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# Retrogression and Re-Ageing In-Service Demonstrator Reliability Trials: Stage III Component Test Report

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**Air Vehicles Division**
Defence Science and Technology Organisation

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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 reliability trials, conducted at Boeing Australia Component Repairs (BACR) in August 2010, with the requirements of the compliance matrix in the Stage III Design Development Plan and, by extension, the Stage III Process Specification for RRA. All properties described by items in the compliance matrix received recommended ratings of either 'Compliant' or 'Non-Compliant (Acceptable)'. Of the 15 items in the compliance matrix only four were rated 'Non-Compliant (Acceptable)'. The trials demonstrated that the RRA process as defined in the Stage III Process Specification can be reliabily applied to an aircraft component in an industrial environment with a reliability exceeding 95%.

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# Retrogression and Re-Ageing In-Service Demonstrator Reliability Trials: Stage III Component Test Report

## 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.

Three industrial trials intended to test the reliability of the RRA heat treatment were on a C-130 Hercules component at Boeing Australia Component Repairs (BACR) on August 2010. This report assesses the compliance of these industrial trials with the requirements of the compliance matrix in the Stage III Design Development Plan and, by extension, the Stage III Process Specification for RRA. The Stage III 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 15 items in these matrices 11 were given recommended ratings of 'Compliant' while the remaining four received recommended ratings of 'Non-Compliant (Acceptable)'. The trials demonstrated that the RRA process as defined in the Stage III Process Specification had a reliability in excess of 95%.

This report concludes with a set of recommendations for updating the Process Specification. These will be incorporated into a fourth revision of the Process Specification.

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# Glossary

| | |
|---|---|
| § | Section or heading number |
| AA7xxx | Ternary wrought aluminium alloy of Zn-Mg-Cu system |
| 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 |
| C-130 | Lockheed Martin C-130 (Hercules) Aircraft |
| CASA | Civil Aviation Safety Authority |
| CDR | Critical Design Review |
| CPCM | Component Properties Compliance Matrix |
| DAR | Design Acceptance Representative |
| DAVCOMP | Directorate Air Vehicle Compliance |
| DDP | Design Development Plan |
| DGTA | (RAAF) Directorate General Technical Airworthiness |
| DSTO | Defence Science and Technology Organisation (Australia) |
| FS | Fuselage Station (C-130 Hercules) |
| FS737 | Fuselage Station 737 (C-130 Hercules) |
| IACS | International Annealed Copper Standard (electrical conductivity) |
| LMA | Letter of Maintenance Authority |
| LOG | Logistics (part of a ALSPO SI identifier) |
| MAC | Maintenance Authority Certificate |
| MEK | Methyl Ethyl Ketone |
| MIL-HDBK | (United States) Military Handbook |
| NATA | National Association of Testing Authorities (Australia) |
| NATO | North Atlantic Treaty Organisation |
| NDI or NDT | Non-destructive inspection/testing |
| NSN | NATO Stock Number |
| OEM | Original Equipment Manufacturer |
| OIC | Officer-In-Charge |
| p/n | Part Number |
| PDF | Probability Density Function |
| PID | Process property IDentification |
| PS§ | Process Specification section number |
| QDS | QANTAS Defence Services |
| RAAF | Royal Australian Air Force |
| RRA | Retrogression and Re-ageing |
| RTCM | Reliability Trials Compliance Matrix |
| SAE | (US) Society of Automobile Engineers |
| SN or s/n | Serial Number |
| SRM | Structural Repair Manual |

| | |
|---|---|
| T6 | Peak-aged temper for aluminium alloys |
| TAMM | (RAAF) Technical Airworthiness Management Manual |
| TMA | Temporary Maintenance Authority |
| US | United States (of America) |

# 1. Introduction

This report forms part of Stage III of the Defence Science and Technology Organisation's (DSTO's) program to certify Retrogression and Re-ageing (RRA) for use on 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 III is dealing with the issues of transferring RRA into ADF service. The reliability of the RRA process is an example of such an issue. 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-5J) (Reference 1). This stage is complete and has been submitted to the Directorate General Technical Airworthiness (DGTA) for their consideration. Stage II was concerned with demonstrating the industrial feasibility of the RRA process and was completed with the production of the Stage II Component Test Report (Reference 2).

This report assesses the compliance of three reliability trials of DSTO's implementation of the RRA heat treatment with the requirements of the Stage III Design Development Plan (DDP) (Reference 3). These trials are the core activity of Stage III.

The Stage III DDP requirements are summarised in the Reliability Trials Compliance Matrix (RTCM) contained in the Stage III DDP and reproduced in Appendix A of this report. Compliance with this matrix provides a demonstration that the RRA process was successfully carried out in an industrial environment. Unlike Stage II proving that the process can be done in an industrial environment, the focus of the Stage III trial is designed to provide data that will enable the reliability of the RRA process to be estimated. This report summarises the testing required to satisfy the compliance matrix and contains a completed RTCM. Full details of the testing and analysis are contained within individual test reports.

# 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 AA7075-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 4). 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 5), has been demonstrated by DSTO to be less than the increase due to improved processing (Reference 6). As such RRA-treated AA7075-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.

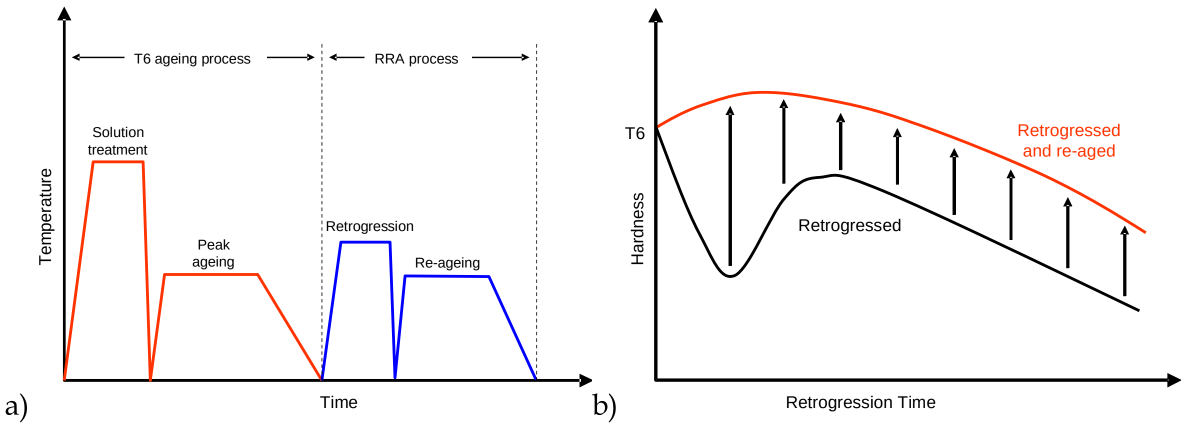


*Figure 1: Schematic representation of the Retrogression and Re-ageing heat treatment (Reference 7) where (a) shows the temperature profile of the heat treatment as compared to a T6 treatment, and (b) shows the response of material hardness to retrogression and subsequent re-ageing. Note that RRA is 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 AA7075-T6 used in the C-130, without reducing their mechanical properties below the certified design allowables for the alloy's peak-aged temper (Reference 6). 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 Original Equipment Manufacturer (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 each stage of its certification project (References 5, 8 and 9). The Stage I RRA Process Specification was used for laboratory scale demonstration of the technology. The Stage II RRA Process Specification was a revision of the original specification for the Stage II industrial scale trial, and all the requirements associated

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

with it. The Stage III Process Specification is a further modification, which includes lessons learnt from the Stage II industrial trial. It also contains a chart to facilitate the selection of an appropriate retrogression time for a given initial electrical conductivity.

# 3. Description of Trial Components

The component selected for Stage II and Stage III trials 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 2.

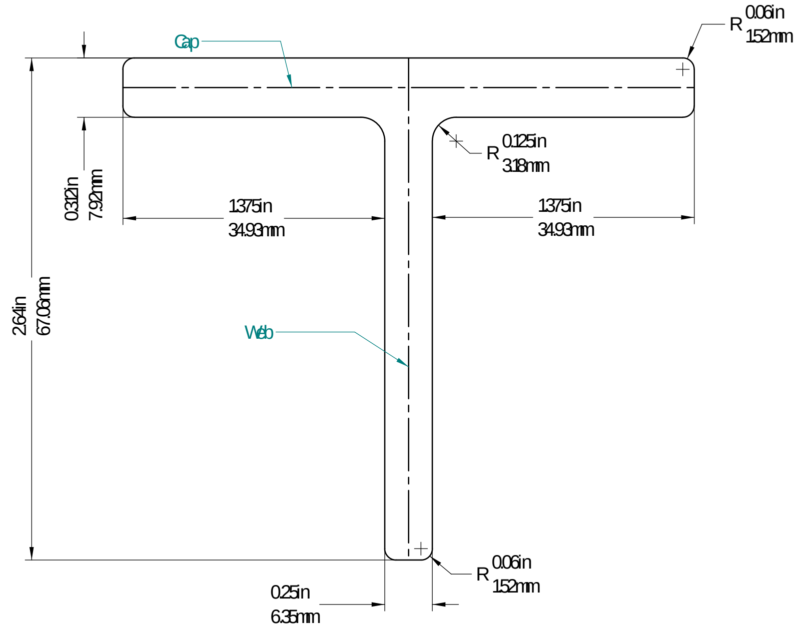


*Figure 2: Schematic of the cross-section of standard Lockheed Martin extrusion #3955-2 from which the C-130 FS737 Lower Cap is formed. US-Customary units (inches) are authoritative while SI units (millimetres) are included for convenience.*

Five FS737 Lower Caps were purchased for the trials described in this report. Of these, three were treated in the trials, one was used to develop the model of the effect of initial electrical conductivity on retrogression time (Reference 10) and the final component was kept in reserve until the trials were completed. After the trials, however, this last component was used to refine the retrogression time model (Reference 11).

# 4. Experimental Method

## 4.1 Introduction

The DSTO RRA trials were conducted at Boeing Australia Component Repairs (BACR)[2] between 17/8/2010 and 24/8/2010. This section is equivalent in purpose to the Component Test Plan (Reference 12) that was written prior to the Stage II Industrial Trial (References 13 and 14). It outlines the process by which the requirements of the RTCM (Reference 3) are met, and reproduces the definitions from the Stage III Process Specification (Reference 9) pertaining to the following RTCM items:

- 1.4 Initial Electrical Conductivity,
- 1.5 Final Electrical Conductivity,
- 3.1 Temperature Profile – Retrogression,
- 3.2 Post-Retrogression Quenching and
- 3.3 Temperature Profile – Re-ageing.

Additionally, the requirements, methods and analysis for the determination of RTCM Item 1.6 'Dimensions' detailed in the Stage III Metrology Report (Reference 15) are summarised here.

The experimental method used for the reliability trials is summarised as a flowchart in Figure 3. This diagram is based on the work order to BACR which is reproduced in Appendix B of this report. The work order was used by BACR to undertake the reliability trials, and was based on the requirements of the Stage III Process Specification and the RTCM.

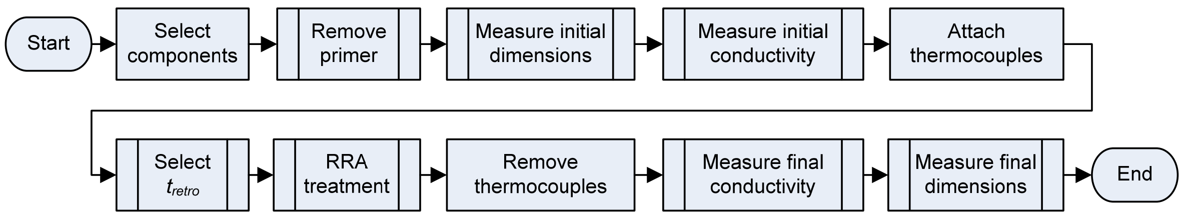


*Figure 3: Flowchart summarising the experimental method followed for each of the three components treated in the Stage III Reliability trial. Note that $t_{retro}$ is the retrogression time.*

## 4.2 Component Selection

As mentioned in §3, five FS737 Lower Cap components were purchased from Qantas Defence Services (QDS) for these trials. Given that only three components were needed for the trials, a selection from the available components had to be made. This was done by selecting those components whose initial conductivity fell within the 31.95 to 33.68% IACS initial electrical conductivity range of the retrogression time model (Reference 10). The conductivity data used to make this selection were collected during the initial examination of the component upon their arrival at DSTO Melbourne. As the components were still coated with primer (paint) at this stage, these data were not used to determine the retrogression time. The remaining two components were used to extend and validate the retrogression time model (Reference 11).

[2] Boeing Australia Component Repairs, 29 Jets Court, Melbourne Airport, VIC 3045.

## 4.3 Component Surface Preparation

Prior to RRA-treatment each component had its primer layer removed. The removal of the primer layer, which is mandated in PS§2.2 and PS§3.5.3.a of the Stage III Process Specification (Reference 9), was undertaken by Brenco Aerospace[3] using low velocity glass bead peening.

## 4.4 Electrical Conductivity Measurement

PS§3.5 of the Stage III Process Specification describes the prescribed method for measurement of electrical conductivity. The same method of measurement was used for initial and final conductivity readings. It is therefore the same for RTCM items 1.4 and 1.5.

For clarity the following terminology is used in this report to describe the collection and analysis of electrical conductivity data:

1. **Reading:** This is the electrical conductivity value returned by a single application of the conductivity meter to the component.
2. **Location Mean:** This is a statistical estimate of the electrical conductivity at a given location. It is the arithmetic mean of multiple readings taken at that location.[4]
3. **Component Mean:** This is a statistical estimate of the electrical conductivity of the component. It is the arithmetic mean of all the readings taken from that component.

A summary of the requirements for taking electrical conductivity measurements along with the relevant paragraph from the Stage III Process Specification is as follows:

1. Ensure that the entire surface of the component is free of primer. (PS§3.5.3.a)
2. Use Methyl Ethyl Ketone (MEK) (or a suitable equivalent) to clean the locations of the component that are to have their conductivity measured (PS§3.5.3.b).
3. Establish that the component, calibration standards and measurement probe are at room temperature prior to testing (PS§3.5.3.c).
4. Calibrate the conductivity meter according to the manufacturers instructions (PS§3.5.3.d).
5. Re-test the calibration of the conductivity meter at least every 15 minutes after the initial calibration is performed, and upon completion of the testing (PS§3.5.3.g).

