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Retrogression and Re-Ageing In-Service Demonstrator Trial: Stage II Component Test Report

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ABSTRACT

Retrogression and Re-ageing (RRA) technology is a two stage heat treatment of 7075-T6 aluminium alloy used to improve corrosion resistance while retaining MIL-HDBK-5J structural properties. This report assesses the compliance of the industrial trial, conducted at Boeing Australia Component Repairs (BACR) on 21st April 2009, with the requirements of the compliance matrices in the Stage II Design Development Plan and, by extension, the Stage II Process Specification for RRA. Of the 35 items in these matrices 31 were given recommended ratings of 'Compliant' while the remaining four received recommended ratings of 'Non-Compliant (Acceptable)'.

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Executive Summary

Retrogression and Re-ageing (RRA) technology is a two stage heat treatment of 7075-T6 aluminium alloy used to improve corrosion resistance while retaining MIL-HDBK-5J structural properties.

The certification and acceptance of the RRA technology for application to Australian Defence Force (ADF) aircraft has been undertaken in sequential stages. The first stage was the qualification of the RRA technology under laboratory conditions. The second stage consisted primarily of an industrial trial of the technology on a real aircraft component. The third and final stage deals with the practical issues of transitioning RRA onto ADF aircraft.

An industrial trial of the RRA heat treatment on a C-130 Hercules component was conducted at Boeing Australia Component Repairs (BACR) on 21st April 2009. This report assesses the compliance of this industrial trial with the requirements of the compliance matrices in the Stage II Design Development Plan and, by extension, the Stage II Process Specification for RRA. The Stage II Process Specification proved to be sufficient to conduct an industrial heat treatment satisfying the great majority of the compliance items from the compliance matrices. Of the 35 items in these matrices 31 were given recommended ratings of 'Compliant' while the remaining four received recommended ratings of 'Non-Compliant (Acceptable)'.

This report concludes with a set of recommendations for updating the Process Specification. These will be incorporated into the Process Specification during the third and final stage of RRA Certification.

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Christopher Loader, Research Scientist, graduated from Monash University in 1998 with Bachelors degrees in Science and Engineering. Since arriving at DSTO in 1998, he has worked on several programs aimed at better understanding corrosion-initiated fatigue in a variety of aerospace aluminium and steel alloys. Chris is currently assessing several novel technologies for use in future and current Australian Defence Force aircraft. For the past year he has been managing the certification of Retrogression and Re-ageing for use on the RAAF C-130 Hercules.

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Dr. Bruce Crawford, Senior Research Scientist, graduated from Monash University in 1991 with a Bachelor of Engineering in Materials Engineering with first class honours. He subsequently completed a Doctor of Philosophy at the University of Queensland in the field of fatigue of metal matrix composite materials. Bruce then lectured on materials science and engineering for four years at Deakin University in the School of Engineering and Technology before joining DSTO in 1999. Since joining DSTO Bruce has worked on the development of deterministic and probabilistic models of corrosion-fatigue and structural integrity management for aerospace aluminium alloys. In the past six years, he has managed the certification of Retrogression and Re-ageing, a technology with the potential to significantly reduce the incidence of exfoliation corrosion and stress corrosion cracking in the 7075 T6 components of the RAAF C-130 Hercules.

Dr. Alexandra Shekhter
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Dr. Alexandra Shekhter, Research Scientist, gained her PhD from Monash University in 2003. She worked in the Department of Materials Engineering at Monash University as a research fellow for two years working on the microstructure and properties of maraging steels. Since commencing in DSTO's Air Vehicles Division in November 2002, she has been involved in long range research focussing on emerging materials technologies for airframes. She has also worked on the certification of Retrogression and Reaging for use on ADF aircraft and on technical risk assessments for novel materials and technologies for new platform acquisitions. As part of the technical risk assessment for the New Advanced Combat Capabilities she is responsible for investigations of thermal exposure of metallic materials and damage tolerance assessment of Ti 6-4 ELI.

Contents

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Glossary

§	Paragraph, section or heading number
AAP	Australian Air Publication
ADF	Australian Defence Force
ALSPO	Airlift Systems Program Office
ALSPO SI	ALSPO Standing Instruction
AMO	Authorised Maintenance Organisation
AMS	Aerospace Material Specification
ASTM	American Society of Testing and Materials
BACR	Boeing Aircraft Component Repairs
CASA	Civil Aviation Safety Authority
CDR	Critical Design Review
CID	Component property IDentification
CPCM	Component Properties Compliance Matrix
DAR	Design Acceptance Representative
DAVCOMP	Directorate Air Vehicle Compliance
DCB	Double Cantilever Beam
DDP	Design Development Plan
DEF(Aust)	Australian Defence Force Standard
DGTA	(RAAF) Directorate General Technical Airworthiness
DSTO	Defence Science and Technology Organisation (Australia)
EXCO	Corrosive solution used in EXfoliation COrrosion testing
FS	Fuselage Station (C-130 Hercules)
FS737	Fuselage Station 737 (C-130 Hercules)
$\mathbf{F_{tu}}$	Tensile strength
$\mathbf{F_{ty}}$	Yield stress (defined as 0.2% offset)
H	DCB Specimen half height
HRB	Rockwell hardness 'B' Scale
IACS	International Annealed Copper Standard (electrical conductivity)
ITAR	International Traffic in Arms Regulations
LM	Lockheed Martin
LMA	Letter of Maintenance Authority
MAC	Maintenance Authority Certificate
MAC	Mean Aircraft Chord
MIL-HDBK	(United States) Military Handbook
Min.	Minimum
MPDR	Materials Property Data Report
NATA	National Association of Testing Authorities (Australia)
NATO	North Atlantic Treaty Organisation
NDI/NDT	Non-destructive inspection/testing
NRC	National research Council of Canada
NSN	NATO Stock Number
OEM	Original Equipment Manufacturer
OIC	Officer-In-Charge
PDR	Preliminary Design Review

PID	Process property IDentification
PRCM	Process Requirements Compliance Matrix
PSCR	Process Specification Compliance Report
QA	Quality Assurance (specimen)
QDS	QANTAS Defence Services
RAAF	Royal Australian Air Force
RRA	Retrogression and Re-ageing
s	Standard deviation
SAE	Society of Automobile Engineers
SCC	Stress Corrosion Cracking
SOR	Statement of Requirement
SRM	Structural Repair Manual
T6	Peak-aged temper for aluminium alloys
TAMM	(RAAF) Technical Airworthiness Management Manual
$\bar{x}$	Arithmetic mean

1. Introduction

This report forms part of Stage II of the Defence Science and Technology Organisation's (DSTO's) program to certify Retrogression and Re-ageing (RRA) for use on components from Australian Defence Force (ADF) aircraft. RRA is a two-stage heat treatment which is used on selected peak-aged AA7xxx-series aluminium alloys to increase their corrosion resistance. Stage I RRA Certification was a laboratory demonstration of the RRA process. Its goal was to determine if RRA-treated AA7075-T6 extrusions met the design allowables for this alloy as contained in Military Handbook 5J (MIL-HDBK-5; Reference 1). This stage is complete and a report (Reference 2) has been submitted to the Directorate General Technical Airworthiness (DGTA) for their consideration. Stage III will deal with the issues of transferring RRA into service.

This report assesses the compliance of an industrial trial of DSTO's implementation of the RRA heat treatment with the requirements of the Design Development Plan (DDP; Reference 3) for Stage II RRA Certification. The industrial trial is the core activity of Stage II of RRA Certification. Full details of the trial may be found in the Process Specification Compliance Report (PSCR) (Reference 4) which compared the trial variables with the requirements of the DSTO Developed Stage II RRA Process Specification (Reference 5).

The Stage II DDP requirements are summarised in the Process Requirements Compliance Matrix (PRCM) and the Component Properties Compliance Matrix (CPCM) contained in the DDP (Reference 3). Compliance with these matrices determines the degree of success of the RRA process in an industrial environment. The testing required to satisfy the two compliance matrices is summarised in this report along with the completed PRCM and CPCM while full details of the testing and analysis are contained within individual test reports referenced within the relevant sections of the report.

2. Background

The C-130 Hercules military transport aircraft was introduced in the mid-1950s and is used for tactical airlift. Twelve C-130H aircraft entered Royal Australian Air Force (RAAF) service in 1978 with 36 Squadron based at RAAF Base Richmond. Subsequently, twelve C-130J–30 entered service with the RAAF in 1998 with 37 Squadron also based at RAAF Base Richmond. It has been found that corrosion of 7075-T6 airframe components is a serious issue for both variants.

Previous testing by the National Research Council of Canada (NRC) has shown that RRA processed aluminium alloys have significantly better corrosion resistance compared to the conventional peak-aged alloys commonly used on aircraft such as the C-130 (Reference 6). RRA treatment does slightly decrease the structural properties of the AA7xxx-series alloys. However for AA7075-T6, the material properties of newly manufactured material are significantly in excess of the certified values in the MIL-HDBK-5J (Reference 1). This is largely due to improvements in materials processing in the five decades since the original certification of AA7075-T6. The decrease in strength allowables due to RRA, conducted as per the Stage I RRA Process Specification (Reference 7), has been demonstrated by DSTO to be less than the increase due to improved processing (Reference 1). As such RRA-treated 7075-T6 can be used with the design allowables of the untreated alloy.

RRA is a two-stage heat treatment process. In the first stage, retrogression, the component is heated to 195 °C for a short period of time which is dependant on the subject material's initial electrical conductivity[1], followed by quenching. This retrogression and quench partially reverses the aging process. Some of the strength of the material is lost during this stage. In the second stage, re-ageing, the component is heated to 120 °C for 24 hours before air cooling to room temperature Figure 1. This partially reverses the loss of strength that occurs during retrogression.

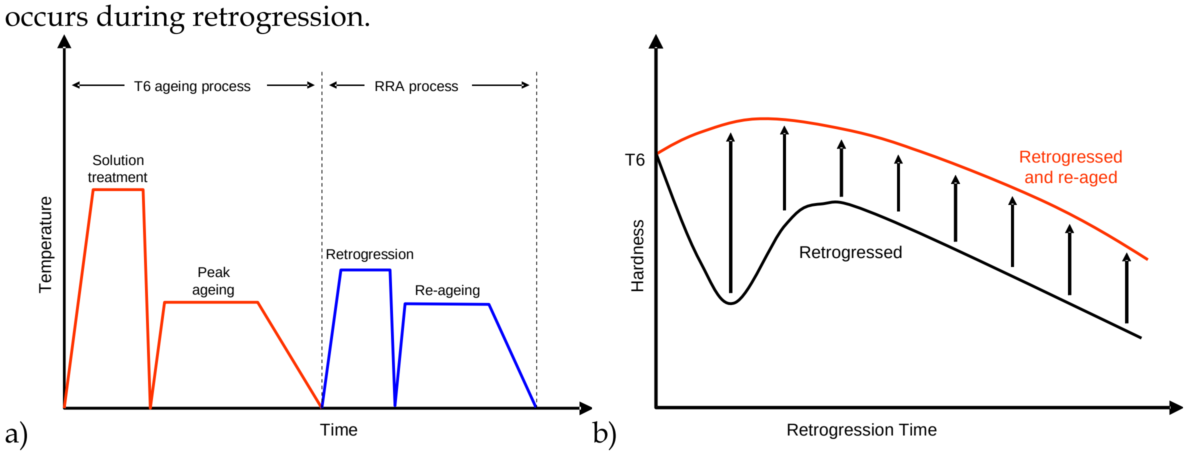

Figure 1: Schematic representation of the Retrogression and Re-ageing heat treatment (Reference 8) where (a) shows the temperature profile of the heat treatment as compared to a T6 treatment, and (b) shows the response of material hardness to retrogression and subsequent re-ageing. Note that RRA is an additional heat treatment conducted following T6 treatment rather than an alternative treatment.

The principal benefit of RRA is that it increases the corrosion resistance of peak-aged AA7xxx-series aluminium alloys, such as the 7075-T6 used in the C-130, without reducing their mechanical properties below the certified design allowables for the alloy's peak-aged temper (Reference 1). This is in contrast to the conventional practice of allowing material substitutions, such as replacing AA7075-T6 with AA7075-T73, which lead to a 10-15% reduction in the certified A-basis value of tensile strength. Therefore, the opportunity exists to use RRA on replacement parts for the C-130 without the need to conduct a redesign or obtain such a redesign from the OEM. An additional benefit is that the increase in corrosion resistance due to RRA could lead to reduced through-life support costs and increased aircraft availability.

DSTO has developed a RRA process specification for both Stage I (Reference 7) and Stage II (Reference 5). The Stage I RRA Process Specification was used for laboratory scale demonstration of the technology. The Stage II RRA Process Specification is a revision of

[1] The length of the initial retrogression is chosen to produce an RRA treated condition that has a targeted final electrical conductivity.

this document which describes the RRA heat treatment process for the industrial scale trial and all the requirements associated with it. The PSCR (Reference 4) describes the industrial scale trial and assesses the compliance of this trial with the Stage II Process Specification.

The industrial scale trial component and its associated certification documentation produced by the end of Stage II of the RRA certification project will demonstrate the feasibility or otherwise of conducting RRA treatment on a C-130 structural component in an industrial environment.

3. Structure of Project Documentation

This section describes the design documentation that has been produced as part of Stage II RRA Certification. It provides an overview of these documents in order to explain how they relate to each other and to the testing that was undertaken. Most of these documents were defined in the Stage II Design Development Plan (Reference 3) and are referred to as deliverables. The remaining documents are either test reports or DSTO reports.

Table 1 lists all of the documents produced in Stage II Certification. It gives the short title of the document and its deliverable number (if any) as defined in the Stage II Design Development Plan (Reference 3). Figure 2 is a flowchart illustrating how these documents are related to each other. Note that for clarity several of the deliverables (highlighted with an *) in Table 1 have been excluded from Figure 2.

