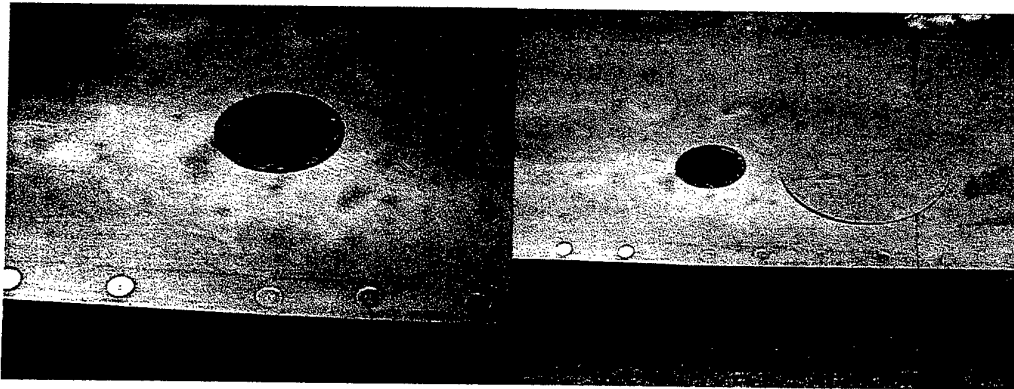


Figure A-7 The plug is sanded back to flush with the skin level and a metallic patch is applied using FM-300 film adhesive.

The skin surface and metallic patch are pre-treated with the standard grit-blast silane process and dried at 110°C for two hours. FM-300 film adhesive is then cured at 160°C for 1 and ¾ hours using the standard vacuum bag procedure.

A.3. Comments on the Repair Procedure

The repair procedure for the partial honeycomb core replacement observed the details prescribed in the C5033 Engineering Standard and the draft AAP 7021.016-2 as far as surface preparation and drying procedures were concerned. However, the other aspects of the core replacement procedure were performed according to AAP 7214.003-3. This provides some insight into the variation in repair methodology that arises. This problem is in part due to the AAP 7021.016-2 only being a draft document. RAAF personnel, whilst being recommended to use the AAP 7021.016-2, are still permitted to apply some of the repair techniques detailed in the AAP 7214.003-3. Once the AAP 7021.016-2 becomes the official document, hopefully, these problems will disappear. The only other difficulty observed during the repair procedure was the problem associated with the foaming adhesive not expanding, refer figure A-5.0, and difficulties associated with the Hot-Bonder Unit. In a large repair situation if the foaming adhesive does not expand the time and cost associated with re-performing the repair may be significant. To what extent the foaming adhesive can be further qualified prior to use is not clear. The Novatech Hot-Bonder only has 16 thermocouples and for the small repair, discussed in this Appendix, 12 were required. For larger repairs several Hot-Bonder units would be required. In light of the potential for more repairs being required over larger areas an updated version of this unit may need to be considered in which a greater capacity to measure the temperature in different zones of a large repair is possible.

12. Recommendations

Consideration of the above conclusions regarding the status of bonded panels and their repair leads to the following recommendations:

- 1) A detailed investigation should be conducted of the bonded repair methods prescribed in draft document AAP 7021.016-2 to determine its suitability for adoption by RAAF for bonded repairs of honeycomb panels.
- 2) Investigate methods for the in-situ detection of moisture in bonded panels. The use of techniques such as Thermography in conjunction with X-ray techniques have the ability to analyse this problem.
- 3) Investigate practical methods to dry moisture laden honeycomb panels with and without pre-existing injection repairs with an aim towards optimising the most suitable drying technique.
- 4) Establish a program to assess the suitability of employing lower temperature curing adhesives for bonded repairs.
- 5) Given the inconsistent cure behaviour of some foaming adhesives examine the possibility of more regular qualification of repair adhesives.
- 6) Investigate alternative methods for repairing injection repairs with an aim towards recommending a solution which RAAF may employ to prevent this problem contributing to further degradation of bonded panels.
- 7) Investigate methods to establish the influence that inadequate surface pre-treatment procedures have on bonded panel strength and durability properties.
- 8) Given the possibility that spare bonded panels are likely to present longer term problems for F-111 maintenance, RAAF should examine the feasibility of bonded panels being rebuilt in Australia. Any panel rebuilds would have to conform with strict manufacturing guidelines, particularly, in regard of surface pre-treatment procedures and quality assurance practices.

Staff at DSTO-AMRL, Melbourne have the knowledge, expertise and experience required to provide assistance to RAAF required for the implementation of the above recommendations.

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19. ABSTRACT A visit was made to Amberley Airbase between the 6th and 9th of September 1998 to consult with RAAF staff on current procedures and problems involved in the maintenance and repair of F-111 honeycomb panels. In conjunction with these discussions, a review of the current methods being used for honeycomb repair procedures was undertaken. The following report summarises the methods being used for repairs and the relevant reference documents. Also detailed are the major problems being encountered in these repairs and future problems which may arise as a result of the current status being maintained during the service life of the F-111.					