The DSTO electrical conductivity readings were made using a Forster Sigmatest 2.069 meter. This meter had its calibration checked (see Appendices C and D) before, during and after examination of each component as described above.

Electrical conductivity readings were taken at the mid-point of both the cap and the web surfaces of the component. These data was collected at six points along the component,

---

[3] Brenco Aerospace Pty. Ltd. 171-173 Fairbarn Road, Sunshine, VIC 3024.

[4] Arithmetic mean = Sum of All Readings / Number of Readings i.e. $\overline{x} = \sum_{i=1}^{n} x_n$

designated Positions A through F (Figure 4). At least three readings were made at each position.

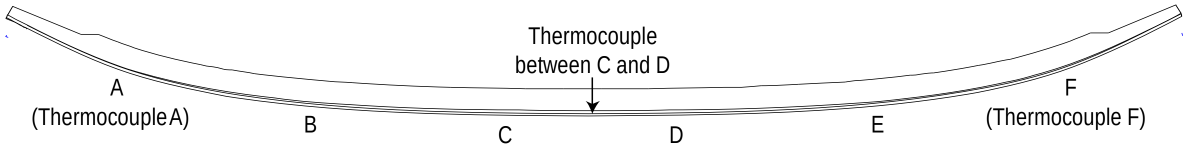


*Figure 4: Schematic showing the approximate locations of conductivity measurements (designated A through F) on the components treated in the DSTO Stage III Reliability Trial, as well as the approximate locations of the three thermocouples*

### 4.4.1 Initial Electrical Conductivity

PS§4.2 of the Stage III Process Specification requires that the mean initial electrical conductivity of each component must be in the range of 31 to 35% IACS. The specification does not give any tolerances on this range. This is in contrast with the final electrical conductivity range which has a tolerance equal to the measurement accuracy of the electrical conductivity meter used to make the measurements. The effects of this inconsistency are discussed in §6 of this report.

### 4.4.2 Final Electrical Conductivity

The Stage III Process Specification requires in PS§4.6 that all measured final electrical conductivity values falls between the range of 38 to 39% IACS plus or minus the measurement tolerance of the conductivity meter used to record them. The Sigmatest 2.069 conductivity meter has a tolerance of 0.5% of the reading. This requirement is interpreted as meaning that all location mean values for final electrical conductivities must be within the range of 37.80 to 39.20% IACS.

## 4.5 Component, Furnace and Quench Bath Thermometry

Immediately prior to RRA treatment, each component had thermocouples attached at the three positions shown in Figure 4. These thermocouples were attached using stationery dog clips in accordance with PS§4.3.1.a. This was the same method used for the Stage II Demonstrator Trial (Reference 13).

In addition to the three thermocouples attached to the component, a further two thermocouples were hung near the component to record the air temperature of the furnace. Another thermocouple was placed in the quench bath to record the temperature of the water in the quench bath. Care was taken to ensure that this thermocouple was not touching the metal walls of the quench bath. Finally, the set-point temperature and control temperature of the furnace were recorded.

The furnace temperature data obtained during the trials were recorded by the BACR furnace controller and sent to DSTO by email in the form of Microsoft Excel spreadsheet attachments (References 16, 17 and 18).

## 4.6 Component Heat Treatment Schedule

Figure 5 illustrates the heat treatment schedule required to conduct a RRA heat treatment on an eligible AA7075-T6 component. This schedule is described in detail in subsequent sections of this report, and in the Stage III Process Specification (Reference 9). It consists of three phases:

1. Retrogression (RTCM Item 3.1)
2. Post-Retrogression Quenching (RTCM Item 3.2)
3. Re-Ageing (RTCM Item 3.3)

The requirements from the Stage III Process Specification relevant to each of the three phases are detailed in the sub-sections below.

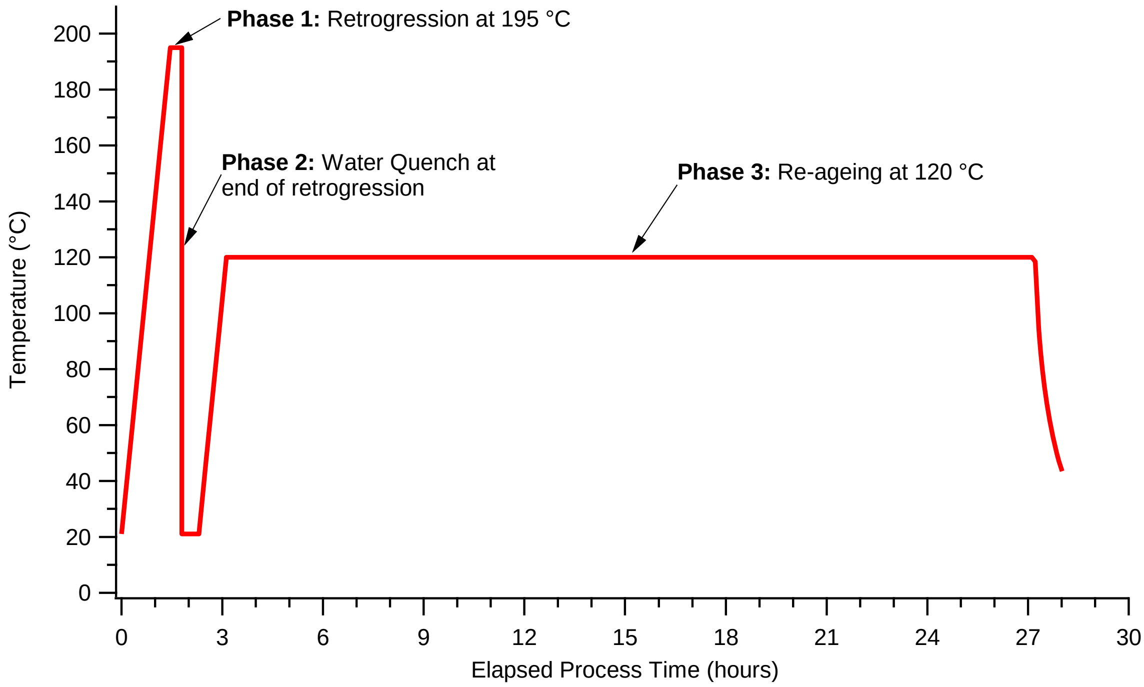


*Figure 5: Schematic of the nominal heat treatment schedule for RRA treatment showing the three phases of treatment as specified in the Stage III RRA Process Specification (Reference 9)*

### 4.6.1 Retrogression

Retrogression refers to the initial heating phase prior to quenching. From the Stage III Process Specification, the following is required:

1. **Initial heating** at a controlled ramp rate of 2 ± 0.1 °C/min to the retrogression start temperature of 181 °C (PS§4.3.1d and PS§4.3.1e). Compliance with this requirement

was determined by examination of the temperature-time data from the thermocouples attached to the component.

2. **Retrogression time** starts when any part of the component exceeds 181 °C (PS§4.3.1e) and continues until the component is quenched. The duration of this phase depends on the component's initial conductivity.
3. **Retrogression temperature** is the temperature set-point of the furnace during the retrogression phase (PS§4.3.1d). This temperature was measured by direct observation and from examination of the set-point values of the BACR furnace controller.
4. **Temperature Variation** across the component for initial heating and retrogression must be less than 10 °C (PS§4.3.1e) as measured by at least three thermocouples positioned evenly across the length of the component (PS§4.3.1a).

The temperature-time profile for the retrogression phase of RRA treatment is shown in Figure 6.

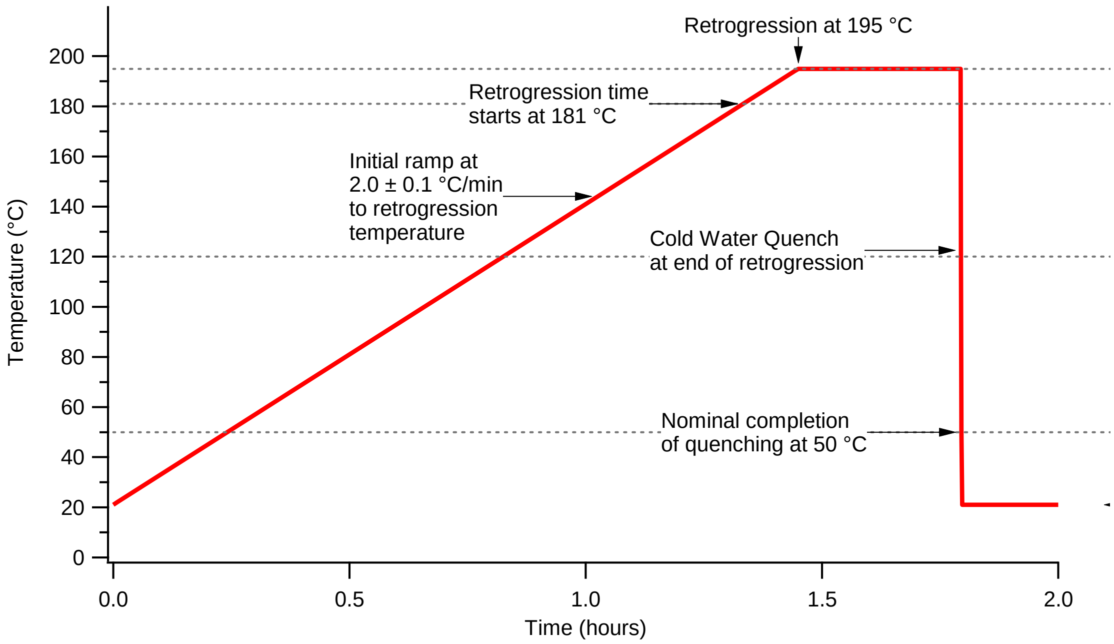


*Figure 6: Temperature-time profile during the retrogression phase of the RRA process. This figure is a subset of the complete heat treatment schedule shown in Figure 5. Note that parts of the cold water quench and dwell phases after the retrogression phase are also shown.*

The three components used in the reliability trials were retrogressed for times based upon their initial electrical conductivities. These times were selected using Figure A.1 and the associated equation in Annex A of the Stage III Process Specification (Reference 9). The equation is:

$$t_{retro} = 862.89 - 25.07\sigma_{T6} \tag{1}$$

where $\sigma_{T6}$ is the initial electrical conductivity. Figure 7 reproduces Figure A.1 from the Stage III Process Specification (Reference 9) showing the line corresponding to the above equation.

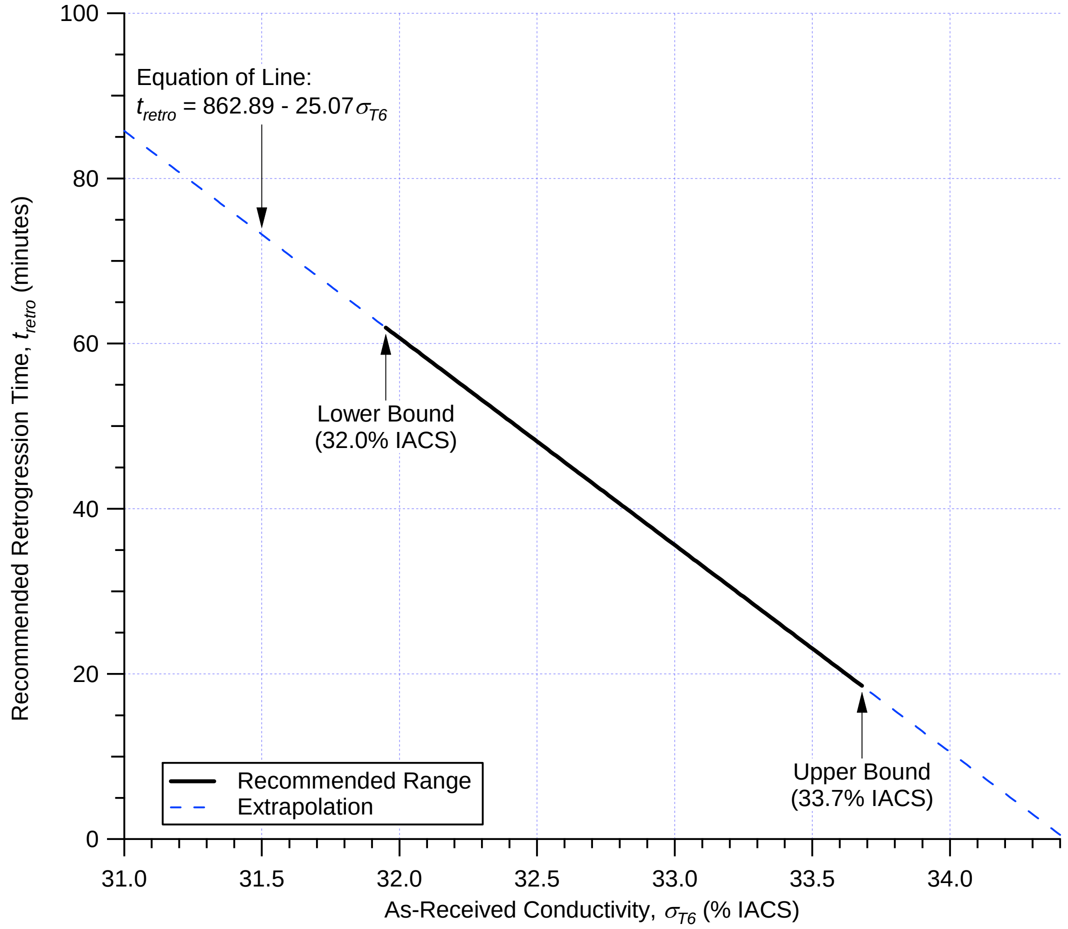


*Figure 7: Calculated retrogression times based on component initial conductivity (Reference 9)*

### 4.6.2 Post-Retrogression Quench

At the completion of the retrogression phase, post-retrogression quench commences. During the quench, component temperature is rapidly reduced to below 50 °C by immersion of the entire component in cold water. Figure 8 illustrates the nominal temperature-time profile for the component during the quench. The requirements for the quench from the Stage III Process Specification are given in two paragraphs. PS§4.3.1.f requires that the components be quenched in cold water within three minutes of the opening of the furnace, while PS§4.3.1.g gives the temperature requirements of the quenchant. Additional requirements for the dwell period between retrogression and re-ageing are contained in PS§4.4. These requirements are summarised by the following four quantities, which together form the basis of the acceptability criteria of RTCM Item 3.2:

1. **Quenching Time:** This is the period between when the furnace door is opened and when the component is fully immersed in the quench bath. Although technically, the quench is complete when the component temperature falls below 50 C, this takes less than 5 seconds in practices. This period shall not exceed 3 minutes (PS§4.3.1.f). It can be measured by direct observation or from temperature readings from thermocouples.