Table 1: List of documentation deliverables and reports for Stage II RRA Certification

Report Title (short form)	**Deliverable**
Design Acceptance Strategy (Letter)*	D1
(Stage II) Statement of Requirement	D2
(Stage II) Design Development Plan	D3
Process Requirements Compliance Matrix*	D4
Stage II Process Specification	D5
Component Properties Compliance Matrix*	D6
RRA Demonstrator Component Test Plan	D7
Preliminary Design Review Minutes*	D8
Heat Treatment Certificates*	D9
Individual Test Reports	D10
Metrology	N/A
Tensile	N/A
Corrosion	N/A
NDI Conductivity	N/A
QA Supplementary Tensile	N/A
Component Test Report (draft)*	D11
Critical Design Review Minutes	D12
Component Test Report (final)	D13
Recommendations Letter*	D14
Stage II RRA Trials Report	N/A
QA Tensile Test Plan*	N/A
Process Specification Compliance Report	N/A
* Not shown in Figure 2	

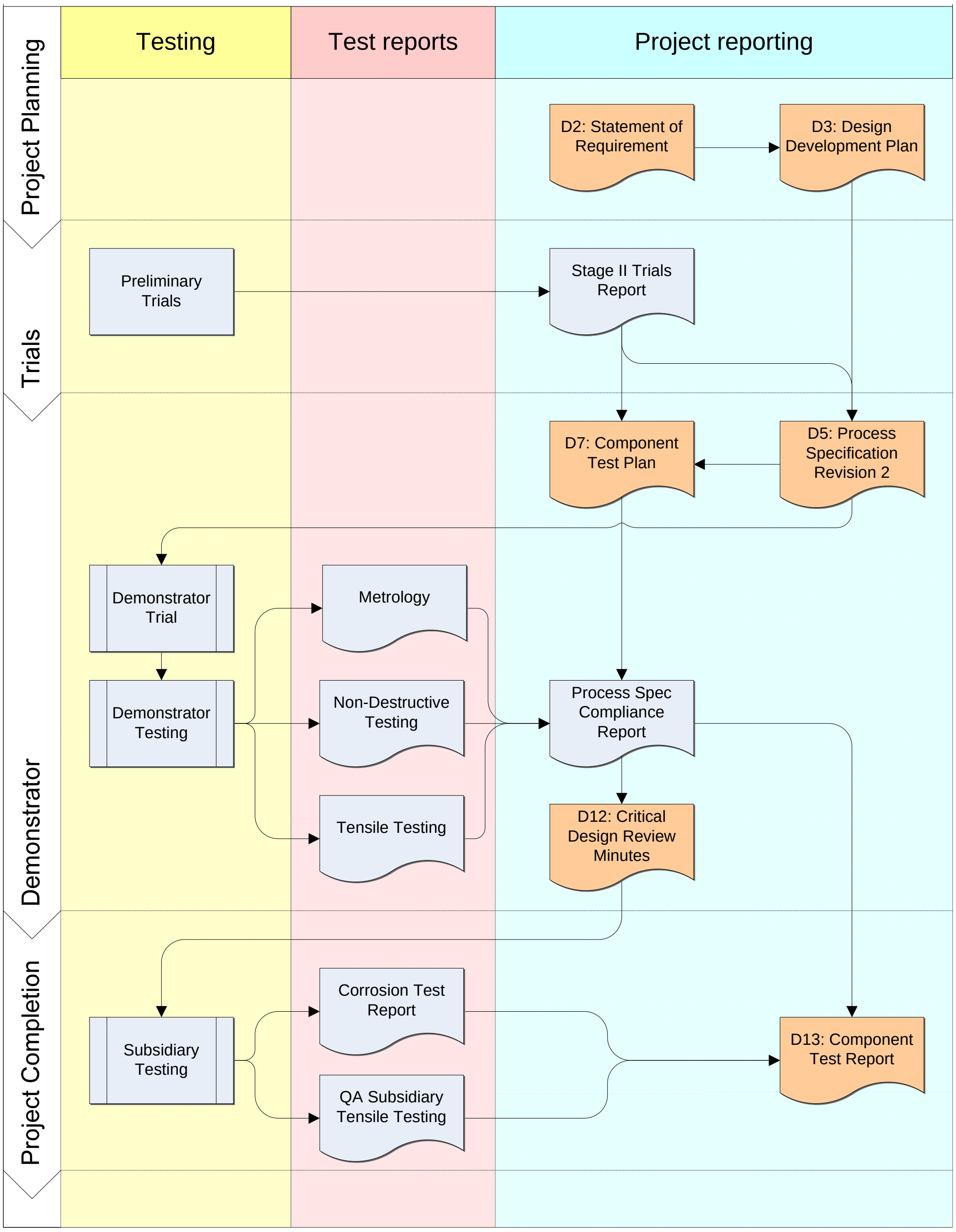

Figure 2: Relationships between various Stage II RRA Certification project documents(to be read in conjunction with Table 1)

4. Description of Trial Component

The component selected for the industrial demonstration was the C-130 Fuselage Station 737 (FS737) Lower Cap. It has a Lockheed Martin part number of 356251-6 and a NATO Stock Number (NSN) of 1560001853031. The component is formed from a standard Lockheed Martin T-section AA7075-T6 extrusion (#3955-2) whose dimensions are illustrated in Figure 3.

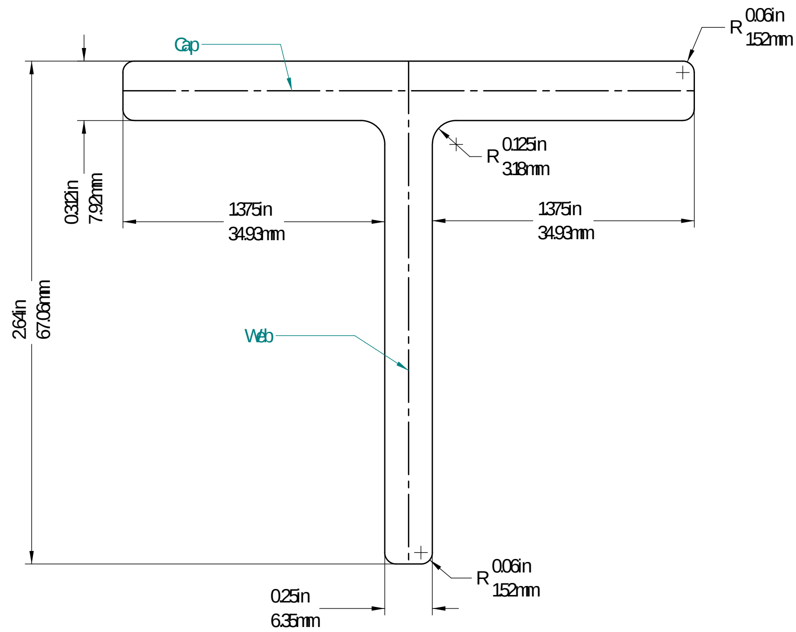

Figure 3: Schematic of the cross-section of standard Lockheed Martin extrusion #3955-2 from which the C-130 FS737 Lower Cap is formed. US-Customary units (inches) are authoritative while SI units (millimetres) are included for convenience.

Two FS737 Lower Caps were used in the trial described in this report. One was the trial component selected for RRA treatment, while the second was sectioned to provide three Quality Assurance (QA) specimens of 300 mm length each.

5. Experimental Method

The testing required in order to satisfy the compliance matrices (PRCM and CPCM) is detailed in the Component Test Plan (Reference 9). This plan describes the tests to be performed during the RRA trial in three discrete stages:

- Pre-RRA treatment testing;
- Post-RRA treatment testing; and,
- Post-sectioning testing, performed following mechanical sectioning of the RRA treated component.

This current section summarises the testing conducted in all three of these stages. It reports some supplementary tests which were conducted by the DSTO to resolve some anomalies in the tensile data from the QA specimens and to resolve experimental difficulties that arose during the corrosion testing that prevented its completion prior to the Stage II Critical Design Review (CDR). This supplementary testing was mandated by the Stage II CDR (Reference 10). The corrosion testing mandated in the Component Test Plan was not finished until after the Stage II CDR due to the experimental difficulties that were encountered in attempting to conduct these tests.

The pre- and post-RRA treatment tests have been reported in detail in the PSCR (Reference 4). The post-sectioning tests have been reported in individual test reports (References 11, 12, 13 and 14). Also noted in the detailed testing descriptions below are the Process property IDentification numbers (PID) from the PRCM and the Component property IDentification numbers (CID) from the CPCM relevant to each test.

Testing was conducted on both the trial component and on three Quality Assurance (QA) specimens that were RRA-treated with the trial component.

5.1 Pre-RRA Treatment Testing

The following pre-trial tests were mandated by the Component Test Plan (Reference 9).

- **Initial Component Condition (PID 1.1):** This was a visual inspection of the trial component prior to treatment. It was recorded in the FS737 Lower Cap Initial Component Condition Report, which is included as an Appendix to the PSCR (Reference 4).

- **Initial Electrical Conductivity (PID 1.4 and 4.2):** Measurements were performed on both the FS737 Lower Cap and the QA specimens prior to RRA treatment according to §4.2 of the Process Specification (Reference 5). The results (in %IACS[2]), of this test were reported in a DSTO NDI Report (Reference 11).

- **QA Initial Hardness (PID 4.1):** Rockwell hardness 'B' scale hardness (HRB) measurements were performed on the three QA specimens prior to treatment according to §4.3 of the Process Specification (Reference 5). These were reported in the PSCR (Reference 4).

- **Dimensions (CID 1.1):** A metrological examination of the trial component was planned for the trial component prior to RRA treatment (Reference 9) to establish its initial dimensions. However, this examination was not carried out. The reasons for this are discussed in Reference 13.

The industrial trial was conducted at the Boeing Australia Component Repairs' (BACR)[3] facility. The test plan was developed such that compliance with the PRCM and CPCM could be achieved.

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[2] **International Annealed Copper Standard**, a unit of electrical conductivity for metals and alloys relative to a standard annealed copper conductor.
[3] Boeing Australia Component Repairs 1/29 Jets Court, Tullamarine, VIC 3043.

5.2 Post-RRA Treatment Testing

The following post-trial tests were mandated by the Component Test Plan (Reference 9):

- **Initial Component Condition (PID 1.1)[4]:** This was a visual inspection of the trial component after treatment. It was recorded in the FS737 Lower Cap Initial Component Condition Report, which is included as an appendix to the PSCR (Reference 4).

- **Final Electrical Conductivity (PID 1.5 and 4.6):** Measurements were performed on both the FS737 Lower Cap and the QA specimens according to §4.2 of the Process Specification (Reference 5). The results of this test were reported in a DSTO NDI Report (Reference 11).

- **QA Final Hardness (PID 4.4):** Rockwell hardness 'B' scale hardness measurements were performed on QA specimens according to §4.3 of the Process Specification and reported in the PSCR (Reference 4).
- **Dimensions (CID 1.1):** A metrological examination was performed on the trial component after RRA treatment (Reference 13) to establish its final dimensions.

5.3 Post-Sectioning Testing

Sectioning of the RRA-treated component and specimen manufacture was performed by Metaltec[5]. A cut-up diagram is contained in Appendix A of this report. The following tests were mandated by the Component Test Plan (Reference 9) and performed following sectioning of the trial component.

- **Tensile Tests (PID 3.1 and 4.5):** These tests were conducted in the Structural Test Laboratory at DSTO Fishermans Bend and the results reported in a NATA accredited report (Reference 12). Four tensile specimens were produced from each of the five locations shown in the trial component cut-up diagram (Appendix A) and labelled such that their original position within the component was traceable. This gave a total of 20 tensile specimens. Similarly, two specimens were taken from each of the QA specimens and labelled such that their original QA specimen was traceable. This gave a total of six QA-derived tensile specimens.

- **Corrosion (PID 3.2 and CID 3.5):** Stress Corrosion Cracking (SCC) and exfoliation tests conducted at DSTO Fishermans Bend (Reference 14). Two SCC specimens were taken from each of the five locations (i.e. 10 SCC specimens in total) shown in the cut-up diagram (Appendix A), while two exfoliation specimens were taken from a single location on the trial component. An equal number of control specimens were machined from equivalent untreated material derived from a FS737 Lower Cap in the original T6 (i.e. not RRA treated) temper.

[4] Component condition reports were completed before and after RRA treatment. These are both reported as PID 1.1.
[5] Metaltec Precision International, 292-298 Bay Road, Cheltenham, VIC, 3192.

5.4 Supplementary Tensile Testing (PID 4.5)

Some anomalies were observed in the results of the tensile tests conducted as part of post-sectioning testing. Specifically, tensile specimens from one of the QA specimens (QA1) gave yield and tensile strength results below the MIL-HDBK-5J A-basis allowables. Discussion of the anomalous results at the Stage II CDR led to a mandate for DSTO to conduct further testing in an attempt to explain and resolve these anomalies (Reference 10). To this end, an additional five tensile specimens were machined from QA1 and tested under the same conditions as used previously. After testing the electrical conductivity of all of the tensile specimens derived from the QA specimens was measured and analysed.

6. Results

6.1 Pre-RRA Treatment Results

6.1.1 Initial Component Condition (PID 1.1)

The FS737 Lower Cap Initial Damage Report, given as an annex in Reference 4, showed no visible damage when inspected prior to RRA treatment.

6.1.2 Initial Electrical Conductivity (PID 1.4 and 4.2)

The initial electrical conductivity was measured on both the trial component's web and cap at six locations in the following manner: two locations were situated 300 mm from each end of the trial component and then the remaining four were situated approximately every 500 mm along the trial component on both the cap and the web between the first two locations. The six locations for the electrical conductivity testing of the QA specimens were chosen arbitrarily with five readings (three from the cap and two from the web) averaged for each location. The mean results for each location on the trial component and the QA specimens prior to RRA treatment were reported in Reference 11 and are reproduced in Table 2 and Table 3 respectively

Table 2: Initial electrical conductivity measurements for the FS737 Lower Cap (Reference 11) showing the mean of three measurements taken at each location

Location	Cap (% IACS)	Web (% IACS)
1	32.1	31.8
2	31.9	31.9
3	32.2	32.1
4	32.4	32.0
5	32.1	31.9
6	31.9	31.9
Mean	32.1	31.9

Table 3: Initial electrical conductivity measurements for the QA specimens (Reference 11) showing individual measurements taken

Measurement	QA1 (% IACS)	QA2 (% IACS)	QA3 (% IACS)
1	31.8	32.1	32.1
2	31.7	32.2	32.1
3	31.7	32.1	32.1
4	31.9	32.4	32.3
5	31.8	32.4	32.2
6	31.7	32.3	32.2
Mean	31.8	32.3	32.2

6.1.3 Initial QA Hardness Measurements (PID 4.1)

Rockwell 'B' hardness scale (HRB) measurements were made on each of the QA specimens prior to RRA treatment. Five readings were taken on both the web and the cap of each of the QA specimens. The means of these readings for both the cap and web of each specimen are shown below in Table 4.