In the current case, it was determined by examination of temperature-time data from the thermocouples attached to the components.

2. **Initial Quench Bath Temperature:** This is the maximum allowed temperature of the water in the quench bath immediately prior to immersion of the component. The initial quench bath temperature shall not exceed 32 °C (PS§4.3.1.g). This quantity was determined by examining the temperature-time data from the thermocouple immersed in the quench bath.

3. **Maximum Quench Bath Temperature:** This is the maximum allowed temperature reached by the quenchant after immersion of the component. The maximum quench bath temperature shall not exceed the lower of either 38 °C, or 14 °C higher than the initial quench bath temperature (PS§4.3.1.g). This quantity was determined by examining the temperature-time data from a thermocouple immersed in the quench bath.

4. **Dwell Duration**: This is the duration of the dwell phase between the end of quenching and the start of re-ageing. The maximum allowed duration of the dwell phase is 30 minutes at room temperature (PS§4.4.1). During the trial a count-down timer was used to ensure that the maximum dwell time is not exceeded. After the trial, the exact dwell duration was determined by examining the time stamps on the temperature-time data.

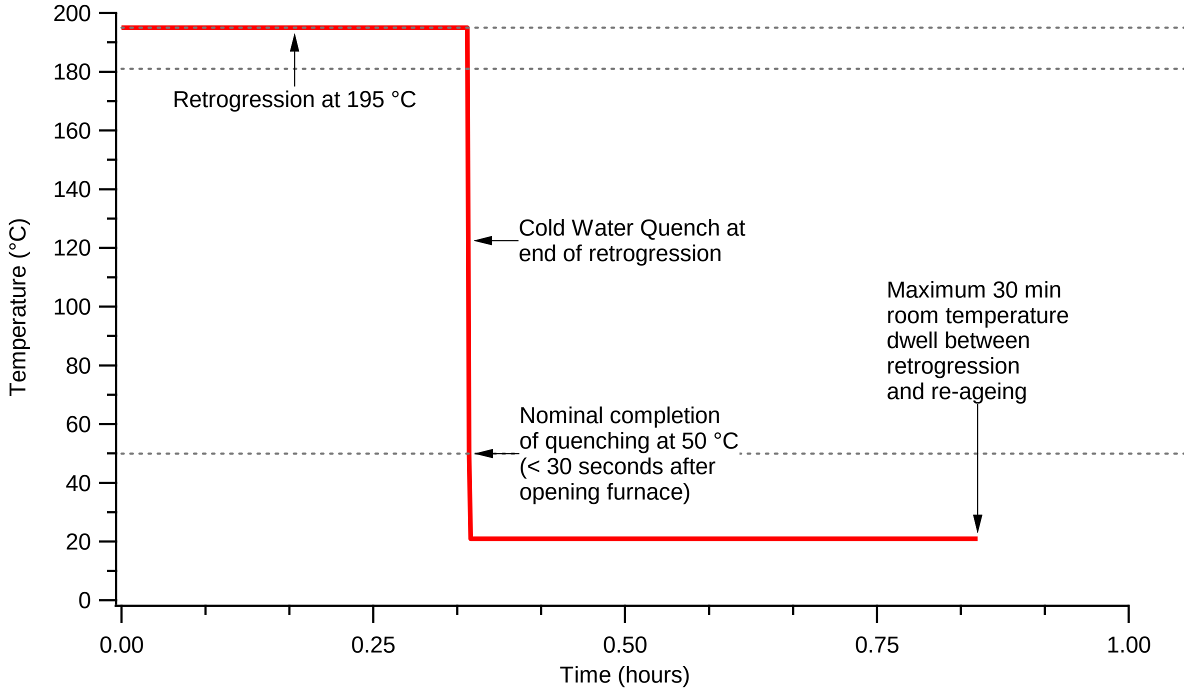


*Figure 8: Schematic of the temperature-time profile during the cold water quench phase of the RRA process. This figure is a subset of the complete heat treatment schedule shown in Figure 5. Note that parts of the retrogression and dwell phases adjacent to the quench phase are also shown.*

### 4.6.3 Re-ageing

Re-ageing starts after the dwell phase and finishes when the component returns to room temperature. The nominal temperature-time profile for the re-ageing phase is illustrated in Figure 9. From the Stage III Process Specification (Reference 9), the following is required:

1. **Initial Furnace Temperature:** the initial temperature of the furnace is not regarded as critical as long as it is below 120 °C to ensure that a stable re-aging ramp rate is achieved (PS§4.5.1.a). This quantity was determined by examination of the temperature-time data from the thermocouples attached to the component.
2. **Re-ageing Ramp Rate:** The rate at which the temperature of the furnace is to increase during the re-ageing phase is 2.0 ± 0.1 °C (PS§4.5.1.d). This quantity was determined by examination of the temperature-time data from the thermocouples suspended in the furnace.
3. **Re-ageing Temperature:** The target temperature for the component during the re-ageing phase is 120 °C. (PS§4.5.1.d).
4. **Re-Ageing Duration:** This is the time between when the set-point for the furnace reaches 120 °C and the removal of the component from the furnace and is 24 hours PS§4.5.1.d.
5. **Temperature Variation:** the maximum allowed temperature variation across the component during re-ageing. This is specified to be less than 10 °C (PS§4.3.1e) as measured by at least three thermocouples positioned evenly across the length of the component (PS§4.3.1a).[5]

[5] Note that the process specification only refers to temperature variation during the retrogression phase. DSTO considers that this requirement is also appropriate during re-ageing and this recommendation has been included in §8.

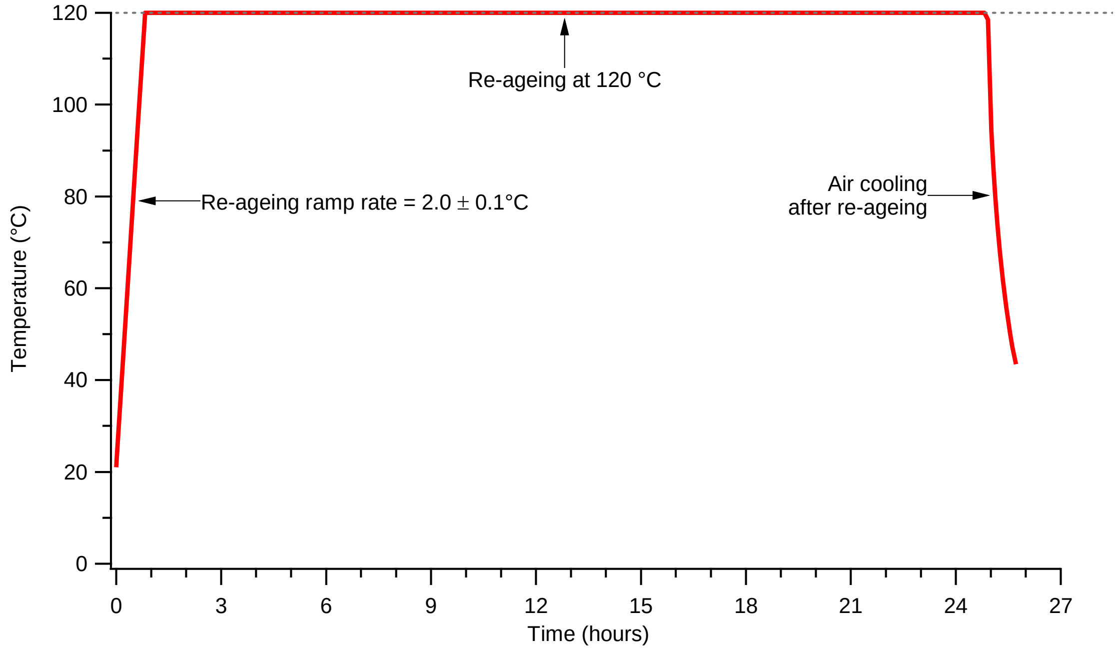


*Figure 9: Schematic of the temperature-time profile during the re-heating, re-ageing and final cooling phases of the RRA process. This figure is Phase 3 of the complete RRA heat treatment schedule shown in Figure 5.*

## 4.7 Comparative Metrology

The Component Properties Compliance Matrix (CPCM) in the Stage II DDP (Reference 19) specifies that RRA should not distort a component beyond the tolerances allowed for in the OEM's manufacturing drawings of the component. Unfortunately, the metrology data obtained during the Stage II trial were inconclusive with regard to component distortion. Therefore, this compliance item was replicated in the Stage III RTCM as Item 1.6.

In order to assess distortion, all three trial components had their dimensions measured before and after RRA treatment. These measurements were made by a metrology contractor - 3d Spatial[6] - using a multi-axis arm to which a laser scanning head was attached. The initial and final measurements were then compared to determine the degree to which the shape of the components was altered by RRA treatment. Further details of the method used by 3d Spatial can be found in the Stage II and Stage III Metrology reports (References 15 and 20).

# 5. Results

## 5.1 Introduction

This section describes the experimental results obtained before, during and after RRA treatment of the three components selected from the five available to be treated in the

[6] 3d Spatial, Level 2, 252 Graham Street, Port Melbourne, Victoria, 3207

reliability trials. Component selection and surface preparation are presented first, followed by the initial conductivity results, which were used to determine the retrogression times for each component. The temperature profiles collected from the trials are then presented and discussed in terms of the requirements set out in §4. Finally, the final electrical conductivity results are presented and discussed in terms of the requirements of the Stage III Process Specification.

## 5.2 Component Selection

The reliability trials detailed in this report only required that three components be tested (Reference 21). As a result it was necessary to select three candidate components from the available five. The criteria used for selection was that the components selected should have initial conductivities within, or at least close to the validity range of the retrogression time model. The electrical conductivities of the components (nominally identified 1 to 5) were measured in the laboratory at DSTO using a Foerster Sigmatest 2.069 electrical conductivity meter. Five replicate readings were made on each component and then the mean conductivity for the component determined. Note that these measurements were made under poorly controlled conditions by uncertified operators and that the components were still coated with primer at this stage. It is emphasised that these preliminary conductivity results were used only to sort the components and *not* to select retrogression times for the components.

The results obtained from the preliminary conductivity measurements are plotted against component identification number in Figure 10. Component 4 had the highest measured conductivity of any of the components, and it was decided that this component would be closely studied for the purpose of developing the retrogression time model (Reference 10). The remaining four components were prepared for use in the trial. After removal of the primer and subsequent measurement of the initial electrical conductivities of the components (Table 1), Component 1, 2 and 5 was selected for the trials while Component 3 was kept in reserve. Component 3 was subsequently used to validate the Retrogression Time Model (Reference 11).

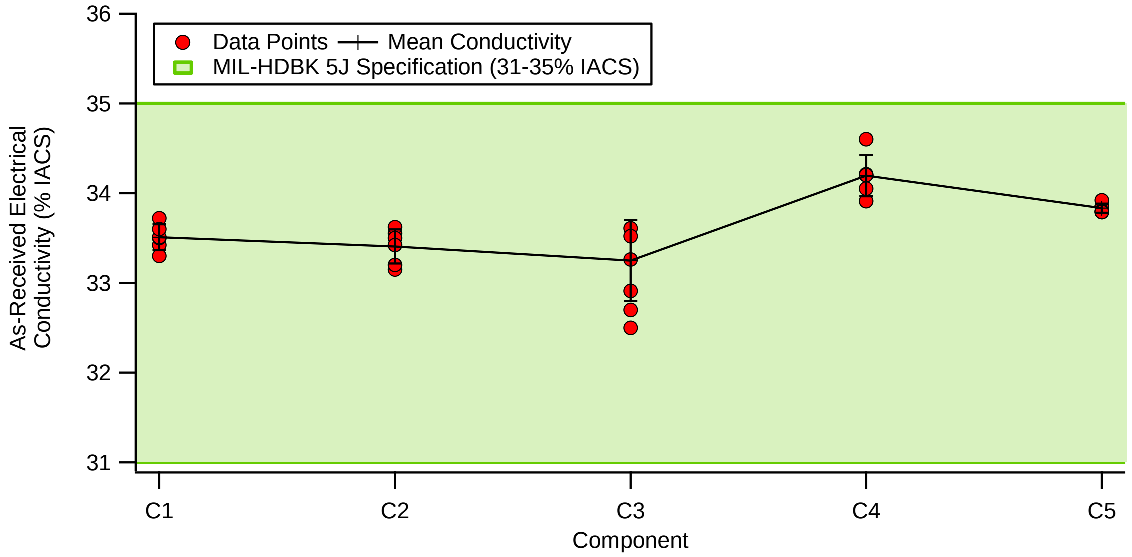


*Figure 10: Preliminary survey of the electrical conductivities of Components 1 to 5. Note the higher conductivity of Component 4 relative to the remaining components (Reference 10).*

## 5.3 Component Surface Preparation

As indicated in §4.3 the primer was removed from the components using low velocity glass bead peening, which left a slightly roughened surface. The roughness of this surface was measured as part of the initial electrical conductivity testing of the components (§5.4). It was found that its roughness exceeded the maximum of 165 RMS recommended by the RAAF NDT General Procedures (Reference 22). However, comparison of conductivity measurements made on polished and unpolished sections of Component 2 in the region of Position A (Figure 4) showed that the variation in conductivity measurements was less than the measurement accuracy of the conductivity meter (Appendix C1). Consequently, the NDT operator indicated that surface roughness of the component was not a significant factor, and that it would not be necessary to polish the planned measurement locations on the components prior to measurement.

## 5.4 Initial Electrical Conductivity

Figure 11, Figure 12 and Figure 13 plot the location mean initial electrical conductivity versus position along Components 1, 2 and 5 respectively. The mean conductivity of each component as well as the minimum and maximum location mean conductivities of each component are given in Table 1. Electrical conductivities that were found to be outside the initial conductivity range of the retrogression time model are marked in red. Only Component 5 was fully compliant with the specified range. Components 1 and 2 had maximum conductivities above the model's range, while Component 3 was completely outside the range of the model. It should be noted that Component 4 is not included in this table because it was used to develop the retrogression time model, and had been heat-treated and sectioned by the time the measurements reported in Table 1 were made. Based on the results in Table 1, Components 1, 2 and 5 were selected for the Stage III Reliability Trials.

Table 1 also includes the range of the electrical conductivity readings for each component (i.e. the difference between the highest and lowest reading). The range was relatively large for Components 1 and 2 compared to Components 3 and 5. Component 1 had a conductivity range of 0.86% IACS which is close to the 1 percentage point range (i.e. 38% - 39%) allowed for final electrical conductivity.

*Table 1: Initial electrical conductivity of all components*[7]

| Component | Conductivity* (% IACS) | | | |
|---|---|---|---|---|
| | Mean | Minimum | Maximum | Range |
| 1 | 33.51 | 33.03 | 33.89 | 0.86 |
| 2 | 33.51 | 33.10 | 33.79 | 0.69 |
| 3 | 34.06 | 33.94 | 34.19 | 0.25 |
| 5 | 33.56 | 33.37 | 33.67 | 0.30 |

*Conductivities outside the range of the Retrogression Time Model are marked in RED

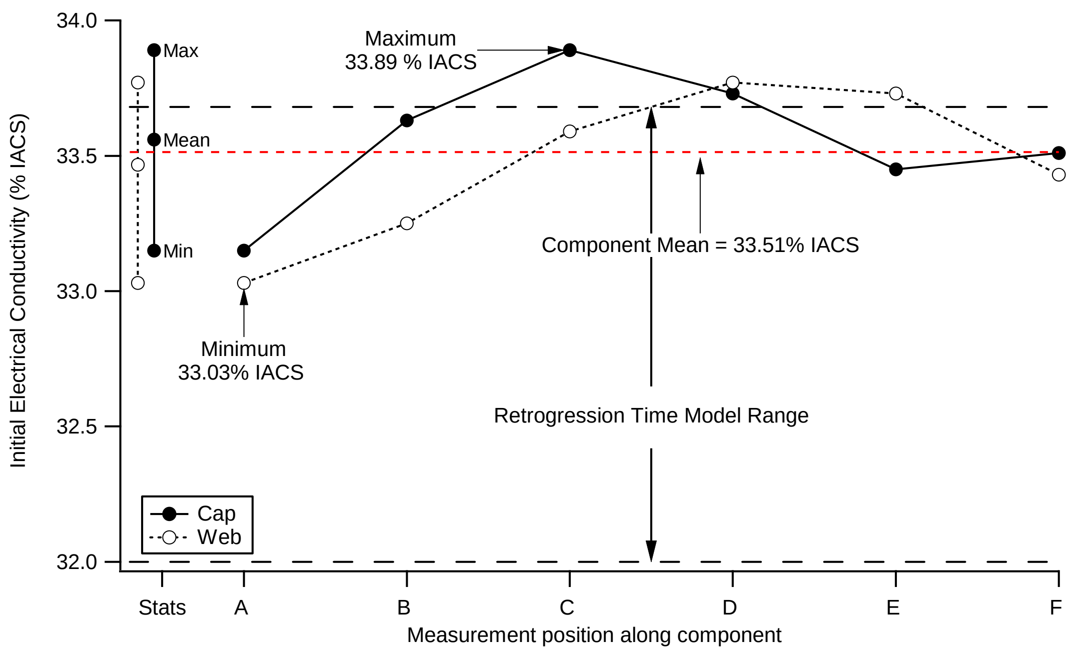


*Figure 11: Component 1 initial electrical conductivity versus position on the component*

[7] Note that Component 4 was used to develop the retrogression time model (Reference 11)

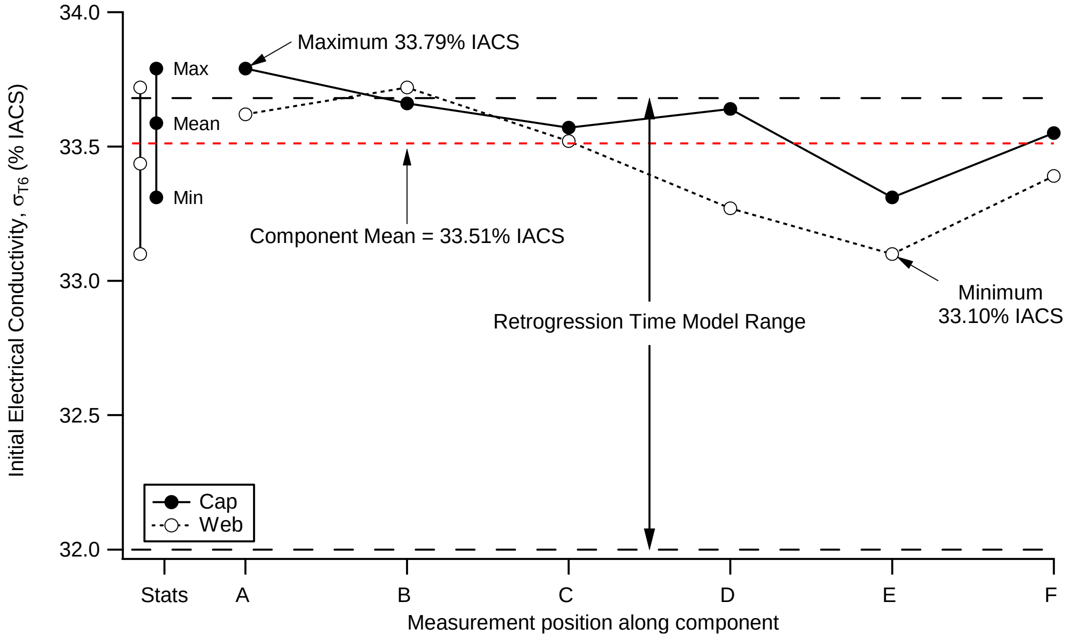


*Figure 12: Component 2 initial electrical conductivity versus position on the component*

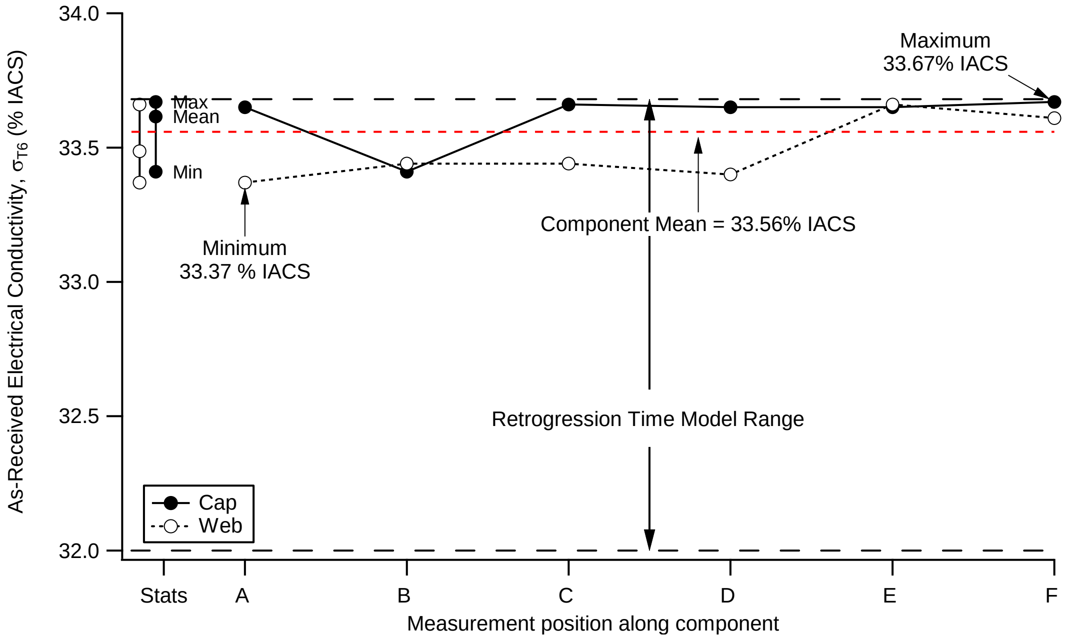


*Figure 13: Component 5 initial electrical conductivity versus position on the component*

## 5.5 RRA Treatment

### 5.5.1 Temperature Profile – Retrogression

Temperature-time traces for Components 1, 2 and 5 for the retrogression phase of the heat treatment are shown in Figures 14, 15 and 16 below. These figures also show the component temperature range[8] versus time during this phase for each component. The figures also contain some data from the quench phase as that defines the end of the retrogression phase.

The horizontal axis is labelled 'Time above 181 °C (minutes)' as PS§4.3.1.e in the Stage III Process Specification states that the retrogression phase begins when any part of the component exceeds 181 °C. Consequently, '0' on the x-axis of each graph represents the start of retrogression (i.e. when the component first exceeds 181 °C). Pre-heating to 181 °C is indicated by 'negative' time values.

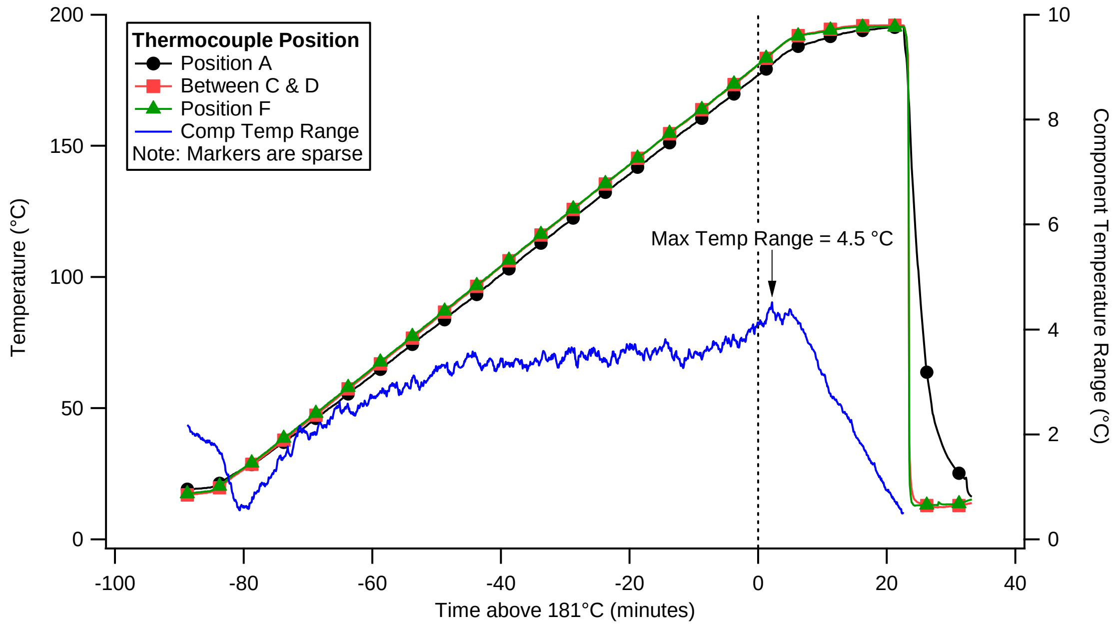


*Figure 14: Temperature-time data collected from the thermocouples attached to the component during retrogression of Component 1. The component temperature range is the difference between the hottest and coldest thermocouples on the component.*

[8] Component temperature range = the temperature difference between the hottest and coldest thermocouples attached to the component

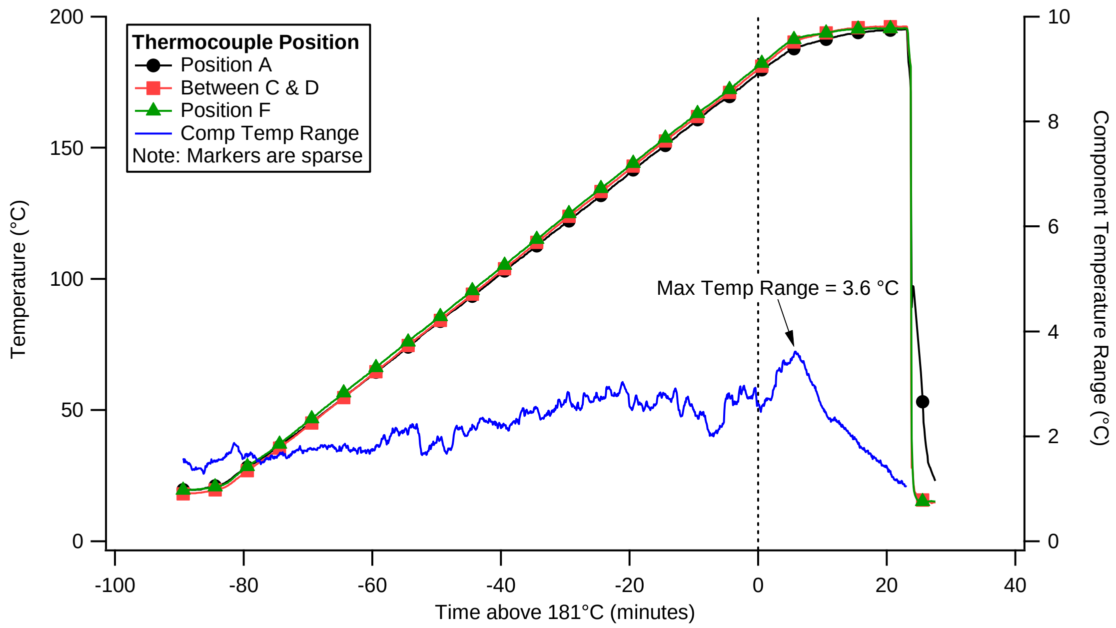


*Figure 15: Temperature-time data collected from the thermocouples attached to the component during the retrogression of Component 2. The component temperature range is the difference between the hottest and coldest thermocouples.*

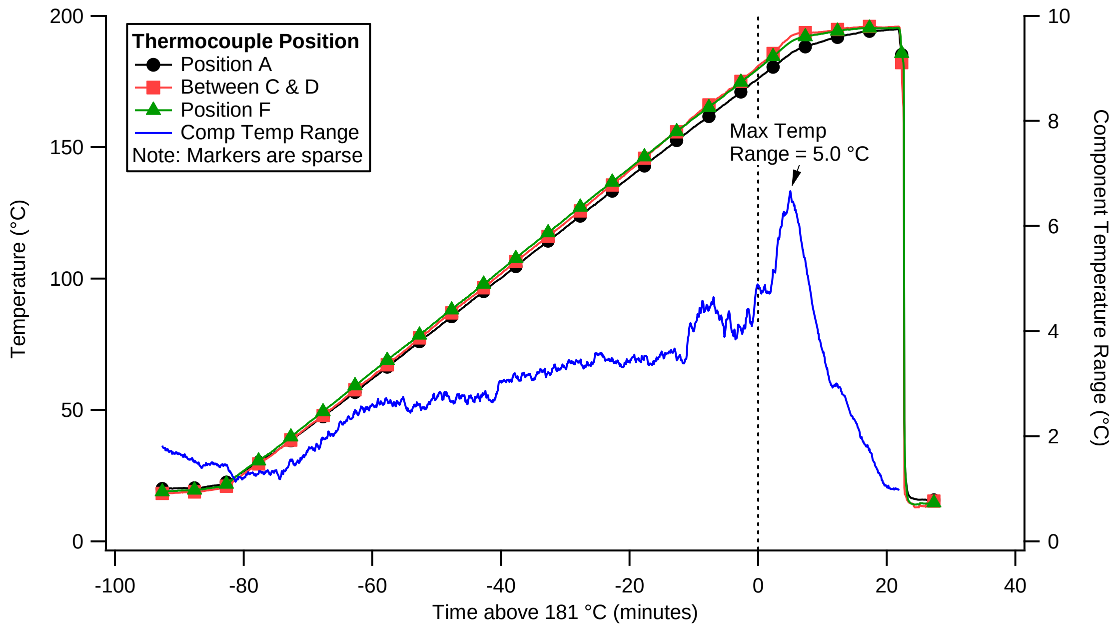


*Figure 16: Temperature-time data collected from the thermocouples attached to the component during the retrogression of Component 5. The component temperature range is the difference between the hottest and coldest thermocouples.*

The following sections investigate the performance of the three trial components against the four requirements drawn from the Stage III Process Specification.