Table 4: Initial Rockwell hardness 'B' results for the QA specimens

Specimen	Cap (HRB)	Web (HRB)
QA1	90.1	90.2
QA2	92.0	90.0
QA3	91.9	90.2

6.2 Post-RRA Treatment Results

6.2.1 Initial Component Condition (PID 1.1)[6]

The FS737 Lower Cap Initial damage report, given as an appendix in Reference 4, showed some visible damage in the form of scratches in three locations following RRA treatment. These scratches were an artefact created by the rig used to hold the trial component during the RRA treatment. As such, they were recorded as being insignificant for the purpose of the RRA certification program, though industrial use would require this to be avoided.

6.2.2 Final Electrical Conductivity (PID 1.5 and 4.6)

Tables 5 and 6 present the respectively, final electrical conductivity data for the trial component and QA specimens conducted in accordance with the Process Specification (Reference 5). The measurement locations were the same as tests conducted in the pre-RRA treated condition. These results are also presented in Reference 11.

[6] Although the specimens are in their final, RRA treated state, the term 'Initial' in this context is used for the sake of consistency with the CPCM

Table 5: Final electrical conductivity measurements for the FS737 Lower Cap

Location	Cap (% IACS)	Web (% IACS)
1	38.9	38.9
2	38.5	38.4
3	39.0	39.0
4	39.1*	38.4
5	39.0	38.9
6	38.9	38.8
Grand Mean	38.9	38.7

*** Outside range allowed by Reference 5**

- **Note: The measurements shown at each location is the mean of three readings.**

Table 6: Final electrical conductivity measurements for the QA specimens

Reading	QA1 (% IACS)	QA2 (% IACS)	QA3 (%IACS)
1	38.2	38.3	38.5
2	38.1	38.3	38.5
3	38.2	38.2	38.4
4	38.3	38.3	38.5
5	38.3	38.3	38.5
6	38.3	38.3	38.5
Mean	38.2	38.3	38.5

- **Note: The measurements shown at each location is the mean of five readings.**

With the exception of one, all measured final electrical conductivity values on the trial component (Table 5) were within the 38-39% IACS range mandated by the Process Specification (Reference 5). The electrical conductivity value recorded on the cap at Location 4, i.e. 39.1% IACS, was above the 39% IACS upper bound for allowable final treatment electrical conductivity. However, the measurement tolerance of the meter should be included in the measurement. The Förster Sigmatest Conductivity Meter D 2.068 operating instructions (Reference 16) defines this tolerance as 1% of the reading of the meter. This was taken as 0.3% IACS corresponding to the lowest tolerance that can be guaranteed based on the initial (i.e. pre-RRA) electrical conductivity readings of approximately 31%. No measurement greater than 39.3% IACS was recorded and the mean electrical conductivity recorded was 38.8% IACS. It was therefore agreed at the Stage II Critical Design Review that the above final electrical conductivity measurements effectively complied with the requirements of the Stage II Process Specification and that the next revision of the Process Specification should include a paragraph detailing how to account for such equipment tolerances.

6.2.3 Final QA Hardness (PID 4.4)

Table 7 shows the hardness measured on the surface of the QA specimens following RRA treatment and the change[7] in hardness due to RRA treatment. Hardness was assessed on both Cap and Web separately and each hardness value is the mean of five readings. The change in hardness due to RRA treatment is also shown. As expected this change in hardness was a decrease in hardness.

Table 7: Final Rockwell hardness 'B' results for the QA specimens

Specimen ID	*Cap (HRB)* Mean	Change	*Web (HRB)* Mean	Change
QA1	87.9	-2.2	87.1	-3.1
QA2	90.0	-2.0	87.2	-2.8
QA3	88.9	-3.0	86.1	-4.1

6.3 Post-Sectioning Results

6.3.1 Tensile Results (PID 3.1 and 4.5)

The results of the tensile tests are presented in tabular form without analysis in the NATA-endorsed test report (Reference 12). The results for the specimens machined from the trial component are reproduced here in Table 8 while the tensile results for the specimens machined from the QA specimens are presented in Table 9. Table 10 gives a statistical summary for both sets of specimens and compares these results with the MIL-HDBK-5J requirements. The success criterion for this PID is that the minimum recorded values for all tensile properties are equal to or greater than the MIL-HDBK-5J A-basis values.

Table 8: Tensile testing results for tensile specimens machined from the trial component

Specimen	F_{ty} (ksi)	F_{tu} (ksi)	% Elongation	Specimen	F_{ty} (ksi)	F_{tu} (ksi)	% Elongation
TF-01	76.3	84.7	13.55	TF-11(a)	72.6	81.8	N/A
TF-02(a)	74.8	83.2	12.82	TF-12	72.5	81.9	14.10
TF-03	76.5	84.8	14.96	TF-13	75.3	83.9	12.51
TF-04	74.9	83.2	15.20	TF-14(a)	73.7	82.7	12.00
TF-05	74.3	82.9	12.67	TF-15	75.2	83.7	14.06
TF-06(b)	75.0	83.8	N/A	TF-16	74.4	82.9	14.28
TF-07(b)	75.0	83.9	N/A	TF-17(c)	N/A	N/A	N/A
TF-08	75.0	83.5	15.03	TF-18	76.4	84.9	13.67
TF-09(a)	75.6	83.9	N/A	TF-19	79.0	86.6	14.33
TF-10	75.1	84.1	14.03	TF-20	76.1	84.5	13.96

(a) Failed near extensometer,
(b) Failed near extensometer removing gauge mark (no elongation determination possible),
(c) Damaged prior to test

[7] The change in hardness was calculated as: change = final hardness – initial hardness

Table 9: Tensile testing results for tensile specimens machined from the QA specimens

QA Specimen	Tensile Specimen	F_{ty} (ksi)	F_{tu} (ksi)	Elongation (%)
QA1	TG01	68.6[(a)]	77.1[(a)]	14.1
	TG02	67.6[(a)]	76.4[(a)]	13.7
QA2	TG03	74.4	82.9	12.7
	TG04	74.3	82.7	12.8
QA3	TG05	72.1	81.1[(b)]	12.8
	TG06	72.0	80.9[(a)]	12.5
MIL-HDBK-5J	Minimum	72	81	7

(a) Does not conform to MIL-HDBK-5J requirements, (b) Conforms to MIL-HDBK-5J requirements when rounded to an integer as per standard practice in MIL-HDBK-5J

Table 10: Statistical summary of tensile testing results

	F_{ty} (ksi)			F_{tu} (ksi)			Elongation (%)		
	$\bar{x}$	s	Min.	$\bar{x}$	s	Min.	$\bar{x}$	s	Min.
Trial Component	75.1	1.5	72.5	83.7	1.1	81.8	14.0	0.8	12.5
QA2 & QA3	73.2	1.3	72.0	82.2	1.0	80.9[(a)]	12.7	0.1	12.5
MIL-HDBK-5J[(a)]			72[(b)]			81			7

(a) Values listed are A-Basis. (b) The MIL-HDBK-5J rounds all values to the nearest integer and so 80.9 ksi is equivalent to 81 ksi, which is the allowable minimum

Extension results were not possible for some specimens due to failures outside of the gauged area. This is expected even with correctly designed specimens and is not considered a problem. From Table 10 above, it is apparent that several of the tensile specimens machined from QA1, specifically TG01 and TG02, did not achieve the minimum values required by MIL-HDBK-5J. Given this, an investigation was undertaken to determine a cause of the anomalous properties of the specimens TG01 and TG02. This investigation, which is presented in Appendix B of this report, concluded that specimen QA1 was heat damaged during either post-RRA handling or machining and that the resulting tensile properties from these tests must be excluded from compliance.

6.3.2 Corrosion Results (PID 3.2 and CID 3.5)

Although material properties, including corrosion resistance, were determined during Stage I of RRA certification (Reference 2), the DSTO decided to assess the corrosion resistance due to RRA in Stage II. Therefore, the resistance of RRA-treated AA7075-T6 to exfoliation corrosion and SCC was tested. These two types of corrosion were selected as RRA is purported to greatly decrease their damaging effect on AA7075-T6. A DSTO minute (Reference 14) describes the results of the corrosion trials undertaken by DSTO, but the results are also summarised in the following Sections.

6.3.2.1 Stress Corrosion Cracking

Ten (10) SCC Double Cantilever Beam (DCB) specimens were manufactured from the FS737 Lower Cap that had been RRA-treated as a part of Stage II Certification (Reference 4). Another ten (10) specimens were machined as control specimens from an untreated FS737 Lower Cap (i.e. it was in the T6 condition). This untreated component was the same as that from which the Quality Assurance (QA) specimens had been extracted. The DCB SCC tests were conducted according to ASTM G168-00 (Reference 17). In designing and machining these specimens it is noted that §7.1.4 of ASTM G168-00 (Reference 17) states that:

> *'The specimen half-height, H, may be reduced for material under 25 mm (1 in) thick. The minimum H that can be used is constrained by the onset of plastic deformation upon pre-cracking'*.

The specimens were therefore designed with the largest possible half-height within the restriction of the thickness of the available material. Specimens with 6 mm total height were the largest that could be produced from a FS737 Lower Cap. This critical dimension was determined by the thickness of the component. Chevron notches were used to increase the likelihood of successful testing without plastic deformation occurring in the arms of the specimens. The use of control specimens of the same dimensions and machined from an untreated FS737 Lower Cap ensured that some comparative data could be obtained even if the tests did not produce plane-strain loading conditions.

ASTM G160-00 requires that the specimens be pre-cracked prior to corrosion testing either by overloading or by fatigue. Figure 4(a) shows a DCB specimen prior to attempting overloading. Initial attempts to overload the control specimens were successful in creating a pre-crack (Figure 4(b)). However, a stable pre-crack could not be formed in the RRA-treated specimens (Figure 5), instead deviating from the centre-line[8]. This difference in behaviour was attributed to the greater fracture toughness of the RRA-treated material resulting in a larger plastic zone and shear stress prior to fracture. Subsequent attempts to initiate pre-cracks in the RRA-treated DCB specimens by cooling the specimens in liquid nitrogen to reduce the fracture toughness also failed to produce a stable pre-crack. Examination of the specimens that were treated in this manner showed that a crack initiated in the chevron notch (shown undamaged in Figure 5(a)) and turned following an initial growth period along the desired plane to form a ductile fracture along a shear plane (Figure 5(b)). This behaviour suggests that pre-cracking was unlikely succeed as the bending moment required to extend the crack would cause the crack to veer away from the required plane. That is, the crack will not grow in a stable manner along the longitudinal plane of the specimen.

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[8] In this context, 'stable' is defined as a pre-crack that grows along the central longitudinal plane of the specimen and does not deviate at an angle either upwards or downwards from that plane.

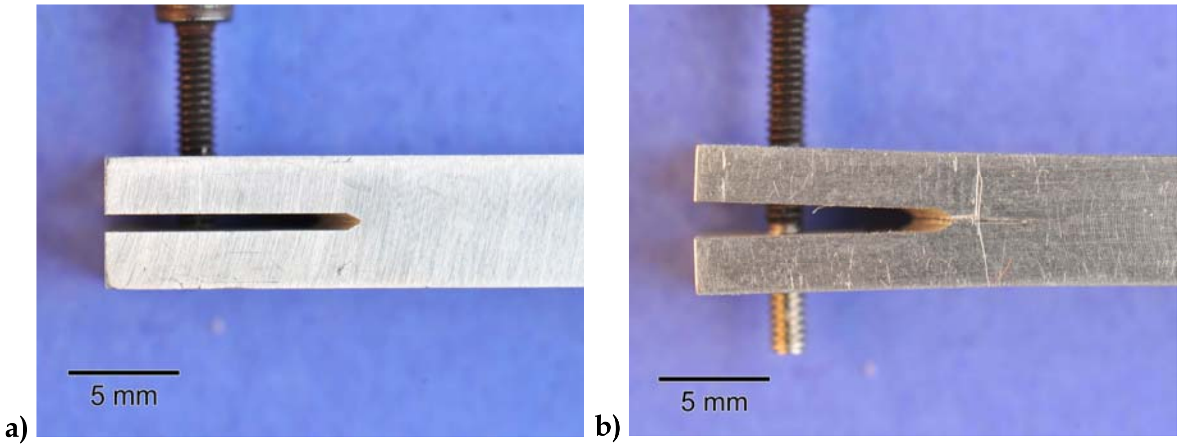


Figure 4: a) Unloaded Control 7075-T6 DCB specimen. b) Pre-cracked Control 7075-T6 DCB specimen.