#### *5.5.1.1 Initial Heating*

Figure 17, Figure 18 and Figure 19 show the initial heating phases for Components 1, 2 and 5 respectively. These traces were compiled from the data acquired by BACR (References 16, 17 and 18) and DSTO equipment during the trials. The component temperature traces indicate the maximum and minimum temperatures as measured by the three thermocouples attached to the components. The furnace set-point temperature ramp rate in all cases was 1.96 °C/min, which was within the allowed 2.0 ± 0.1 °C/min required by PS§4.3.1d. The process temperature traces show that the furnace air temperature and component temperature matched closely with the set-point temperature during heating. Examination of the component temperatures data showed that the component temperature ramp rates were within 0.04 °C/min across all locations for all components.

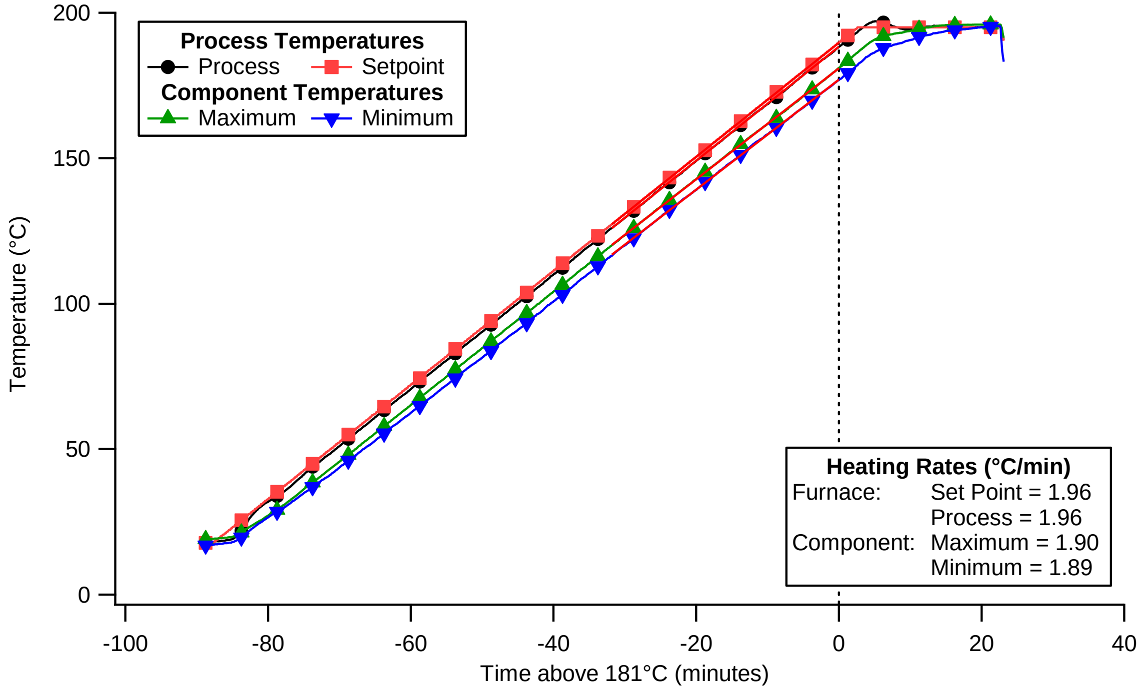


*Figure 17: Heating rates for Component 1 and the furnace during the initial heating phase*

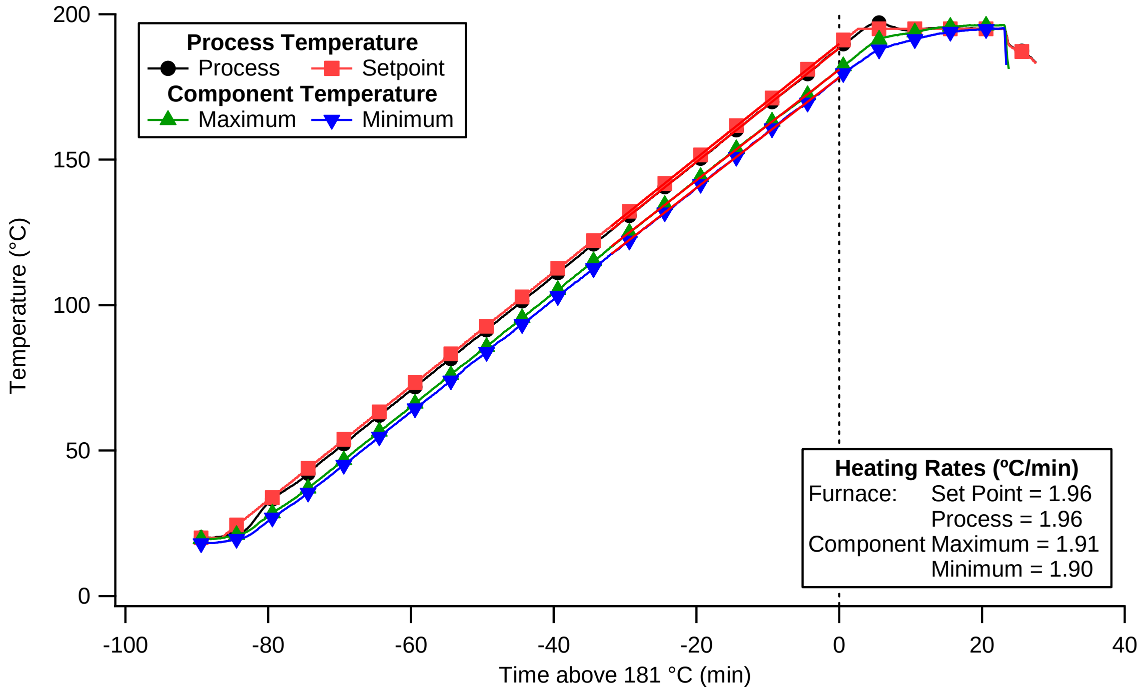


*Figure 18: Heating rates for Component 2 and the furnace during the initial heating phase*

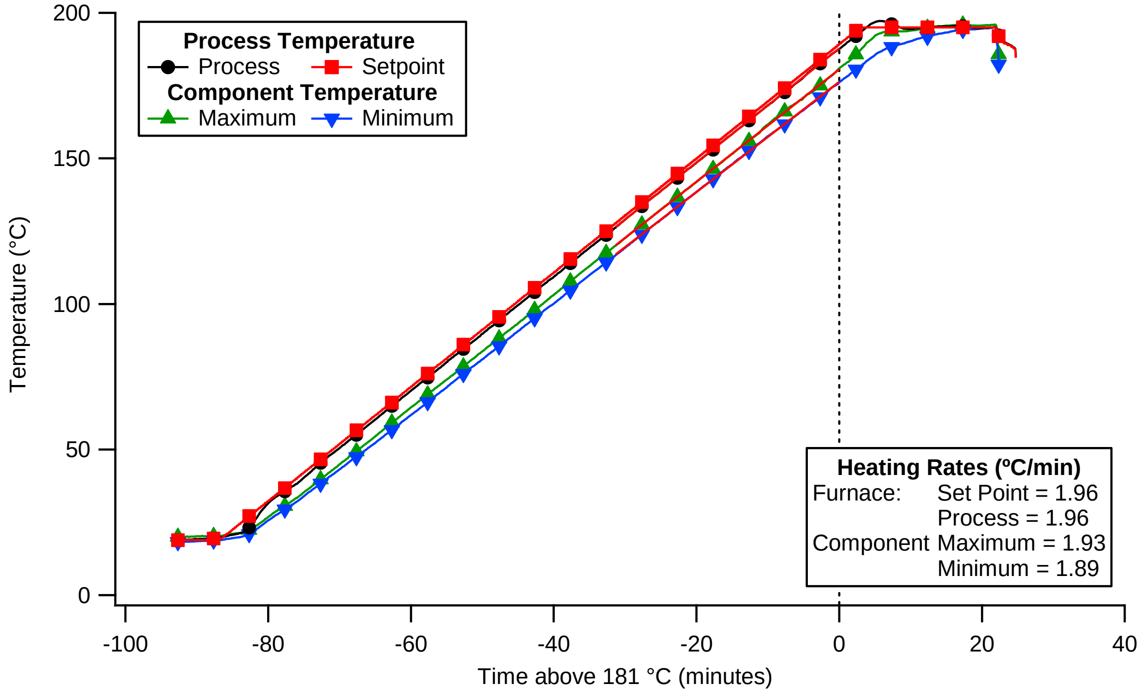


*Figure 19: Heating rates for Component 5 and the furnace during the initial heating phase*

#### *5.5.1.2 Retrogression Temperature and Time*

In order to clearly show temperature trends during retrogression, Figures 20, 21 and 22 show the temperature-time data from the point that thermocouple readings exceeded 181 °C, for components 1, 2 and 5, respectively. In each case it was noted that the temperature at the component's midpoint (i.e. between positions C and D) and Position F were very similar throughout the retrogression phase. In contrast, Position A was up to seven degrees colder than the other locations.

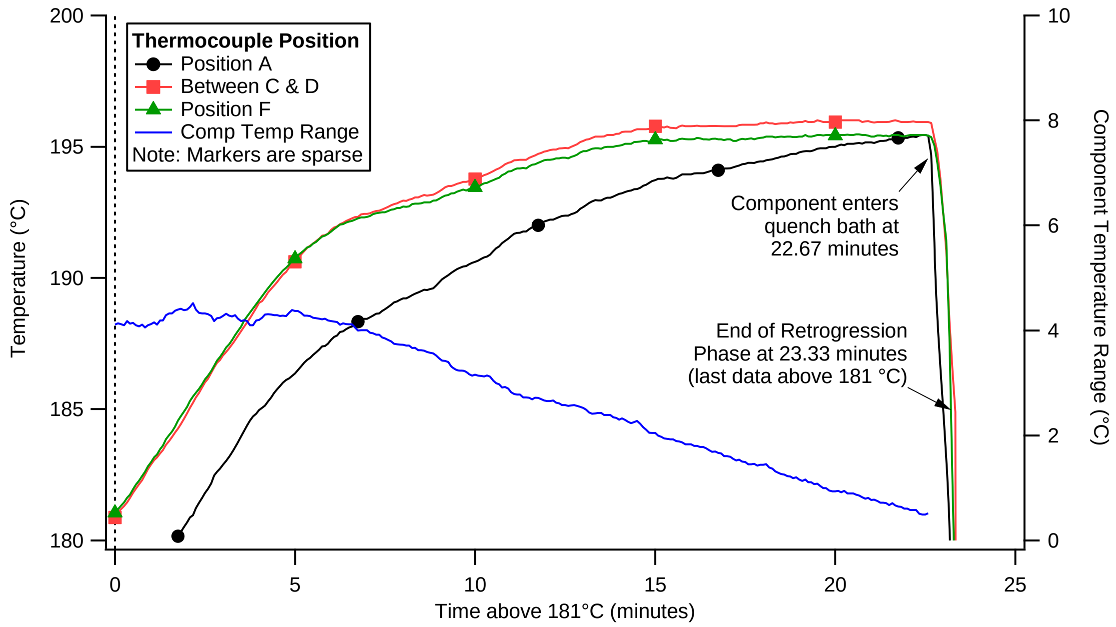


*Figure 20: Temperature-time data collected from the thermocouples attached to Component 1 during its retrogression processing after component temperatures exceeded 181 °C. The component temperature range is the difference between the hottest and coldest thermocouples on the component.*

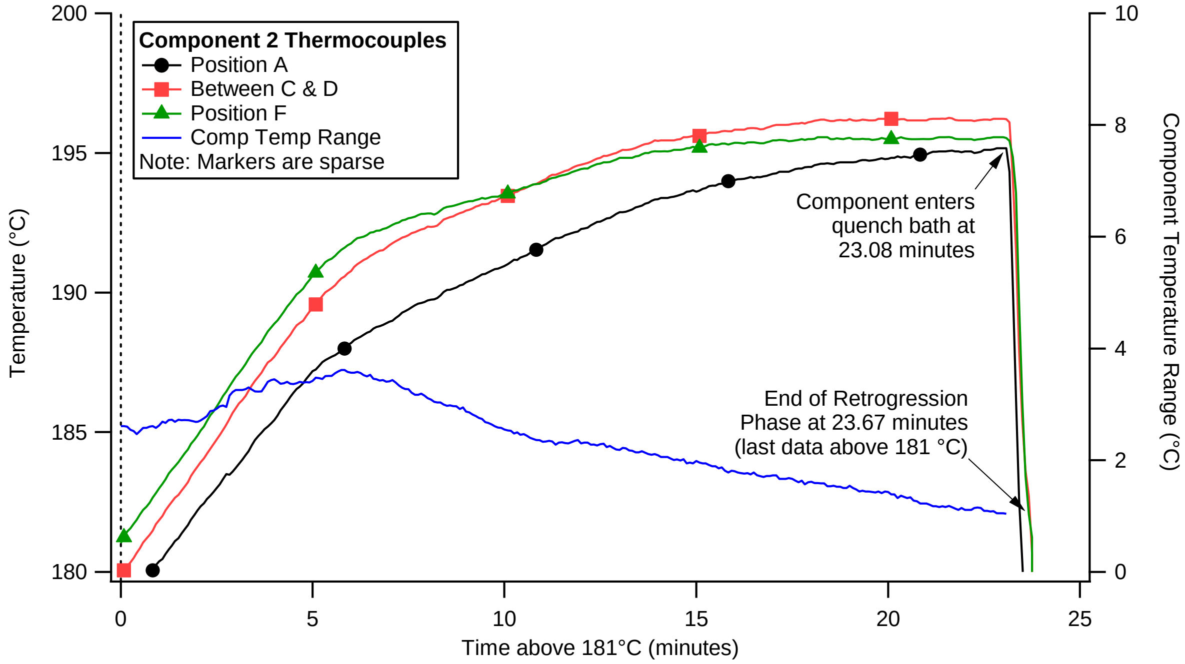


*Figure 21: Temperature-time data collected from the thermocouples attached to Component 2 during its retrogression processing for temperatures above 181 °C. The component temperature range is the difference in temperature between the hottest and coldest thermocouples on the component.*

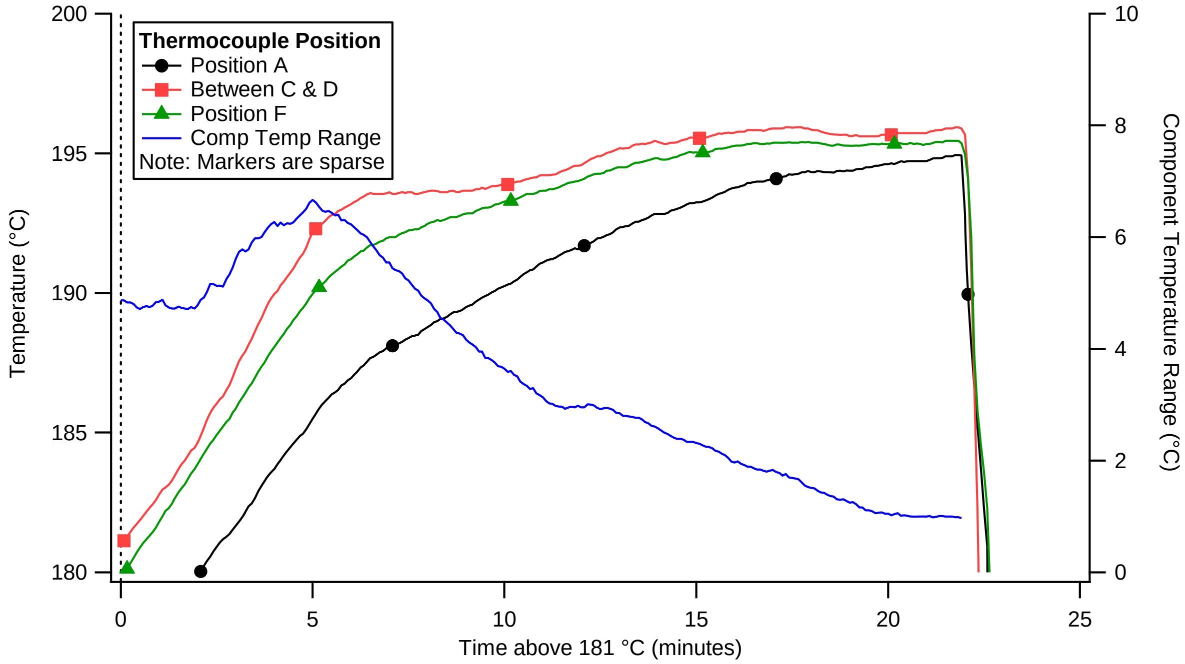


*Figure 22: Temperature-time data collected from the thermocouples attached to Component 5 during its retrogression for temperatures above 181 °C. The component temperature range is the difference between the hottest and coldest thermocouples on the component.*

The Stage III Process Specification gives recommended retrogression times for components based on their initial electrical conductivities. Nominal retrogression times according to PS§4.3.1e are taken from when any part of the component first exceeds 181 °C until when the furnace door is opened. The opening of the furnace was determined by examination of the temperature traces in Figures 23, 24 and 25. Actual retrogression time (i.e. the total time any part of the component is above 181 °C) was used for modelling purposes, which required the increased accuracy of that measure (Reference 11). Actual retrogression times were determined directly from the temperature-time data. The difference between the nominal and actual retrogression values is the time period between the furnace door opening and the component dropping below 181 °C, which is the quenching time shown in Table 2 below.

*Table 2: Retrogression times for components used in the trial*

| **Component** | **Initial Conductivity (% IACS)** | **Desired Retrogression Time (min:sec)** | **Nominal Retrogression Time (min:sec)** | **Actual Retrogression Time (min:sec)** | **Quenching Time (seconds)** |
|---|---|---|---|---|---|
| 1 | 33.51 | 22:43 | 22:35 | 23:20 | 45 |
| 2 | 33.51 | 22:45 | 23:05 | 23:45 | 40 |
| 5 | 33.56 | 21:35 | 21:55 | 22:40 | 40 |

The retrogression temperature was provided by DSTO for the purpose of the BACR work orders (Appendix E). The maximum value of the set point was 195 °C as required by the Stage III Process Specification. This is also shown by the temperature traces for all thermocouples (see Figures 20, 21 and 22), which peak at 195 °C after a period of time.

#### *5.5.1.3 Temperature Variation*

Component temperature variation was taken as the maximum temperature range seen during retrogression. For all three components, the maximum variation occurred slightly after the component reached 181 °C, which coincided with the furnace air temperature reaching 195 °C. The maximum temperature variation during the retrogression phase was 4.5 °C for Component 1, 3.6 °C for Component 2 and 6.7 °C for Component 5.

### 5.5.2 Temperature Profile – Post-Retrogression Quenching

The temperature-time data for Components 1, 2 and 5 during cold water quenching are shown in Figures 23, 24 and 25. These figures show that it took between 40 and 45 seconds to remove the components from the furnace and insert them into the quench bath. These data are also shown in Table 2. It took another 5 to 10 seconds for the temperature of the components to drop below 50 °C. In total, this is less than the three minute (180 second) maximum time allowed by PS§4.3.1.f in the Stage III Process Specification (Reference 9).

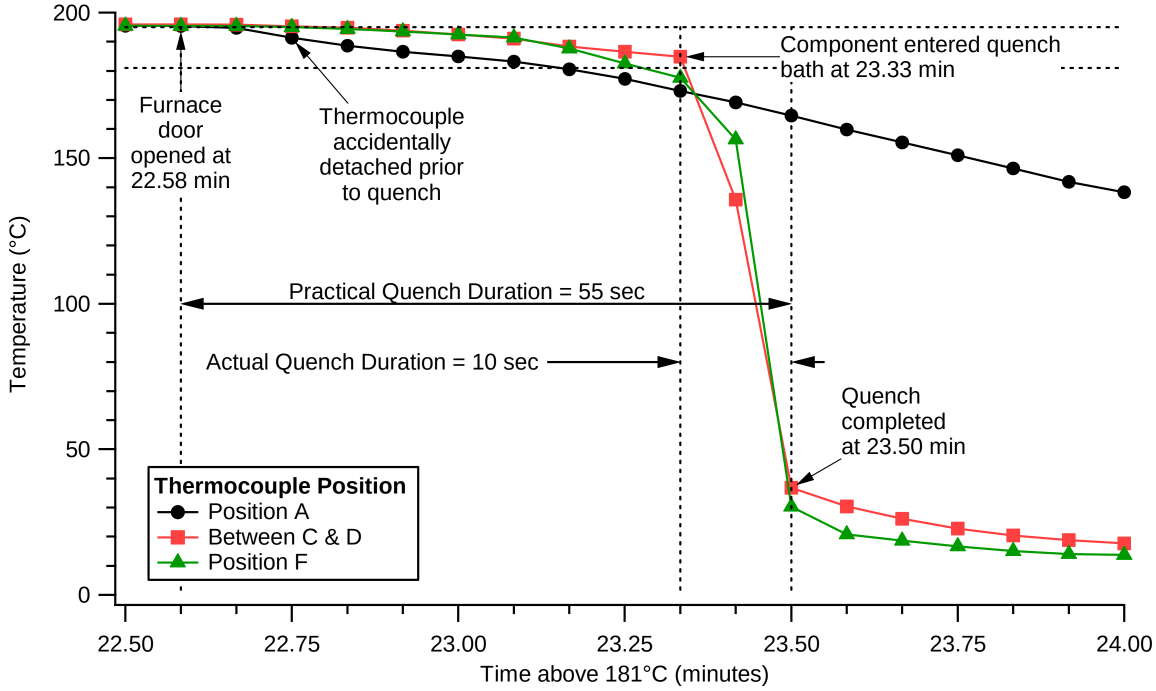


*Figure 23: Temperature-time data collected from the thermocouples attached to the component during cold water quenching of Component 1*

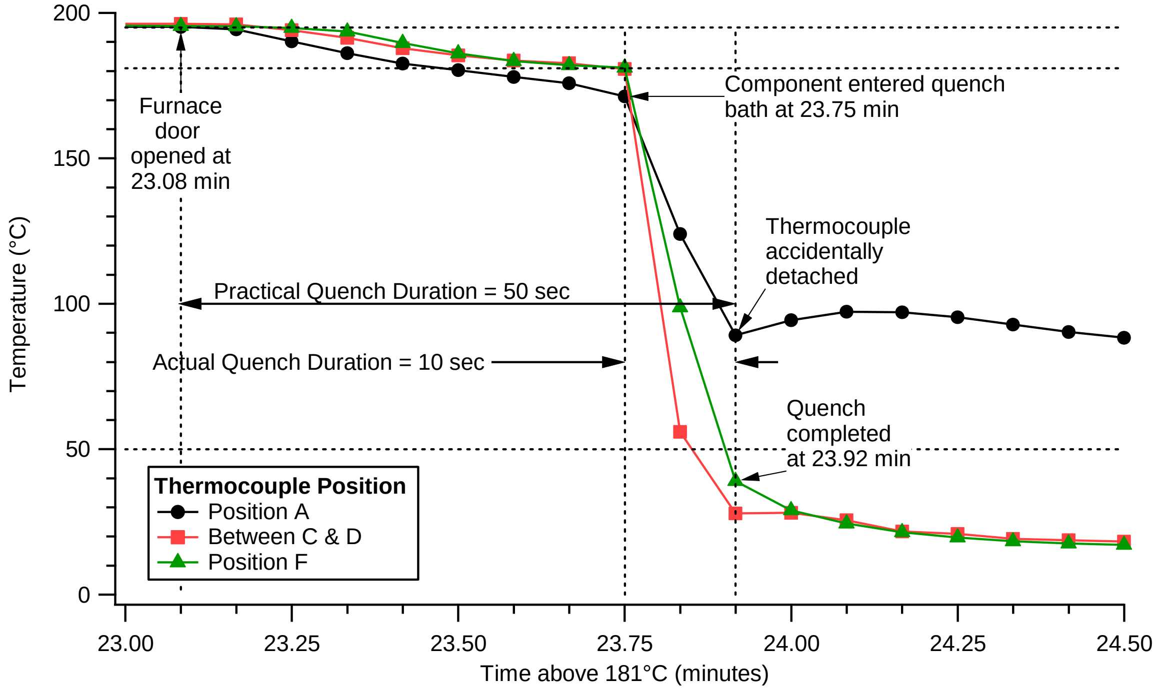


*Figure 24: Temperature-time data collected from the thermocouples attached to the component during cold water quenching of Component 2*

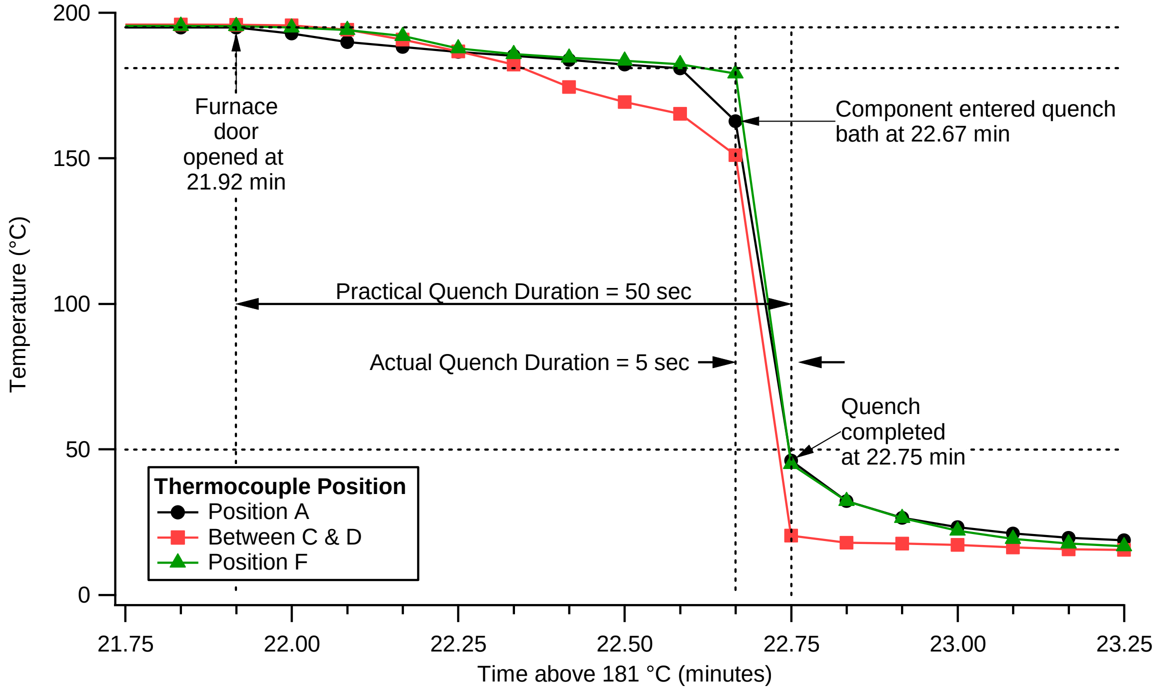


*Figure 25: Temperature-time data collected from the thermocouples attached to the component during cold water quenching of Component 5*

The temperature data for the quench bath are shown in Figures 26, 27 and 28 below. The intent of the requirement in PS§4.3.1g of the Stage III Process Specification is that the quenchant may increase in temperature by up to 14 °C but its initial temperature must be below 32 °C and its final temperature must be below 38 °C. From Table 3 it can be seen that the initial temperature of the quenchant was less than 32 °C and the final temperature was below 38 °C for all components. Table 3 also shows that the quenchant temperature increased by between 1.9 and 2.3 °C across the three components, which is significantly less than the maximum of 14 °C allowed by the specification.