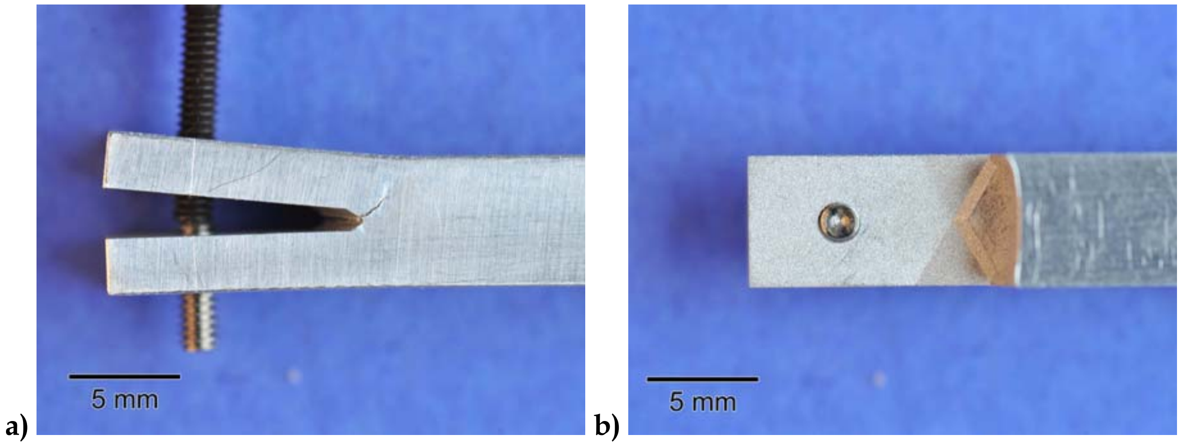


Figure 5: a) Side view of failed RRA-treated 7075-T6 DCB specimen showing failure by shearing. b) Top down view of failed RRA-treated 7075-T6 DCB specimen showing in-plane crack along the chevron notch that preceded failure by shearing.

It was recognised in producing the Component Test Plan (Reference 9) that the small specimen size necessitated by the thickness of the FS737 Lower Cap introduced a risk of the DCB specimens failing to produce stable pre-cracking. For this reason, exfoliation corrosion resistance tests were included in the Component Test Plan as a complement to the SCC tests and the effect of RRA treatment on corrosion resistance will consequently be demonstrated by exfoliation resistance alone.

6.3.2.2 Exfoliation Corrosion

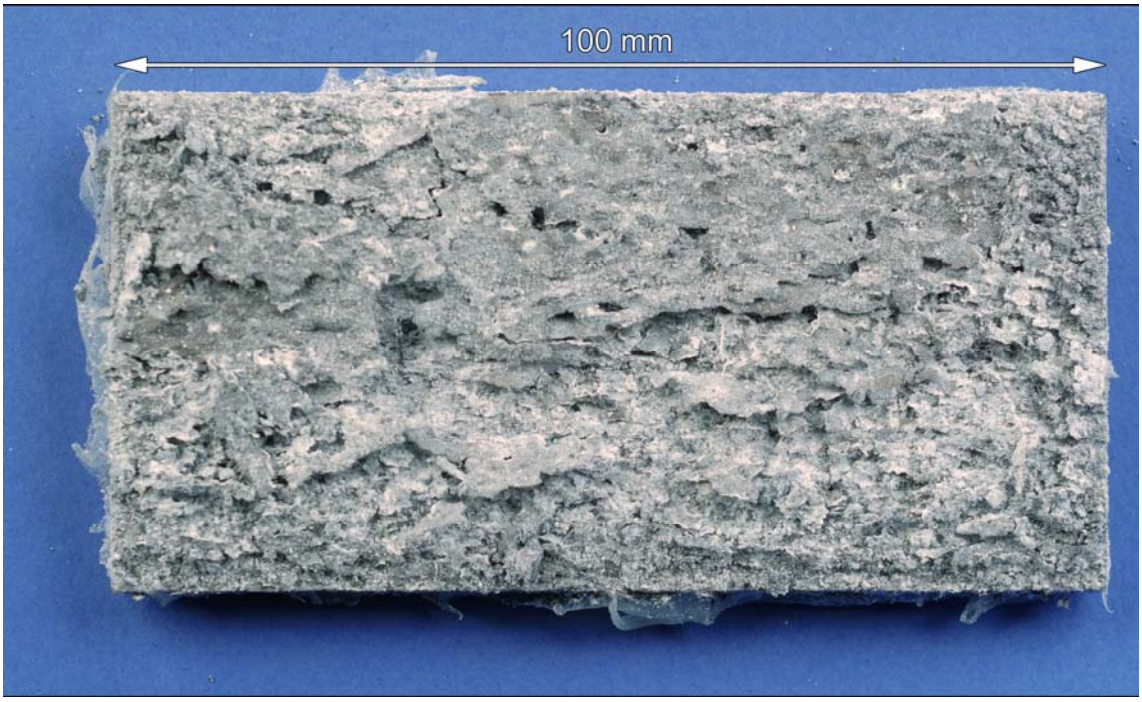
Exfoliation testing was performed according to ASTM G34-01 (Reference 18) using 3 mm thick flat plate specimens with surface dimensions 100 mm x 50 mm (Reference 14). Two (2) specimens were machined from the trial component (Reference 4) and another two (2) specimens were machined from material from the same untreated component the QA specimens were produced from. All four specimens were submerged in EXCO solution for 48 hours with specimen monitoring after 1, 4 and 24 hours exposure to see if the corrosion had progressed beyond the specified maximum level (Reference 18). Following exposure, the specimens were cleaned using distilled water, visually inspected, photographed (Figure 6 and Figure 7) and given a letter rating according to ASTM G34-01. The results of the DSTO exfoliation corrosion tests are presented in Table 11.

Table 11: Results of exfoliation testing by heat treatment

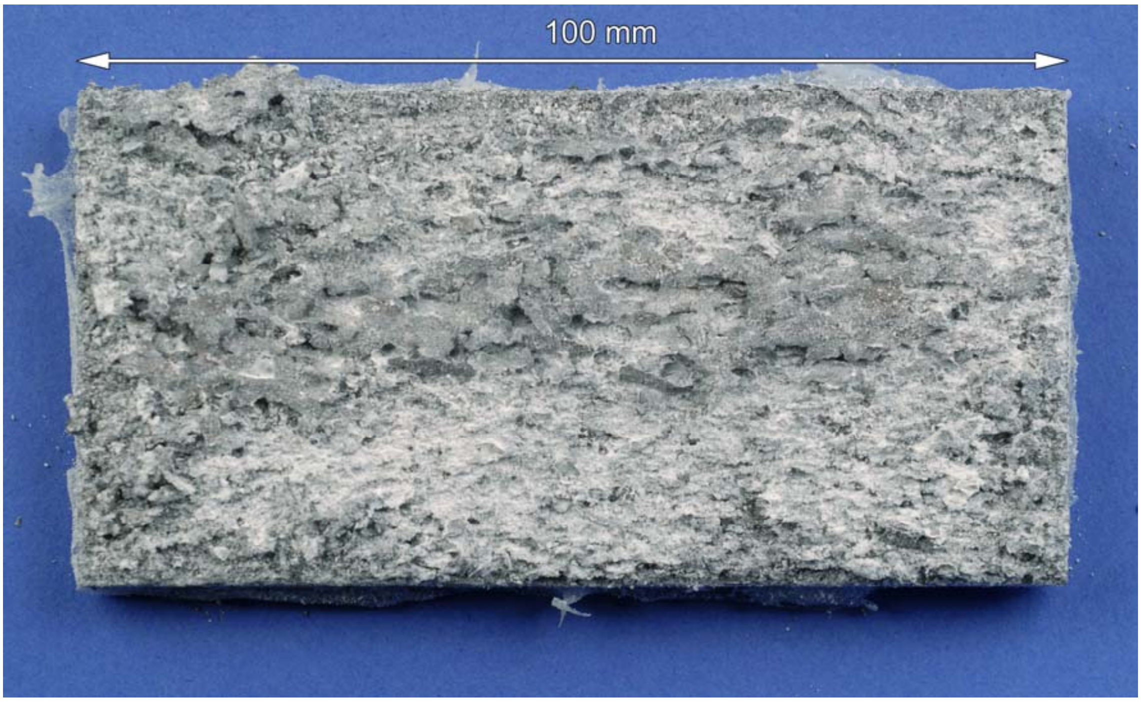
Heat Treatment	RRA	T6
Product Form	Extruded T-section 0.30 inch (7.62 mm) thick	
Number of Specimens	2 (EA01 & EA02)	2 (EB01 & EB02)
Rating	P	EC

The rating of the RRA-treated material was determined to be 'P', indicating discrete pitting, is an improvement of three rating steps from the 'EC' rating (moderate to severe exfoliation) determined for the extruded untreated (T6) material. This confirms that the exfoliation corrosion performance of the RRA treated material is significantly improved compared to the untreated (T6) material.

The 'EC' rating for AA7075-T6 is consistent with the findings published in MIL-HDBK-5J (Reference 1) and is the second-worst rating possible. An EXCO rating of 'P' for the RRA-treated material indicates an exfoliation corrosion resistance similar to that of AA7075-T73 which is also rated P in MIL-HDBK-5J (Reference 1).



a)



b)

Figure 6: Exfoliation corrosion control specimens manufactured from AA7075-T6 material following 48 hours exposure to EXCO solution. a) Specimen EB01 , b) Specimen EB02. Both specimens were rated as 'EC' (moderate to severe exfoliation; Reference 18).

a)

b)

Figure 7: Exfoliation corrosion, RRA-treated AA7075-T6 specimens following 48 hours exposure to EXCO solution. a) Specimen EA01 b) Specimen EA02. Both specimens were rated as 'P' (discrete pitting; Reference 18).

6.3.3 Dimensions (CID 1.1)

The Stage II Metrology Report (Reference 13) describes the metrology results obtained from two separate trials of the DSTO implementation of RRA treatment. The first of these trials was conducted in 2008 at Qantas Defence Services (QDS)[9] and was found to produce maximum distortions in the component of about ±1 mm. The second trial was conducted at BACR and is the trial reported in detail in this report. No initial dimensions were recorded for the trial component treated at BACR. These results were therefore inconclusive and it was necessary to conduct metrological examinations on the three components RRA-treated in Stage III of RRA Certification to obtain the required data.

The metrological results of these Stage III examinations are detailed in Reference 19 and summarised in Table 12 below. A decrease in length of between 1.1 and 2.0 mm was observed. The mid-section Z height of the components decreased by between 0.95 and 1.5 mm. Figure 8 shows, at a greatly exaggerated scale, the effect of these changes on the curvature of the Stage III trial components.

Table 12: Results of metrological examination of FS737 Lower Cap components

Component	**Overall Length (mm)**			**Mid-Section Z Height (mm)**		
ID	**Initial**	**Final**	**Change**	**Initial**	**Final**	**Change**
1	3119.10	3117.10	-2.00	-265.95	-267.40	-1.45
2	3119.50	3118.30	-1.20	-265.90	-267.40	-1.50
5	3120.00	3118.90	-1.10	-266.40	-267.35	-0.95
Mean	3119.53	3118.10	-1.43	-266.08	-267.38	-1.30
Range	0.90	1.80	-0.90	-0.50	-0.05	-0.55

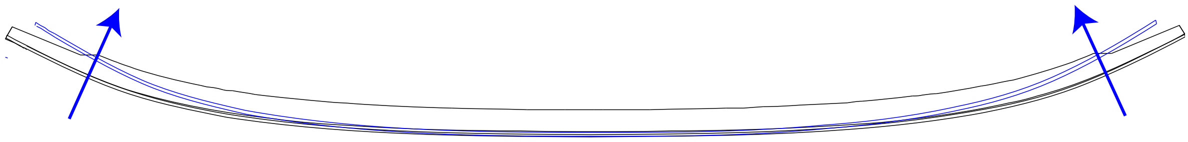


Figure 8: Schematic drawing showing, at an exaggerated scale, how RRA treatment slightly increased the curvature of the component. Arrows show the direction of movement and partial outline shows final configuration of the cap of the component. The web has not been illustrated in its final state for clarity.

The lack of OEM engineering drawings for this component means that it was not possible to compare the above data with an authoritative source. It was therefore decided to calculate approximately the load required to produce the observed deflection (i.e. the mid section Z height) by modelling the components as thin cantilever beams using the Euler formulae for such beams. Specifically, as the beam was clamped to the workbench in the middle during metrology each end of the beam can be treated as a separate cantilever beam of 1560 mm length. Full details of this calculation can be found in Reference 19. It was found that a deflection of 1.5 mm would require a force of 31 N (3.2 kgf) applied at each end of the beam. Therefore, the total force to deflect both ends of the beam would be 62 N (6.4 kgf) Furthermore, it was estimated that the beam's deflection under its own

[9] QANTAS Defence Services (QDS), Airport Drive, Mascot, NSW 2020.

weight would be approximately 0.75 mm, which is of the same order of magnitude as the deflection due to RRA treatment. These two calculations suggest that the observed distortion of the component due to RRA may be considered negligible.

7. Summary of Compliance with the PRCM

The following are the requirements as identified by the PRCM in the Stage II RRA DDP (Reference 3). Each requirement is rated as '**Compliant**', '**Non-Compliant (Acceptable)**' or '**Not-Demonstrated**' in accordance with the Technical Airworthiness Management Manual (TAMM) (Reference 20). Note that, in the case of a conflict between this report and the PSCR, the results in this section supersede those in the corresponding section in the PSCR.

7.1 PID 1.1: Initial Component Condition

The trial component was purchased new from QDS and assessed by DSTO as having 'not been in-service' (i.e. new). This assessment was made as the trial component lacked the machined holes (i.e for bolts and rivets) that would be required to mount it on an aircraft. Additionally, no evidence of surface treatments such as shot-peening or cold working to induce residual stresses were evident.

The trial component was examined by BACR before RRA treatment and no damage was found. Following RRA treatment, a second examination was performed and scratches on three areas of the trial component were found. This is reported in the completed 'FS737 Lower Cap Initial Component Condition Report' (Reference 4). Examination by DSTO staff indicated that the scratches were minor, and had probably been caused either by the mechanism used to hold the trial component or by the trial component hitting the edge of the quench tank during quenching. Significantly, the scratches were not a result of the RRA process itself. This property is assessed as being '**Compliant**'.

7.2 PID 1.2: Alloy Identification and Initial Temper

The trial component was an extruded T-section of AA7075-T6 as per SAE AMS-QQ-A-200/11. The part number was verified by inspection of the invoice received from QDS upon receipt of the component. The alloy identification and initial temper of this part number was verified by inspection of Lockheed Martin drawing 356251 (Reference 21). This property is assessed as being '**Compliant**'.

7.3 PID 1.3: As-Extruded Short Transverse Thickness

The FS737 Lower Cap has a specified thickness of 0.312 inch on the cap and 0.25 inch on the web. These values are less than the maximum 1.0 inch thickness allowed and the minimum is the same as the lower bound of 0.25 inch allowed by the Process Specification. The cross sectional measurements of the component extrusion were obtained from Figure 51-130-06 in AAP7211.031-3-3 (Reference 21) provided by Air Lift Systems Program Office (ALSPO). This property is assessed as being '**Compliant**'.

7.4 PID 1.4: Initial Electrical Conductivity

The measured initial electrical conductivity, Table 2, had values between 31.8%IACS and 32.4%IACS. These were within the range of 31 to 35% IACS specified by the Process Specification (Reference 5). This property is assessed as being '**Compliant**'.

7.5 PID 1.5: Final Electrical Conductivity

With one exception, all measured final electrical conductivity values (Table 5) were within the range 38 to 39% IACS specified by the Process Specification (Reference 5). The electrical conductivity value recorded on the cap at Conductivity Station 4, (i.e. 39.1% IACS), was slightly above the 39%IACS upper bound. However, the mean electrical conductivity readings for both the cap and the web were within the required range. The Process Specification (specifically §4.7.2) does not allow for a measurement tolerance. The next revision of the Process Specification will address this issue. After discussion at the Stage II CDR, this property is assessed as being '**Compliant**'.

7.6 PID 2.1: Authorised Maintenance Organisation (AMO) Status

The AMO status of BACR was confirmed by OIC CMSA3 - DAVCOMP (Directorate Air Vehicle Compliance) on 9/4/09. Copies of the Letter of Maintenance Authority (LMA) (Reference 22) and Maintenance Authority Certificates (MAC) for BACR (Reference 23) were supplied for verification. This property wis assessed as being '**Compliant**'.

7.7 PID 2.2: Ability to Heat Treat Aluminium Alloys

The LMA and MAC (References 22 and 23) for BACR do not include authorities for the heat treatment of aluminium alloys. However:

(i) BACR are approved by the Civil Aviation Safety Authority (CASA) for the processing of composite aircraft components and the requirements for the thermal treatment of composites are more stringent than those for treating aluminium alloys; and

(ii) DSTO staff conducted an inspection and trial of the oven facility at BACR and were satisfied that it is capable of successfully performing the heat treatment defined in the Stage II Process Specification with the required level of control (Reference 5). BACR's CASA Certificate of Approval is reproduced in the PSCR (Reference 4).

Discussions held at the Stage II CDR concluded that while the above measures were sufficient justification for the current trial, they would not be sufficient for generic use of RRA technology on RAAF aircraft components (Reference 10). This is because the use of RRA on new components is regarded as a construction activity and not a maintenance activity by the RAAF. Therefore, it was further suggested that DSTO approach the Directorate of Aviation Regulation (DAVREG) within the Directorate General Technical Airworthiness (DGTA) for guidance regarding the upcoming regulations controlling construction of aircraft materiel. This property is assessed as being '**Compliant**' for the purpose of the trial only.

7.8 PID 2.3: Furnace Classification

According to its latest calibration certificate the BACR oven is a Class 4 furnace, (Reference 4). This is superior to the requirements of a Class 5 furnace, which is the class of furnace mandated in the Stage II Process Specification. This property is assessed as being '**Compliant**'.

7.9 PID 2.4: Furnace Calibration

The calibration certificate of the BACR oven was issued by Australian Calibrating Services on 26 November 2008 and was valid for six months from that date with the date of the next calibration being scheduled for 24 May 2009 (Reference 4). This trial was conducted on the 21 and 22 April, 2009, which falls within this calibration period. The calibration report is also NATA compliant and stated that the measured temperature variation at 180 °C was 7.51 °C.

The internal dimensions of the furnace enclosure were 2500 mm high, 3680 mm wide and 6200 mm deep. The test volume was 200 mm from the floor and roof and 100 mm from the walls. The trolley used for the quench system ensured that the trial component was 400 mm from the oven floor and the placement of the trolley in the oven was greater than 100 mm from the oven walls. This property is assessed as being '**Compliant**'.

7.10 PID 2.5: Thermocouple Calibration

Six thermocouples were placed on the component: four DSTO thermocouples and two BACR thermocouples. The DSTO thermocouples Serial Numbers (SN) 5358, SN: 5360 and SN: 5361 were attached to the component and were designated as thermocouples 1, 3 and 4. Thermocouple SN5359 was attached to a QA Specimen (Specimen QA2). These thermocouples were calibrated by FastLab Calibration Laboratory on 13/11/2008, (Reference 24). The remaining three DSTO placed thermocouples were calibrated by secondary calibration from these (Reference 15). This property is assessed as being '**Compliant**'.

7.11 PID 3.1: Tensile Properties

The measured tensile properties (tensile yield, tensile ultimate strength and elongation) of specimens manufactured from the trial component (Reference 12) were above the A-basis values set by the MIL-HDBK-5J (Reference 1). This property iss assessed as being '**Compliant**'.

7.12 PID 3.2: Corrosion

The limitations placed on the dimensions of the DCB specimens by the available material thickness prevented SCC testing of RRA-treated material from the trial component. However, the exfoliation resistance ratings are summarised in Table 11. The RRA-treated material was rated 'P', indicating discrete pitting. This is an improvement by three rating steps from the EC rating of the extruded untreated (T6) material. The EC rating for AA7075-T6 is consistent with the findings published in MIL-HDBK-5J (Reference 1) and is the second-worst rating possible. An EXCO rating of P for the RRA-treated material indicates an exfoliation corrosion resistance similar to that of AA7075-T73 which is also rated P in MIL-HDBK-5J (Reference 1). This property is assessed as being '**Compliant**'.

7.13 PID 4.1: QA Initial Hardness

The initial hardness values of the QA specimens is summarised in Table 4. All hardness values were consistent with those of AA7075-T6 alloy (Reference 2). As there is a requirement only for these to be taken, but no requirement for assessment, this property is deemed '**Non-Compliant (Acceptable)**'.

7.14 PID 4.2: QA Initial Electrical conductivity

The initial electrical conductivity of the QA specimens is summarised in Table 3. All values were within the limits allowed by the Process Specification (Reference 5). This property is assessed as being '**Compliant**'.

7.15 PID 4.3: RRA Heat Treatment Stability

The National Research Council of Canada has observed no systematic variation in electrical conductivity for RRA-treated AA7075-T6 over a three month period after treatment (Reference 25). This property was assessed as being '**Compliant**'.

7.16 PID 4.4: QA Final Hardness

The final hardness values of the QA specimens are summarised in Table 7. All recorded values are consistent with the hardness values obtained previously for RRA-treated material (Reference 1). As there is no formal requirement for hardness values in the Process Specification, this property is deemed '**Non-Compliant (Acceptable)**'.

7.17 PID 4.5: QA Tensile Properties

The tensile properties (tensile yield, tensile ultimate strength and elongation) of specimens manufactured from two of the three QA specimens (Reference 12) were above the A-basis limits set by the MIL-HDBK-5J (Reference 1). Investigations determined that the QA specimen for which low tensile results were detected had undergone a heating event during tensile specimen manufacture and that the anomolous tensile properties were not a result of RRA treatment. This property is assessed as being '**Compliant**'.

7.18 PID 4.6: QA Final Electrical Conductivity Measurements

All of the measured final electrical conductivity values for the QA specimens, (Table 6), were within 38 to 39%IACS range specified by the Process Specification (Reference 5). This property iss assessed as being '**Compliant**'.

7.19 PID 5.1: Data Device Calibration

The NATA compliant BACR furnace calibration report was issued by Australian Calibrating Services on 26 November 2008 and is valid for six months with the next calibration being scheduled for 24 May 2009. The Controller Measured Temperature is included in the calibration report covering the data acquisition system used by BACR. The DSTO dataTaker was model DT85 (serial #085024). The calibration certificate for this device has a NATA Certified Reference Fluke 8840A Serial 5141011 (Reference 15). This property was assessed as being '**Compliant**'.

8. Summary of Compliance with the CPCM

The following are the requirements as identified by the CPCM in the Stage II RRA DDP (Reference 3). Each requirement is rated as '**Compliant**', '**Non-Compliant (Acceptable)**' or '**Not-Demonstrated**' as per Reference 20.

8.1 CID 1.1: Dimensions

This compliance item requires that the '*component dimensions and shape should not change beyond levels allowed by manufacturing specification*' for the trial component. To assess the compliance of the trial component with this requirement ALSPO approached the RAAF Technical Liaison Officer at Warner Robbins Air Force Base to obtain engineering drawings of the FS737 Lower Cap for comparison with the metrology scans that were conducted as part of this trial (§6.3.3) and the earlier trial conducted at QDS (Reference 15). These drawings were received after the Stage II Critical Design Review. The drawing numbers and titles are listed in Table 13.

Table 13: Assembly drawings of Fuselage Station 737 provided to the DSTO

Drawing Number	Title	Sheet
356251_1_AN	Bulkhead Assembly – FUS STA 737	1/5
356251_2_U	Bulkhead Assembly – FUS STA 737	2/5
356251_3_AM	N/A	3/5
356251_4_AN	Bulkhead Assembly – FUS STA 737	4/5
356251_5_AK	N/A	5/5

Review of these drawings showed that they were assembly drawings and not manufacturing drawings. While they did have some dimensions for various parts of the FS737 Lower Cap, they do not provide overall dimension and tolerances of the component. This meant that they cannot be used to establish the compliance of the trial component with this compliance item. In addition, the distribution of the drawings is restricted by ITAR[10], which means they cannot be provided to unapproved third parties for comparison with the trial component and cannot be reproduced in this report. However, the drawings do give some generic tolerances, which are reproduced in Table 14 below. These tolerances however are likely to only relate to the fitting of the component

[10] International Traffic in Arms Regulations

and not its manufacture. The drawings also give the drawing number of the manufacturing (#355111) and finish (#355000) drawings. These latter drawings were obtained and found to contain no relevant information.

Table 14: Drawing tolerances given in OEM drawings

Fractions	Decimals			Angles
	X.X	X.XX	X.XXX	
±1/16	±0.1	±0.03	±0.010	±2°

Since the FS737 lower cap provided do not provide definitive information on the tolerances of the FS737 Lower Cap this compliance item has not been satisfied using the Stage II data. Additionally, the analysis described in the Stage II component metrology report (Reference 13) and summarised in §6.3.3 was inconclusive. As such, this compliance item could not be demonstrated using the above data and it was necessary to carry it over to Stage III of RRA certification. The Stage III DDP (Reference 26) included a requirement for three further trials of the RRA process on three separate FS737 Lower Caps. Complete metrology data were obtained from all three of these trials and analysed (Reference 19). It was found that the distortion due to RRA was very small. An approximate calculation using Euler's formula for thin cantilever beams suggested that the observed deflection could be produced by applying a load of 31 N (3.2 kgf) to each of the component's ends when it was clamped to a bench at its midsection[11]. Similar deflections would be caused by the component's own weight. As a result, it was concluded that RRA produced no significant distortion of the component. This property is therefore assessed as being '**Non-Compliant (Acceptable)**'.

8.2 CID 1.2: Final Surface Finish

The final surface finish was determined by visual analysis to be unaffected by RRA treatment; RRA treatment temperatures are too low to cause oxidation and no mechanical deformation is caused by the RRA process. This property is assessed as being '**Compliant**'.

8.3 CID 1.3: Weight

The total weight of the trial component was determined by analysis to be unaffected by RRA treatment. The temperatures used in RRA treatment are too low to cause melting, oxidation or vaporisation and RRA treatment involves no bulk material addition or removal. As such no change in mass, and therefore weight, can occur. This property is assessed as being '**Compliant**'.

8.4 CID 1.4: Balance

The temperatures used in RRA treatment are too low to cause melting, oxidation or vaporisation and RRA treatment involves no bulk material addition or removal. As such

[11] Holding the components in this way is a reasonable approximation of how the components were clamped to the workbench during metrology.

no change in mass distribution, and therefore weight distribution, can occur. This property was assessed as being '**Compliant**'.

8.5 CID 2.1: Structural Strength

The strength of the trial component's material was addressed in Stage I RRA Certification (Reference 2) which determined that RRA treatment did not detrimentally affect this material property. The structural strength of the component was also assessed by tensile testing of specimens manufactured from the component and QA specimens (Reference 12) which showed no reduction below the A-basis allowables in MIL-HDBK-5J. This property is assessed as being '**Compliant**'.

8.6 CID 3.1: Fatigue Life – Material Performance

Material effects on fatigue life were addressed in Stage I RRA certification which determined that RRA treatment produced no detrimental effect on this property (Reference 2). This property is assessed as being '**Compliant**'.

8.7 CID 3.2: Fatigue Life – Stress Modification

Inspection showed no evidence of treatments to modify residual stresses (shot peening or cold working). DSTO research has shown that RRA treatment relieves residual stresses induced by such processes. This property is assessed as being '**Compliant**'.

8.8 CID 3.3: Fatigue life -Initiation

Initiation effects on fatigue life were addressed in Stage I RRA certification which determined that RRA treatment produced no detrimental effect on this property. This property is assessed as being '**Compliant**'.

8.9 CID 3.4: Fatigue Crack Growth

Fatigue Crack Growth was addressed in Stage I RRA certification which determined that RRA treatment produced no detrimental effect on this property (Reference 2). This property iss assessed as being '**Compliant**'.

8.10 CID 3.5: Corrosion Resistance - Stress Corrosion Cracking

This property was reported in PID 3.2 (§7.12). RRA treatment increased corrosion resistance. This property is assessed as being '**Compliant**'.

8.11 CID 3.6: Corrosion Resistance – Dissimilar Metals

Since the alloy composition remains the same, RRA treatment is not expected to require practices different from those currently used for AA7075-T6 and AA7075-T7 components. The use of primer and wet-sealed fasteners should provide adequate protection. This property was assessed as being '**Compliant**'.