*Table 3: Quenching data for all components*

| Component | Temperatures (°C) | | | | Dwell Time (min) |
|---|---|---|---|---|---|
| | Initial Quench bath | Final Quench Bath | Acceptable Initial Quench Bath | Acceptable Final Quench Bath [9] | |
| 1 | 12.9 | 15.1 | <32.0 | <26.9 | 12.7 |
| 2 | 15.0 | 16.9 | <32.0 | <29 | 15.5 |
| 5 | 13.6 | 15.9 | <32.0 | <27.6 | 11.4 |

[9] Acceptable final quench bath temperature is the minimum of 38 °C or 14 °C greater than the initial quench bath temperature. For all components, this was initial quench bath temperature plus 14 °C.

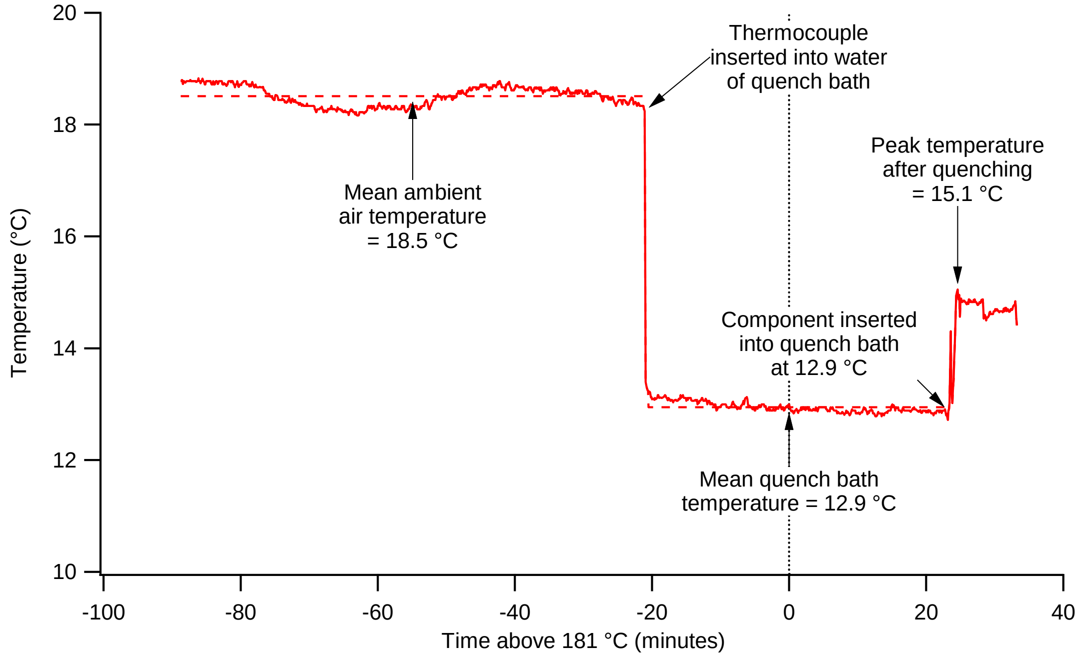


*Figure 26: Quench water temperature-time data during retrogression and quenching of Component 1. Note that the thermocouple was inserted into the bath prior to quenching of Component 1, but was not removed from the bath until after the completion of the quench of Component 5 (see Figures 27 and 28).*

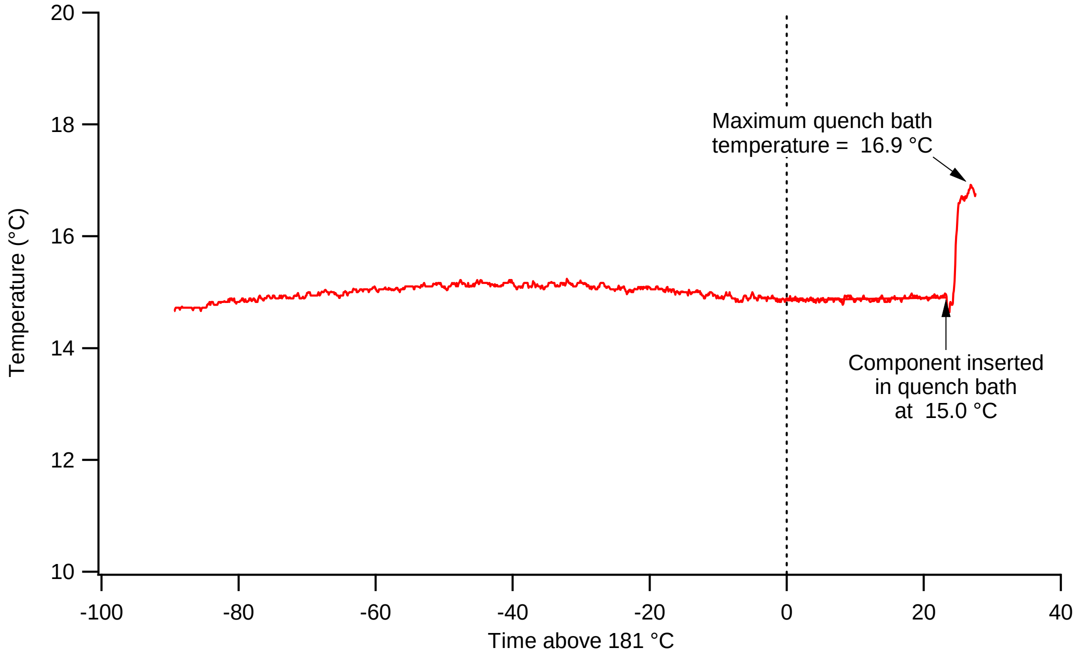


*Figure 27: Quench water temperature-time data during retrogression and quenching of Component 2*

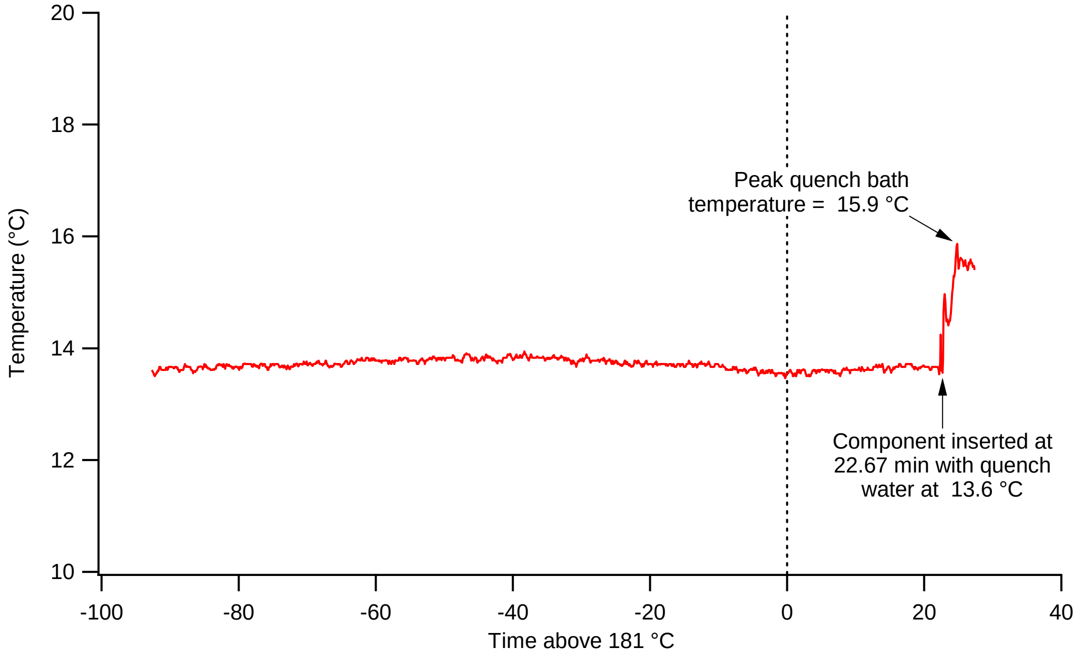


*Figure 28: Quench water temperature-time data during retrogression and quenching of Component 5*

Table 3 also shows the duration of the dwell time between the end of quenching and the start of component re-heating for the purpose of the re-ageing phase. For all three components, the dwell was less than the 30 minutes maximum allowed by PS§4.4.1.

### 5.5.3 Temperature Profile – Re-Ageing

The temperature-time data for the re-ageing and final cooling phases of each component are shown in Figures 29, 30 and 31. For a stable re-ageing ramp rate to be achieved, the initial furnace temperature must be below 120 °C. This requirement was achieved for all three components, and the ramp rates are shown in Table 4, along with the re-ageing durations and temperatures. The set-point values indicated that the re-ageing duration was 24 hours for all three components, i.e. the furnace was set to maintain 120 ° C for 24 hours. The duration for which each component was maintained at the required re-ageing temperature was confirmed from the thermocouple data and is included in Table 4 below.

*Table 4: Re-ageing data for all components*

| **Component** | **Initial Furnace Temperature (°C)** | **Re-ageing Ramp Rate (°C/min)** | **Re-ageing Set-Point (target) Temperature (°C)** | **Mean Re-ageing Temperature (°C)** | **Component Duration at temperature (hours)** | **Maximum Temperature Range (°C)** |
|---|---|---|---|---|---|---|
| 1 | <120 | 1.96 | 120 | 121 | 23.8 | 1.4 |
| 2 | <120 | 1.96 | 120 | 121 | 23.8 | 1.5 |
| 5 | <120 | 1.96 | 120 | 121 | 24.0 | 2.5 |

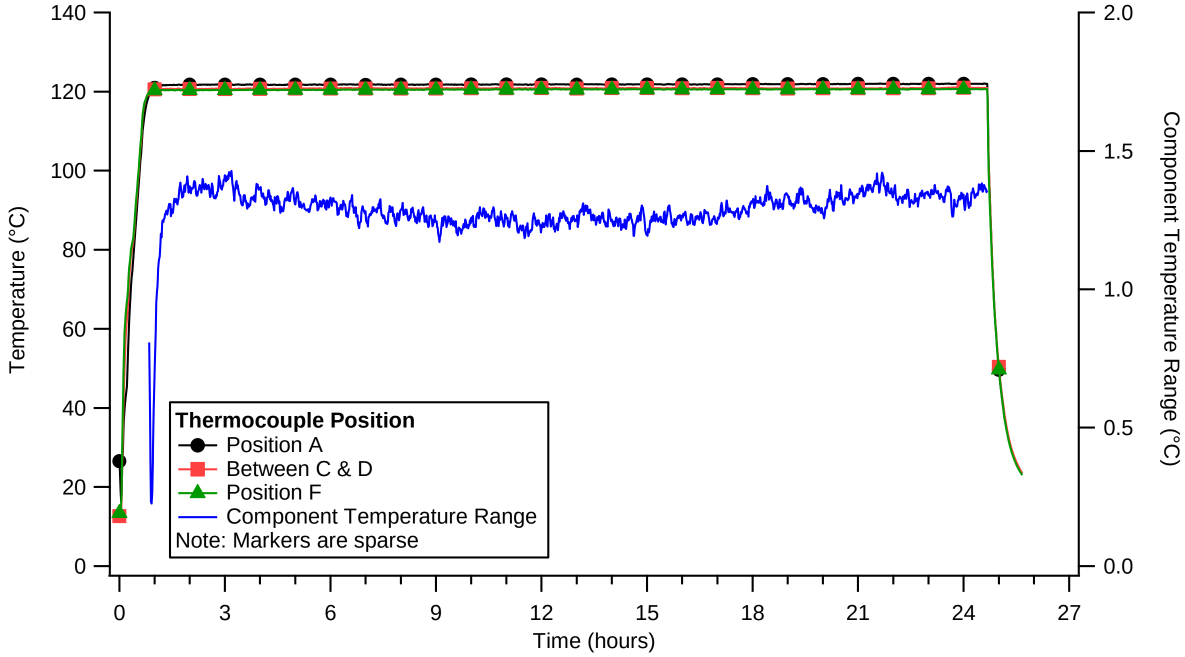


*Figure 29: Temperature-time data from the re-ageing of Component 1. 'Component Temperature Range' is the difference between the maximum and minimum temperatures measured by thermocouples attached to the component.*

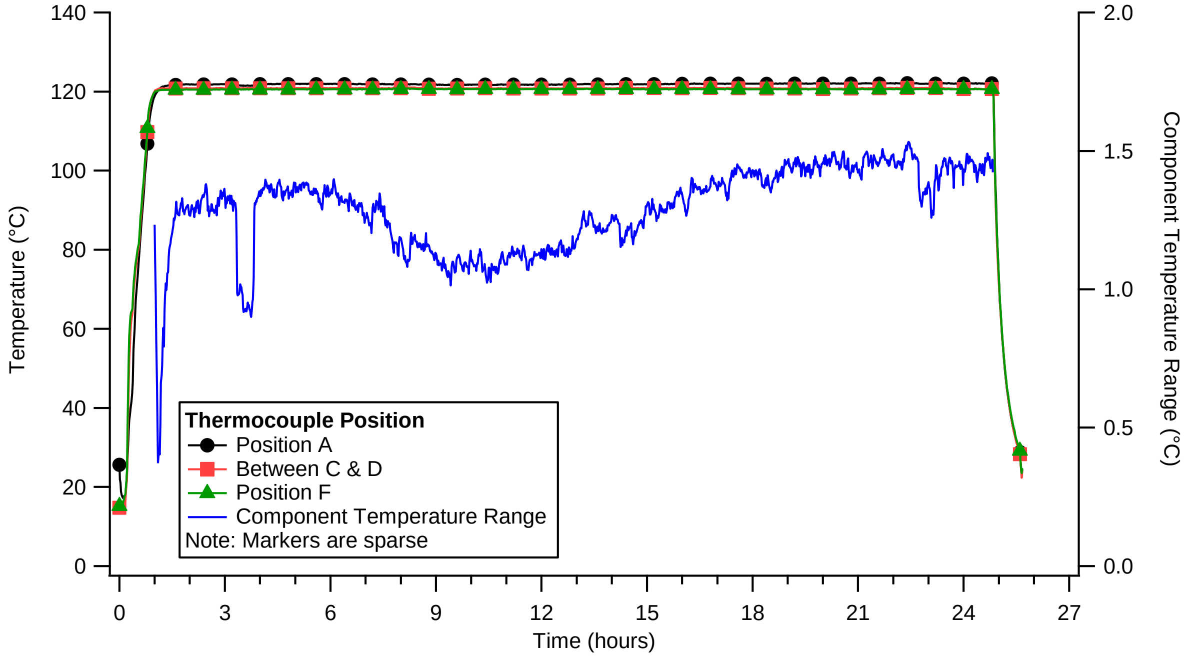


*Figure 30: Temperature-time data from the re-ageing of Component 2. 'Component Temperature Range' is the difference between the maximum and minimum temperatures measured by thermocouples attached to the component.*