8.12 CID 4.1: Primer and Pre-Treatment

DEF(AUST)9001 (Reference 27) requires all aluminium alloys in ADF aircraft to be primed and pre-treated in the same manner. RRA-treated alloys are largely identical to AA7075-T6 and AA7075-T73 and should not require a change in primer or pre-treatment. This property is assessed as being '**Compliant**'.

8.13 CID 4.2: NDI Practices

The issue of the effect of RRA treatment on NDI practices was discussed with Mr Peter Virtue, a DSTO NDI specialist with extensive experience with the practical application of NDI methods to ADF aircraft and components (Reference 28). The effects of RRA on visual, eddy current, radiographic, ultrasonic, die penetrant and ferromagnetic methods were considered separately. The conclusions from this discussion are as follows:

- Visual inspection: RRA treatment produces no change in the surface appearance of the component and will not interfere with visual examination.
- Eddy current inspection (EC): RRA produces a minor increase in electrical conductivity which may be accounted for during the initial set-up of the NDI apparatus.
- Radiographic inspection (X-ray): RRA treatment will not produce any change in x-ray atomic cross-section and will therefore not require changes to radiography procedures.
- Ultrasonic Inspection (UT): RRA treatment will change neither the elastic modulus nor the density of the material which control the propagation of sound in materials. Therefore it will not effect ultrasonic NDI techniques.
- Dye Penetrant inspection (DPI and FPI): Die Penetrant examination is already used routinely on overaged high-strength aluminium alloys. As such no change in practices is expected and will be readily accommodated.
- Ferromagnetic inspection (PMI): cannot be performed on aluminium alloys so will not be affected by RRA treatment.

This property is assessed as being '**Compliant**'.

8.14 CID 4.3 Machinability

The issue of the effect of RRA treatment on machinability was discussed with Mr Bruce Grigson, a DSTO metrology and machining specialist with extensive experience (Reference 29). The conclusions reached in this discussion were that RRA treatment will not require a tooling change since RRA-treated and untreated material have similar mechanical and therefore machining properties. The machining of metals is largely influenced by their hardness, which relates directly to strength. This property was assessed as being '**Compliant**'.

8.15 CID 4.4: Repairability

RRA-treated components have properties that meet the mechanical property requirements of MIL-HDBK-5J (Reference 1). As such the repair methods used for untreated components will be applicable to RRA-treated components with minor changes. Specifically, structural repairs to RRA-treated components should account for the altered heat treatment of the components. Consideration should be given to using RRA-treated materials in any straps or doublers used in repairing a RRA-treated component. However, the material used to make these straps and doublers would also need to conform to the material requirements for RRA treatment as outlined in the PRCM and the CPCM. If this is not the case then the straps or doublers would need to be made from their conventional materials without RRA treatment. This property is assessed as being '**Compliant**'.

8.16 CID 4.5: Replaceability

The referenced standard for this item is MIL-I-8500D (Reference 30). An RRA-treated component cannot be visually distinguished from an untreated component and has been shown to have the same mechanical properties relative to MIL-HDBK-5J. However, while the component may look identical dimensional changes due to RRA treatment may prevent its fitting to an aircraft. This item is therefore dependant on CID 1.1. Given that this earlier compliance item has been rated as '**Non-Compliant (Acceptable)**' (§8.1) this property is also assessed as being '**Non-Compliant (Acceptable)**'.

9. Compliance Matrices

The PRCM and CPCM are included as Appendix B and Appendix C, respectively, in this report. These matrices have been duplicated from the Stage II DDP and the compliance results from §7and §8 have been added to them. Specifically, this means that the 'Compliance Method Justification/Comments', 'Compliance Result' and 'Reference to Documentary Evidence' columns have been completed.

10. Process Specification Revision Recommendations

This section discusses the implications of all aspects of the industrial trial for further development of the Process Specification.

10.1 Quality Assurance Specimens and Destructive Testing

A number of the properties identified in the PRCM were noted as being for trial only. These properties relate to the use of QA specimens, destructive testing of the component and the use of an independent data acquisition system. While destructive testing of the component must be removed from the requirements of a production stage heat treatment, the value of the items relating to QA specimens will need to be assessed with regards to meeting requirements for practicality, verification and acceptance criteria for any future revision of the Process Specification

The tensile testing of quality assurance specimens in the heat treatment of wrought aluminium products assumes that the results from these tests are representative of the rest of the material being processed. Normally, the source material for the tensile specimens is a random component selected for destructive testing from the batch being processed (Reference 5). However, there is no guarantee of any correspondence between the properties of different components purchased by the ADF as they are unlikely to come from the same product lot. Therefore, QA specimens from another source material cannot be used to infer the properties of these components.

Quality assurance for RRA technology comes from the demonstrated link between the heat treatment parameters, the final electrical conductivity of RRA-treated material and the resulting mechanical properties that result from these. This link was proven to the high degree of statistical significance required by MIL-HDBK-5J in the Reference 1. Therefore, the continued use of QA specimens beyond the Stage II Certification will not provide any additional benefit and their use should be discontinued.

10.2 Furnace Classification

Additional revision of the Process Specification will be necessary as the preliminary trials determined that the classification of the furnace in the standard manner (Reference 31) does not provide enough information on the suitability of a furnace to carry out a RRA treatment. The temperature uniformity requirements of the various furnace classes as per SAE AMS2750D are given in Table 15.

Table 15: Furnace classes as defined in SAE AMS2750D (Reference 31)

Furnace Class	Temperature Uniformity Range (Degrees F)	(Degrees C)	Notes
1	±5	±3	
2	±10	±6	Classification of QDS oven
3	±15	±8	
4	±20	±10	Classification of BACR oven
5	±25	±14	Required by Stage II Process Specification
6	±50	±28	

The following argument is used to demonstrate how furnace classification according to SAE AMS2750D is inadequate for defining suitability for RRA treatment:

1. Oven classification as defined in SAE AMS2750D (Reference 31) is a measure of the temperature uniformity of an oven at equilibrium.
    a. Temperature uniformity is defined in SAE AMS2750D as: 'the uniformity of the temperature of the furnace as measured by a number of thermocouples spaced throughout the working volume of the furnace'.
    b. Equilibrium is interpreted in SAE AMS2770H (Reference 32) as: 'a constant temperature (within the constraints of the furnace classification) for a period of 20 minutes for an unloaded furnace and 40 minutes for a loaded furnace'.

2. The retrogression phase of the RRA process as defined in the Stage II Process Specification is approximately one hour in duration, which means that the time taken for the oven to reach uniformity is a large percentage of the retrogression time.
3. As a result of 1 and 2, furnace class is a poor measure of the ability of an oven to undertake RRA treatment and should not be relied on.
4. The short duration of the retrogression phase means that the performance of an oven during heating needs to be measured directly.
5. For the demonstrator stage of RRA certification, the performance of the BACR oven was assessed by direct testing (Reference 15). Using this method the BACR oven was found to be able to sustain a temperature delta along a similar component of 7.4 °C degrees.

Accordingly, it is recommended that future versions of the Process Specification include a note that furnace class is not a sufficient measure of oven performance, and a requirement for direct testing of oven performance. The purpose of these tests will be to measure the ability of the oven to maintain a small temperature gradient (less than 10 °C) in the component undergoing treatment at all times during processing.

10.3 Recommendations from the Process Specification Compliance Report

The PSCR (Reference 4) found that some aspects of the Stage II Process Specification did not adequately describe the process such that it could be followed by a heat treatment organisation without additional clarification. Therefore a series of changes should be made to the Process Specification as part of its next release. The recommended changes are:

1. Clarification that the retrogression time count should start from the time the component first reaches 181 ºC, and not the oven set point or oven air temperature.
2. The Stage II Process Specification currently states that the component should be placed in the oven and then pre-heated to 120 ºC for the re-ageing stage. It should state that component should be placed in the oven first and then heated up to 120 ºC.
3. Tolerances should be added to both the retrogression time and the temperature ramp rate.
4. Data collection rates of 1 Hz (60 data point per minute) are more appropriate for a laboratory trial than for industrial use. Collection rates of 0.2 Hz (12 data points per minute) for the retrogression and 0.0167 Hz (1 data point per minute) for re-ageing are considered by the DSTO to be appropriate for RRA treatment under industrial conditions.
5. The maximum temperature variation allowed across a component should be explicitly stated.
6. The final electrical conductivity definitions must include an allowance for the tolerance inherent in the measurement technique. Specifically, the measurement error of the electrical conductivity meter needs to be accounted for.

10.4 Other Recommendations

As noted in §6.1.2 the Stage II Process Specification is unable to account for the effect of initial electrical conductivity on the retrogression time required to achieve a target final electrical conductivity. The next revision of the Process Specification should therefore contain a chart or table that allows the selection of an appropriate retrogression time as a function of initial electrical conductivity.

11. Conclusions

This report describes a trial of the RRA process specification on a real aircraft component using industrial equipment. The trial has shown that the RRA process as defined in the Stage II RRA Process Specification can be successfully applied in an industrial environment on an aircraft component. All properties described by items in the compliance matrices received recommended ratings of either '**Compliant**' or '**Non-Compliant (Acceptable)**'. Of the 35 items in the compliance matrix only four received ratings of '**Non-Compliant (Acceptable)**', but that was only due to the absence of a suitable compliance specification for these items. The trial revealed a small number of deficiencies in the Stage II Process Specification which will be corrected in a subsequent version of the document.

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Appendix A: RRA Industrial Trial Cutting Diagram for Post Sectioning Tests

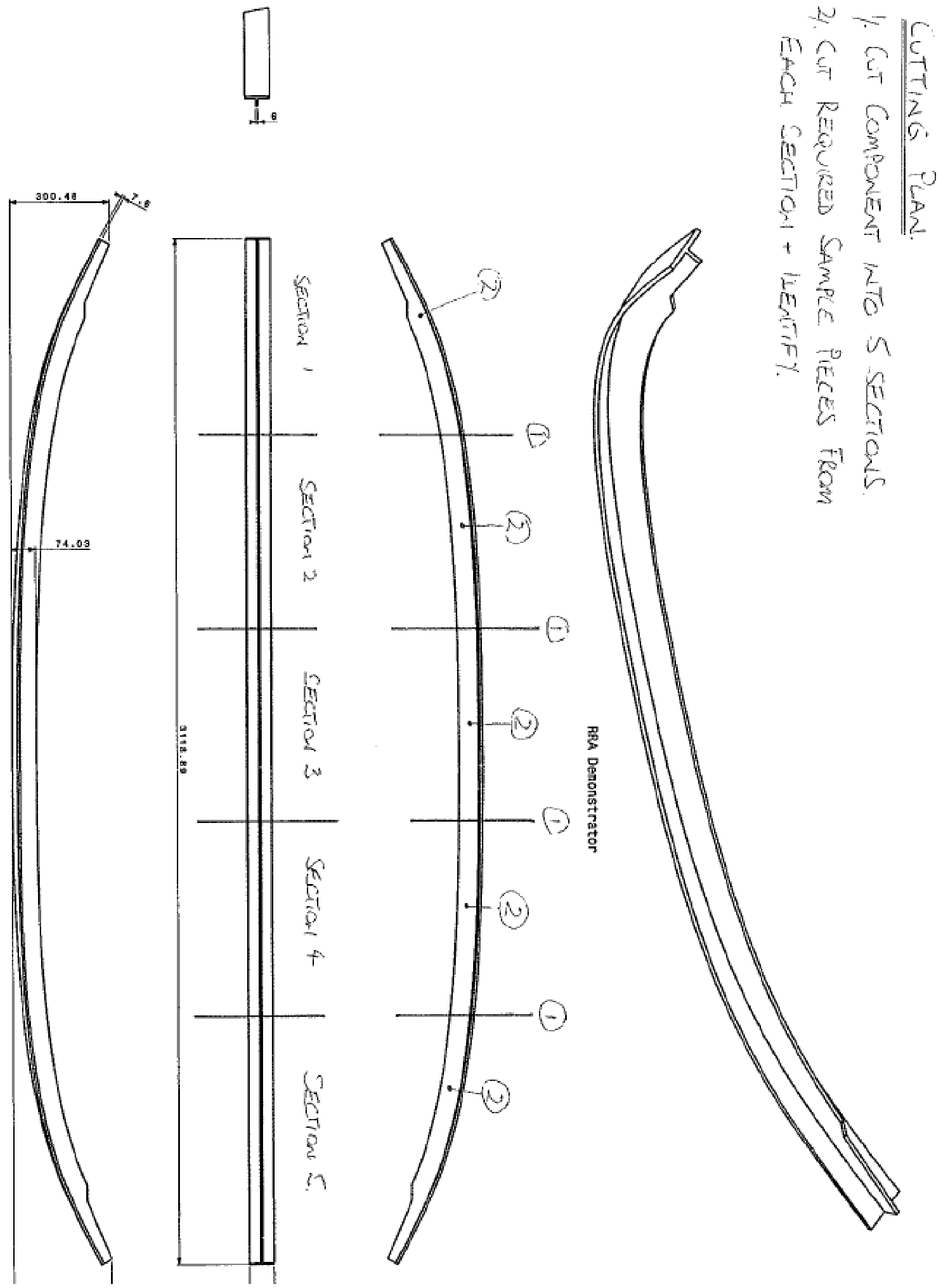

Figure 9: Cutting Diagram showing sectioning as supplied my Metaltec

Appendix B: Analysis of Anomalous Tensile Results from the Quality Assurance Specimens

From §6.3.1, it is clear that several of the tensile specimens machined from QA1, specifically TG01 and TG02, did not achieve the minimum values required by MIL-HDBK-5J. Given these low results, an investigation was undertaken to determine the likely cause of the anomalous properties of specimens TG01 and TG02. This investigation initially went through the pre-RRA treatment testing, RRA treatment and post-RRA treatment testing and reviewed the specimen properties data collected for all specimens at each step as follows.

1. **Material Source:** All three QA specimens were extracted from the same FS737 Lower Cap. As this component is extruded it is very unlikely to have significant property variations along its length. However, the age of the FS737 Lower Cap used to make the QA specimens (not the trial component) is unknown.
2. **Initial Electrical Conductivity:** The QA specimens (Table 3) and the trial component (Table 2) had their electrical conductivities measured prior to RRA treatment and were found to be within in 31-35% IACS range allowed by the Stage II Process Specification.
3. **Initial Hardness:** The mean hardness of the source material (i.e. cap) of QA1 was approximately 2 HRB lower than that of QA2 and QA3 (Table 4), which is a difference of approximately 2%. However, the webs of all three QA specimens were within 0.2 HRB in hardness. It was therefore concluded that the initial hardness of QA1 was not substantially different from the other QA specimens. Note that the Stage II Process Specification does not mandate required hardness values.
4. **Retrogression:** Examination of the trial data showed that the temperatures of all the QA specimens and the trial component were within 7.4 °C of each other during the entire retrogression phase of the RRA treatment. This is within the bounds allowed by the Stage II Process Specification. Furthermore, the temperatures of QA1 and QA3 were very consistent with the temperature of the trial component (Reference 4). In contrast, QA2 was consistently several degrees colder than the trial component, though still within the allowable limits. It was concluded that the temperatures experienced by all QA specimens and the component during the retrogression phase were acceptable.
5. **Quench:** Review of the thermocouple data from the QA specimens during quenching showed that these specimens had been quenched correctly. This was confirmed by a review of a video of the quenching operation which showed that all three QA specimens were quenched in the same quench bath within 30 seconds of removal from the oven.

6. **Re-ageing::** The DSTO dataTaker only recorded incomplete temperature data during this phase due to a buffer over-run on the dataTaker. As such the only complete dataset for this phase came from the BACR oven controller, which did not have thermocouples attached to the QA specimens. However, the long duration of this phase (24 hours) and the lack of any variations in the trial component as well as the available oven temperature data (according to the BACR oven controller data) indicate that no temperature excursions occurred during this phase of the treatment.
7. **Final Electrical Conductivity:** The QA specimens (Table 6) and the trial component (Table 5) had their electrical conductivities measured after RRA treatment and were found to be within the 38-39% IACS range allowed by the Stage II Process Specification. QA1 had the lowest mean electrical conductivity of the three QA specimens and its range of readings overlapped with the other QA specimens. The mean electrical conductivities of the QA specimens were 0.5% IACS less than that of the trial component. It was therefore concluded that the final electrical conductivity of QA1 was acceptable.
8. **Final Hardness:** The mean hardness of the cap of QA1 was 2.1 HRB lower than that of QA2 and 1.0 HRB less than QA3 (Table 7). However, the webs of all three QA specimens were within 1 HRB in hardness. It was concluded that the final hardness of QA1 was not substantially different from the other QA specimens. Note that the Stage II Process Specification does not mandate required hardness measurements.

Given all of the above it was concluded that no anomalous temperature, electrical conductivity or hardness data were associated with QA1 prior to it being sent out for machining of the test specimens. It was therefore decided at the Stage II CDR to conduct a further investigation of QA1 since it may have suffered damage while it was outside of DSTO's control for the purpose of machining of the tensile specimens. The DSTO investigation consisted of the machining of supplementary tensile specimens to confirm the results obtained from TG01 and TG02 (Reference 33) followed by an electrical conductivity survey of the initial and supplementary specimens.

The supplementary tensile program required the machining of another five tensile specimens from QA1. These specimens were machined to the same geometry and tolerances as the initial specimens. However, a different machining company (Boeing Engineering Services) was used as the original (i.e. Metaltec) had ceased operations. The specimens were subsequently tested under the same conditions as in the initial testing program. The results from these tests from each specimen are shown in Table 16, while Table 17 is a statistical summary of all five specimens. The results of these tests were consistent with those from the initial tests (i.e. specimens TG01 and TG02) (Reference 12). As such it was concluded that QA1 had been damaged somehow prior to or during machining but after RRA treatment. The exact cause of this damage cannot be determined but the mechanism is likely to be some form of heat damage.

The electrical conductivities of all tensile specimens machined from QA specimens were measured to test the heat damage hypothesis. The small size of the tensile specimens required the use of a different instrument (a Sigmatest 2.069) and a smaller diameter probe than was used previously. Because of the change in instrumentation, the assumption was made that QA2 and QA3 Specimens had unchanged electrical conductivity. The offset of the second electrical conductivity meter (measuring small specimens) relative to the first electrical conductivity meter (measuring the large QA Specimens) was determined to be 0.65%IACS.

The results obtained from the second survey of electrical conductivities are shown in Figure 10. The results show that all specimens machined from QA1 have significantly lower electrical conductivity readings relative to QA2 and QA3. Electrical conductivity for an aluminium alloy will only change if heating or severe plastic deformation occurs. Severe plastic deformation would have been detectable in the stress-strain traces. From these data it is concluded that QA1 as a whole experienced excessive heating between final electrical conductivity testing and the end of machining of specimens TG01 and TG02. As heating above 80 ºC is not allowed by the Process Specification (Reference 5), the results from these specimens do not effect the certification.

Table 16: Stage II tensile testing results for tensile specimens machined from the QA specimens (supplementary series)

Tensile Specimen	F_{ty} (ksi)	F_{tu} (ksi)	Elongation (%)
TG07	68.3	77.2	13.2
TG08	67.2	76.3	12.1
TG09	67.9	77.0	12.1
TG10	67.3	76.6	12.6
TG11	67.7	76.9	12.7
MIL-HDBK-5J	72	81	7

Table 17: Statistical summary of Stage II tensile testing results for tensile specimens machined from the QA1 specimen (supplementary series)

QA Specimen	F_{ty} (ksi)			F_{tu} (ksi)			Elongation (%)		
	Mean	Standard Deviation	Minimum	Mean	Standard Deviation	Minimum	Mean	Standard Deviation	Minimum
QA1	67.7*	0.47	67.2*	76.8*	0.35	76.3*	12.5	0.46	12.1
MIL-HDBK-5J			72			81			7

*** Does not conform to MIL-HDBK-5J requirements**

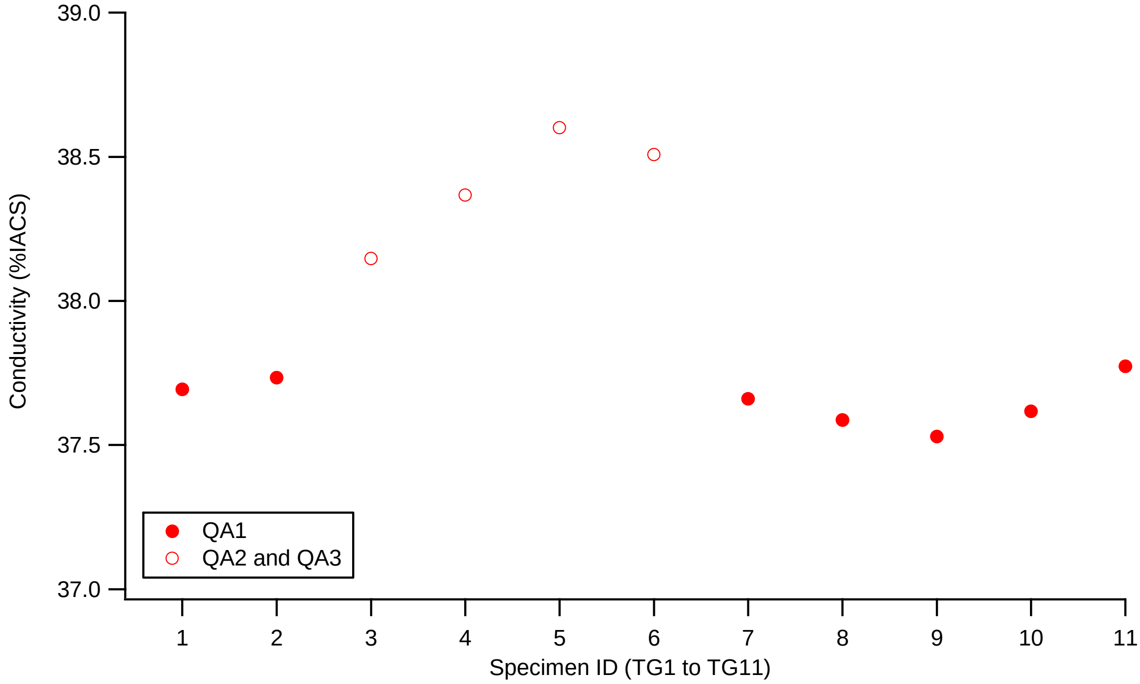

Figure 10: Post-tensile testing electrical conductivity results by QA specimen (with offset from differing electrical conductivity test setup removed). Note how the conductivities of specimens derived from QA1 are consistently lower than those from the other QA specimens.

Appendix C: Process Requirements Compliance Matrix

Process Element	*ID*	*Property*	*Requirement Specification*	*Requirement*	*Compliance Method*	*Compliance Specification*	*Compliance Method Justification/Comments*	*Compliance Result*	*Reference to Documentary Evidence*
Aircraft Component - Generic	1.1	Initial Component Condition	Stage II RRA Process Specification (Reference 5) and C-130H or J SRM (References 34 and 35)	The candidate (pre-RRA) component has neither been in-service nor damaged during transit or storage	Inspection	N/A	Verification via examination of the component and accompanying documentation. The component needs to be free of any nicks, dents or scratches that exceed SRM limit. The component was examined by BACR on 21/4/2009 and no damage was found. Following RRA treatment, a second examination was performed on 22/4/2009 and scratches on three areas of the component were found. The scratches were deemed by DSTO staff to be minor. They are not an inherent consequence of the RRA processes.	Compliant	§7.1 PSCR Appendix C (Reference 4)
	1.2	Alloy Identification and Initial Temper	SAE AMS-QQ-A-200/11. (Reference 36)	The parent extrusion of the component must comply with Reference 36.	Inspection	N/A	Direct verification.	Compliant	Lockheed Martin Drawings (Reference 21)
	1.3	As-extruded short transverse thickness	Stage II RRA Process Specification (Reference 5) §2	The extruded thickness of the parent extrusion in the short-transverse direction is in the range 0.25-inch to 1-inch	Inspection	N/A	Verification via direct measurement and comparison with the manufacturing specification or engineering drawing for the blank extrusion. The LM Standard extrusion 3955 has a thickness of 0.312 inches , Web thickness 0.25 inches. This is less than a maximum of 1.0 inch allowed and the same as the lower bound allowed by the Process Specification.	Compliant	§7.3 Lockheed Martin Drawings (Reference 21)
	1.4	Initial Electrical Conductivity	Stage II RRA Process Specification (Reference 5) §3	The candidate (pre-RRA) component's electrical conductivity must be within the range 31-35% IACS	Test	ASTM E1004-02 (Reference 37)	Verification via direct measurement. All values within specified range for compliance. Measured initial conductivity had values between 31.8%IACS and 32.4%IACS. These were within the range of 31 to 35% IACS specified by the Process Specification (Reference 5).	Compliant	§7.4 PSCR (Reference 4)
	1.5	Final Electrical Conductivity	Stage II RRA Process Specification (Reference 5) §4	The post-RRA electrical conductivity of the component must be within the range 38-39% IACS	Test	ASTM E1004-02 (Reference 37)	Verification via direct measurement. Values must be within specified range for compliance. Mean values within specified range for compliance, no values beyond range ± tolerance of equipment used.	Compliant	§7.5 PSCR (Reference 4)
Heat Treatment Organisation - Generic	2.1	AMO Status	TAMM Reg. 4.1.1.a) (Reference 20) and/or ALSPO SI (LOG) 02-08 (Reference 38)	The heat treatment organisation must be an Authorised Maintenance Organisation (AMO) with authority to heat treat aircraft components for use on ADF aircraft	Inspection	TAMM (Reference 20)	• It is recognised that the number of organisations having the required AMO status is limited. To avoid unnecessary restrictions to the use of RRA it is therefore acceptable to allow the use of temporary maintenance authority. • The organisation must be considered suitable for issuing of a TMA be documentation review if a TMA has not been issued. AMO status of BACR confirmed: Letter of Maintenance Authority (LMA) and Maintenance Authority Certificates (MAC) held by BACR.	Compliant	§7.6 LMA (Reference 22) MAC (Reference 23)
	2.2	Authority to Heat Treat Aluminium Alloys	TAMM Reg. 4.1.1.d (Reference 20) and/or ALSPO SI (LOG) 02-08 (Reference 38)	The heat treatment organisation's AMO or equivalent certification must include the ability to conduct heat treatments upon aluminium alloy components	Inspection	TAMM (Reference 20)	As for AMO Status. DSTO assessed the BACR facility as capable of holding authority to heat treat aluminium on the basis of the similarity to the composite treatments carried out under their AMO and an inspection of the facilities for RRA treatment.	Compliant	§7.7 PSCR (Reference 4)
Heat Treatment Furnace - Generic	2.3	Furnace Classification	Class 5 Air-Circulating Furnace	The temperature distribution as per requirements for Class 5 furnace	Test	AMS 2770H (Reference 32)	Review calibration records for furnace prior to heat treatment. In addition to the BACR furnace's classification as a Class 4 furnace (superior), capability of the BACR Furnace to perform RRA treatment was assessed by analysis of the temperature profiles achieved in the trial.	Compliant	§7.8 PSCR (Reference 4)
	2.4	Furnace	Stage II RRA Process	The thermocouples	Inspection	NATA or similar	Verified by inspection of calibration records for BACR furnace prior	Compliant	§7.9

Process Element	ID	Property	Requirement Specification	Requirement	Compliance Method	Compliance Specification	Compliance Method Justification/Comments	Compliance Result	Reference to Documentary Evidence
		Calibration	Specification (Reference 5) §3	used in the most critical location of the component should have a traceable and current calibration certificate.			to heat treatment.		PSCR (Reference 4)
	2.5	Thermocouple Calibration	Stage II Process Specification (Reference 5) §3	The thermocouples used in the most critical location of the component should have a traceable and current calibration certificate.	Inspection	NATA or similar	Obtain calibration certificate for sufficient thermocouples to record temperatures in critical component locations. Thermocouples in non-critical locations are only required to have secondary calibrations. Verified by inspection of calibration certificates for thermocouples sufficient to record temperatures in critical component locations, and analysis of temperature profiles from the trial. Thermocouples in non-critical locations had secondary calibrations.	Compliant	§7.10 PSCR (Reference 4)
Aircraft Component – Trial Only	3.1	Tensile Properties	Stage II RRA Process Specification (Reference 5) §3	RRA-treated components should have mechanical properties equal to or better than A-basis values for 7075-T6	Test	ASTM E8M-08 (Reference 39)	• Tensile testing performed following the heat treatment of the component. • Blanks cut from the component must be of a suitable geometry for the machining of tensile specimens. Tensile testing performed following the heat treatment of the component. The tensile properties (tensile yield, tensile ultimate strength and elongation) of specimens manufactured from the component were above the limits set by the MIL-HDBK-5J (Reference 1).	Compliant	§7.11 Tensile Test Report (Reference 12)
	3.2	Corrosion	ASTM G34-01 (2007) (Reference 18) ASTM G 168-00 (2006) (Reference 17)	Corrosion resistance of RRA-treated material should be equal to or better than that of 7075-T6 (i.e. ED)	Test	ASTM G34-01(2007) (Reference 18) ASTM G 168-00 (2006) (Reference 17)	Exfoliation property should be P or EA. Stress corrosion cracking should show increasing corrosion resistance between RRA material and control material. Exfoliation resistance increase to 'P' rating was demonstrated. Stress Corrosion Cracking resistance could not be tested due to limitations placed on specimen manufacture by component dimensions.	Compliant	Reference 14
Heat Treatment Process – Trial Only	4.1	QA Initial Hardness	Stage II RRA Process Specification §4 (Reference 5)	The hardness of all quality assurance specimens must be measured before RRA treatment	Test	ASTM E18-08a (Reference 40)	Direct Verification. All hardness values were consistent with those of 7075-T6 alloy.	Non-Compliant (Acceptable)	MDPR (Reference 2)
	4.2	QA Initial Conductivity	Stage II RRA Process Specification §3 (Reference 5)	The QA specimen electrical conductivity must be within the range of 31-35% IACS.	Test	ASTM E1004-02 (Reference 37)	Direct Verification. Values must be within specified range for compliance. All values were within the limits allowed by the Process Specification.	Compliant	§7.4 PSCR (Reference 4)
	4.3	RRA Heat Treatment Stability	DAR Requirement	Electrical conductivity of RRA-treated components should not change with time once RRA treatment is completed	Analysis	ASTM E1004-02 (Reference 37)	The National Research Council of Canada observed no systematic variation in electrical conductivity for RRA-treated 7075-T6 over a three month period after treatment.	Compliant	NRC Report (Reference 25)
	4.4	QA Final Hardness	Stage II RRA Process Specification (Reference 5) §4	The hardness of all quality assurance specimens must be measured after RRA treatment	Test	ASTM E18-08a (Reference 40)	As for QA Initial Hardness. All recorded values were consistent with the hardness values obtained previously for RRA-treated material. As there is no formal requirement for hardness values in the Process Specification, these have been deemed Non-Compliant (Acceptable) as per the Technical Airworthiness Management Manual (Reference 20).	Non-Compliant (Acceptable)	§ 7.16 MDPR (Reference 2)
	4.5	QA Tensile	Stage II RRA Process	RRA-treated QA	Test	ASTM E8M-08	Tensile testing performed following the heat treatment of the	Compliant	Tensile Test

Process Element	ID	Property	Requirement Specification	Requirement	Compliance Method	Compliance Specification	Compliance Method Justification/Comments	Compliance Result	Reference to Documentary Evidence
		Properties	Specification (Reference 5) §3.	specimens should have mechanical properties equal to or better than A-basis values for 7075-T6.		(Reference 39)	component. The tensile properties (Tensile Yield, Tensile Ultimate Strength and elongation) of specimens manufactured from two of the three QA specimens were above the A-basis values set by the MIL-HDBK-5J. Investigations into QA1 anomalous results concluded that specimen QA1 underwent a heating event during manufacture and the tensile properties were not a result of the RRA treatment		Report (Reference 12) §7.17.
	4.6	QA Final Conductivity Measurements	Stage II Process Specification (Reference 5) §4.	The conductivity of all quality assurance specimens must be measured following to RRA. The post-RRA electrical conductivity must be within the range 38-39% IACS.	Test	ASTM E1004-02 (Reference 37)	Direct verification. Values must be within specified range for compliance. All of the measured final conductivity values for the QA specimens, were within 38 to 39%IACS range specified by the Process Specification (Reference 5).	Compliant	PSCR (Reference 4)
Data Acquisition System-Trial only	5.1	Data Device Calibration	Stage II RRA Process Specification (Reference 5) §3	The data acquisition system used to record temperature data from the thermocouples attached to the Control Specimens must have a current calibration	Inspection	OEM specification	Review currency of calibration record of data acquisition system and renew if needed. The BACR furnace calibration was issued by Australian Calibrating Services on 26 November 2008 and is valid for six months with the next calibration being scheduled for 24 May 2009. The calibration report is NATA compliant.	Compliant	Stage II Trials Report (Reference 15)

Appendix D: Component Properties Compliance Matrix

Property Group	*ID*	*Component Property*	*Requirement Specification*	*Requirement*	*Compliance Method*	*Compliance Specification*	*Compliance Method Justification/Comments*	*Compliance Result*	*Reference to Documentary Evidence*
Physical/ geometric	1.1	Dimensions	Manufacturing Specification	Component dimensions and shape should not change beyond levels allowed by manufacturing specification.	Test	NATA approved metrology	Dimensional analysis showed slight relaxation in curvature of heat-treated component to the order of 1 mm. No profile distortion occurred due to heat treatment. Discussion of the dimensional requirement in the Stage II CDR agenda following inability of DSTO, DGTA and ALSPO attempts to procure engineering drawings.	**Non-Compliant (Acceptable)**	§8.1 Stage II Metrology Report (Reference 13) Stage III Metrology Report (Reference 19)
	1.2	Final Surface Finish	Manufacturing Specification	Component surface should not be roughened beyond the level allowed by the manufacturing specification.	Analysis	N/A	RRA treatment is unlikely to cause any change in surface finish as it does not mechanically deform the material being treated. Furthermore, the temperatures involved in RRA are too low to oxidise or deform the surface.	**Compliant**	§8.2
	1.3	Weight	ALSPO SI (LOG) 02-47 §17c(2) (Reference 41)	Component weight should not change by more than ±10 lb (4.54 kg).	Analysis	N/A	RRA treatment cannot alter component weight as the temperatures used are too low to cause melting, oxidation or vaporisation. Additionally, RRA treatment involves no bulk material addition or removal.	**Compliant**	§8.3
	1.4	Balance	ALSPO SI (LOG) 02-47 §17d (Reference 41)	Aircraft centre-of-gravity not changed by more than ±0.1% MAC.	Analysis	N/A	No mass redistribution can occur as a result of RRA treatment as the temperatures involved are too low to cause melting, oxidation or vaporisation. Additionally, RRA treatment involves no bulk material addition or removal.	**Compliant**	§8.4
Mechanical	2.1	Structural Strength	MIL-HDBK-5J (Reference 1)	RRA-treated components should have mechanical properties equal to or better than A-basis values for 7075-T6.	Test	Various ASTM standards refer Reference 42	Addressed by Stage I RRA Certification.	**Compliant**	§7.11 and 8.5 MDPR (Reference 2) Tensile Test Report (Reference 12)
Durability	3.1	Fatigue life - material performance	C-130H or J ASIMP (References 43 and 44) as appropriate	RRA treatment should not reduce constant amplitude fatigue life	Test	ASTM E466-07 (Reference 45)	Addressed by Stage I RRA Certification. Comparison testing showed that RRA did not decrease fatigue life for constant amplitude loading tests conducted at three different load ratios.	**Compliant**	§8.6 MDPR (Reference 2)
	3.2	Fatigue life - Stress	C-130H or J ASIMP (References 43 and 44)	Candidate components for RRA treatment should be	Inspection	N/A	Pre-existing residual stresses primarily effect fatigue life. There is evidence that RRA treatment reduces these residual stresses. As such, components cannot have deliberately	**Compliant**	§8.7

Property Group	ID	Component Property	Requirement Specification	Requirement	Compliance Method	Compliance Specification	Compliance Method Justification/Comments	Compliance Result	Reference to Documentary Evidence
		Modification	as appropriate	free of deliberately induced beneficial residual stresses.			introduced residual stresses such as those induced by shot peening or cold working. Compliance will be demonstrated via documentation review and component inspection for evidence of such stresses. The component has not undergone any treatment to induce beneficial residual stress and is therefore compliant.		
	3.3	Fatigue life - initiation	C-130H or J ASIMP (References 43 and 44) as appropriate	RRA treatment should not reduce fatigue life	Test	ASTM E466-07 (Reference 45)	Addressed by Stage I RRA Certification	**Compliant**	§8.8 MDPR (Reference 2)
	3.4	Fatigue Crack Growth	C-130H or J ASIMP (References 43 and 44) as appropriate	RRA should not decrease fatigue crack growth life by increasing fatigue crack growth rates.	Similarity /Test	ASTM E647-08 (Reference 46)	Addressed by Stage I RRA Certification	**Compliant**	§8.9 MDPR (Reference 2)
	3.5	Corrosion Resistance – Stress Corrosion Cracking	MIL-HDBK-5J (Reference 1)	RRA-treated components should have corrosion resistance equal to or better than that of untreated 7075-T6	Test	ASTM G47-98 (Reference 47)	Research done at DSTO has demonstrated that RRA significantly increases the resistance of treated 7075-T6 to stress corrosion cracking. Analysis of data from NRC also shows this and was confirmed by discussions with a subject matter expert at NRC. Addressed by Stage I RRA Certification. Also demonstrated by comparative Exfoliation tests in Stage II RRA Certification.	**Compliant**	§8.10 MDPR (Reference 2) §6.11.
	3.6	Corrosion Resistance - Dissimilar Metals	C-130H SRM Chapter 51-30 Page 1 §1A (Reference 34) & C-130J SRM (Reference 35)	RRA-treated components should be protected from dissimilar metal contact to inhibit corrosion.	Similarity	C-130H SRM (Reference 34) & C-130J SRM (Reference 35)	RRA treatment is not expected to require practices different from those used where 7075-T6 and 7075-T7 components come into contract in the C-130 airframe. The use of primer and wet-sealed fasteners should provide adequate protection.	**Compliant**	§8.11
Maintenance	4.1	Primer and pre-treatment	DEF(AUST)9001 (Reference 27)	RRA treatment should not require a change in ADF pre-treatment or priming practices.	Similarity	N/A	DEF(AUST)9001 requires all aluminium alloys in ADF aircraft to be pre-treated and primed in the same manner. Therefore, no change in pre-treatment or primer will be necessary following RRA treatment	**Compliant**	§8.12
	4.2	NDI practices	AAP 7002.043-36 (Reference 48)	RRA treatment should not require a change in NDI practice.	Analysis	N/A	Visual: RRA treatment produces no change in the surface appearance of the component and therefore cannot interfere with visual examination. Eddy current: RRA produces a minor increase in electrical conductivity which	**Compliant**	§8.13 P. Virtue e-mail

Property Group	*ID*	*Component Property*	*Requirement Specification*	*Requirement*	*Compliance Method*	*Compliance Specification*	*Compliance Method Justification/Comments*	*Compliance Result*	*Reference to Documentary Evidence*
							is easily accounted for during the initial set-up of the NDI apparatus. Radiographic: RRA treatment will not produce any change in x-ray atomic cross-section and will therefore not change x-radiography procedures. Ultrasonic: RRA treatment will change neither the elastic modulus nor the density of the material which control the propagation of sound in materials. Therefore it will not affect ultrasonic NDI techniques. Die Penetrant: Die Penetrant examination is already used on overaged alloys. As such no change in practices is expected and will be readily accommodated. Ferromagnetic: cannot be performed on aluminium alloys so will not be affected by RRA treatment.		(Reference 28)
	4.3	Machinability	DAR Requirement	RRA-treated components should not require a significant change in tooling or machining practices.	Similarity	N/A	RRA treatment will not require a tooling change as RRA-treated and untreated material have similar mechanical properties. The machining of metals is controlled by their hardness, which relates directly to strength. Most tool shops use tungsten carbide tooling to minimise issues with different metals. Technical advice can be readily obtained from tooling manufacturers if required	**Compliant**	§8.14 B. Grigson e-mail (Reference 29)
	4.4	Repairability	C-130H or J SRM (References 34 and 35) (as appropriate) various sections	RRA-treated components should be repairable using the methods outlined in the C130H or J Structural Repair Manuals	Similarity	N/A	RRA-treated components have effectively the same mechanical properties as untreated components. As such the repair methods used for untreated components will be applicable to RRA-treated components with minor changes. Specifically, structural repairs to RRA-treated components should account for the altered heat treatment of the components. Consideration should be given to using RRA-treated materials in any straps or doublers used in repairing a RRA-treated component.	**Compliant**	Paragraph 8.15 MDPR (Reference 2)
	4.5	Replaceability	MIL-I-8500D §6.2.9 (Reference 30)	RRA-treated components should be able to directly replace an untreated component under deeper maintenance conditions without atypical modifications to adjoining structural components.	Test	N/A	An RRA-treated component cannot be visually distinguished from an untreated component and has been shown to have the same mechanical properties relative to MIL-HDBK-5J.	**Non-Compliant (Acceptable)**	§8.1, 8.2, 8.3, 8.4 and 8.16

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19. ABSTRACT
Retrogression and Re-ageing (RRA) technology is a two stage heat treatment of 7075-T6 aluminium alloy used to improve corrosion resistance while retaining MIL-HDBK-5J structural properties. This report assesses the compliance of the industrial trial, conducted at Boeing Australia Component Repairs (BACR) on 21st April 2009, with the requirements of the compliance matrices in the Stage II Design Development Plan and, by extension, the Stage II Process Specification for RRA. Of the 35 items in these matrices 31 were given recommended ratings of 'Compliant' while the remaining four received recommended ratings of 'Non-Compliant (Acceptable)'.