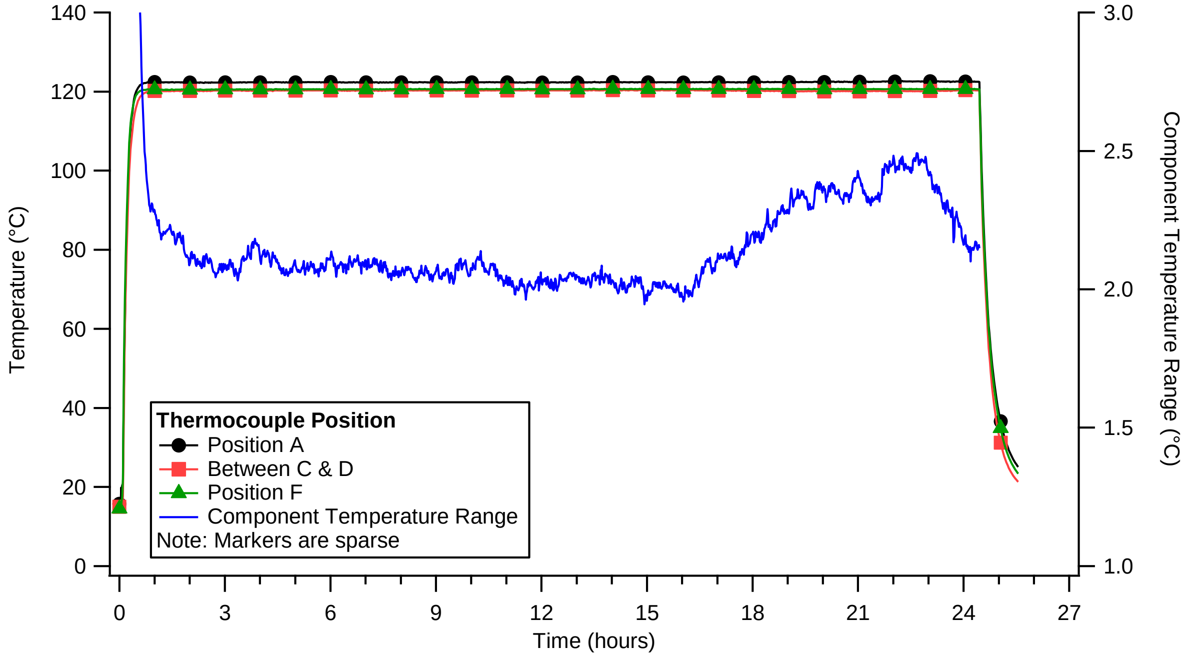


*Figure 31: Temperature-time data from the re-ageing of Component 5. 'Component Temperature Range' is the difference between the maximum and minimum temperatures measured by thermocouples attached to the component.*

## 5.6 Final Electrical Conductivity

The final electrical conductivities of Components 1, 2 and 5 as a function of position along the component are plotted in Figure 32, Figure 33 and Figure 34, respectively. Components 1 and 2 had mean electrical conductivities of 39.3 and 39.29 %IACS respectively. These values are outside the 37.81% to 39.20% IACS (including an allowance for instrument tolerances)[10] range specified in PS§4.6.1 of the Stage III Process Specification (Reference 9). All three components had locations that were outside of the required range. These locations are highlighted in Figure 32, Figure 33 and Figure 34 below using different symbols to highlight the in-tolerance locations.

[10] The Stage III Process Specification in PS§4.6.1 specifies a final conductivity range between 38 and 39% IACS, but also allows for values outside that range if they can be shown to be within the reading tolerance of the conductivity meter used to make the measurements. The Forster Sigmatest 2.069 meter used to measure conductivities detailed in this report has a tolerance of 0.5%of the measured value, which has been included here.

In contrast, the Forster Sigmatest 2.068D electrical conductivity meter that was used for conductivity measurements in Stages I and II of the RRA project had a 1% of the measured value instrument tolerance. That would give an acceptable range of 37.62 to 39.39% IACS. Note that the original 38 to 39%IACS range of acceptable final electrical conductivity ranges was also determined using the 2.068D meter.

The significance of this change in instrument tolerance is discussed in detail in §6.1.

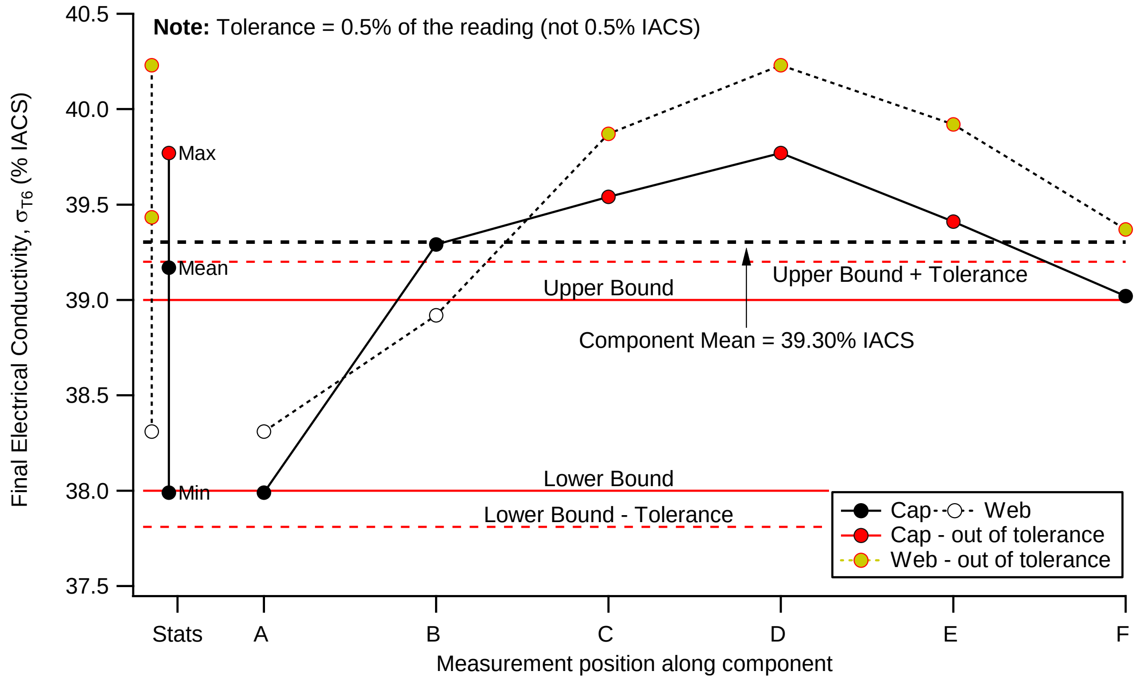


*Figure 32: Component 1 final electrical conductivity as a function of position on the component*

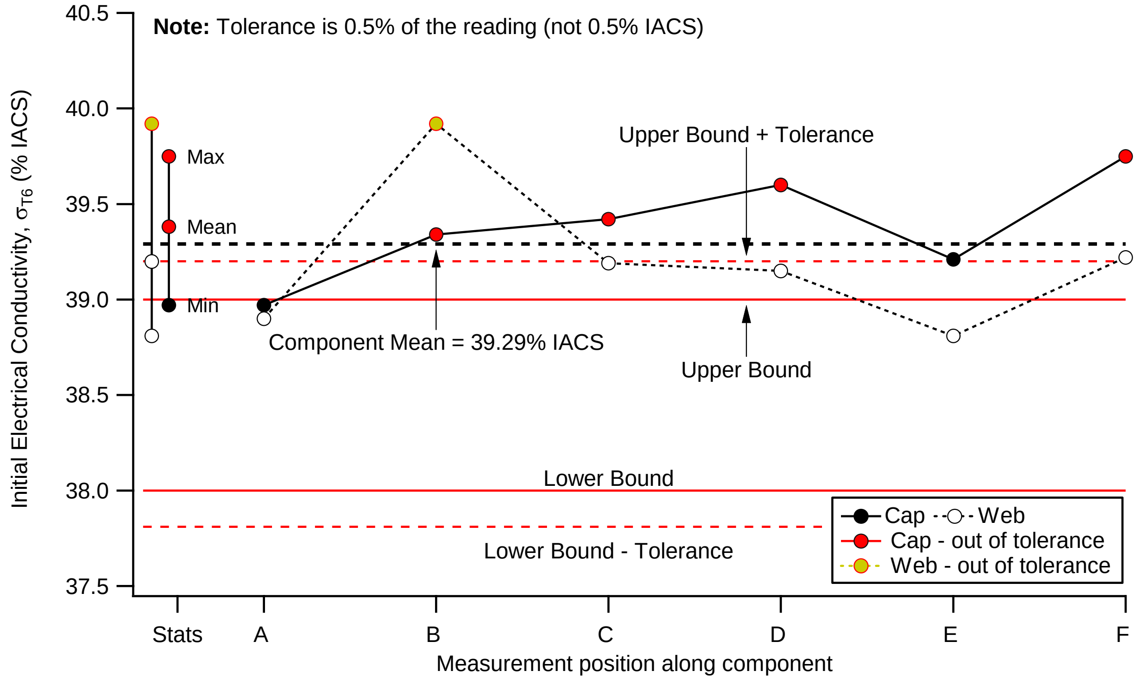


*Figure 33: Component 2 final electrical conductivity as a function of position on the component*

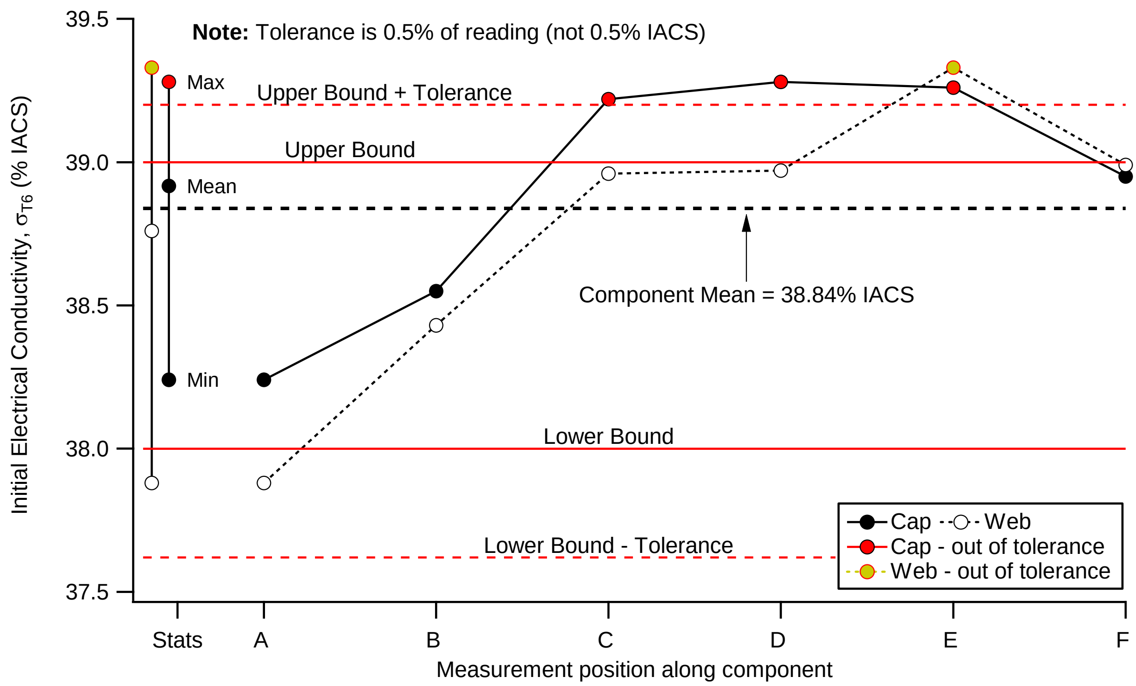


*Figure 34: Component 5 final electrical conductivity as a function of position on the component*

Comparing the initial and final electrical conductivity measurements of Component 1 as a function of position along the component, it is apparent that RRA treatment has increased the range of electrical conductivity of the component from 0.86% IACS to 2.24% IACS. The majority of this increase however is due to a smaller increase in conductivity of Position A on this component compared to the other positions. This is most likely because Position A was colder than other parts of the component during retrogression (Figure 20). This can be seen in Figure 35 which plots the actual change in electrical conductivity of Component 1 versus position and compares this change with the change expected from the model in Annex A of the Stage III Process Specification. The expected change values shown in Figures 35, 36 and 37 below are based on the recommended retrogression time for the component rather than for each location from temperature trace data.

Although the temperature variations for all components were well under the maximum of 10 °C recommended by the Process Specification, they caused significant differences in the final conductivities along the length of the component. These differences were exaggerated further by the low retrogression times required because of the high initial electrical conductivities. The retrogression time model developed (Reference 10) recognised that this dog leg may occur. The variations are not considered a problem as the deviations shown are the maximum possible under the system.

All components showed an increase in the range of electrical conductivity values as a result of RRA treatment. Component 2 had maximum change in conductivity in the area (Position B) that experienced lower temperatures during retrogression (thermocouple at Position A recorded the lowest readings). The limitations of the point by point measurement technique for conductivity are discussed below in §6.2.

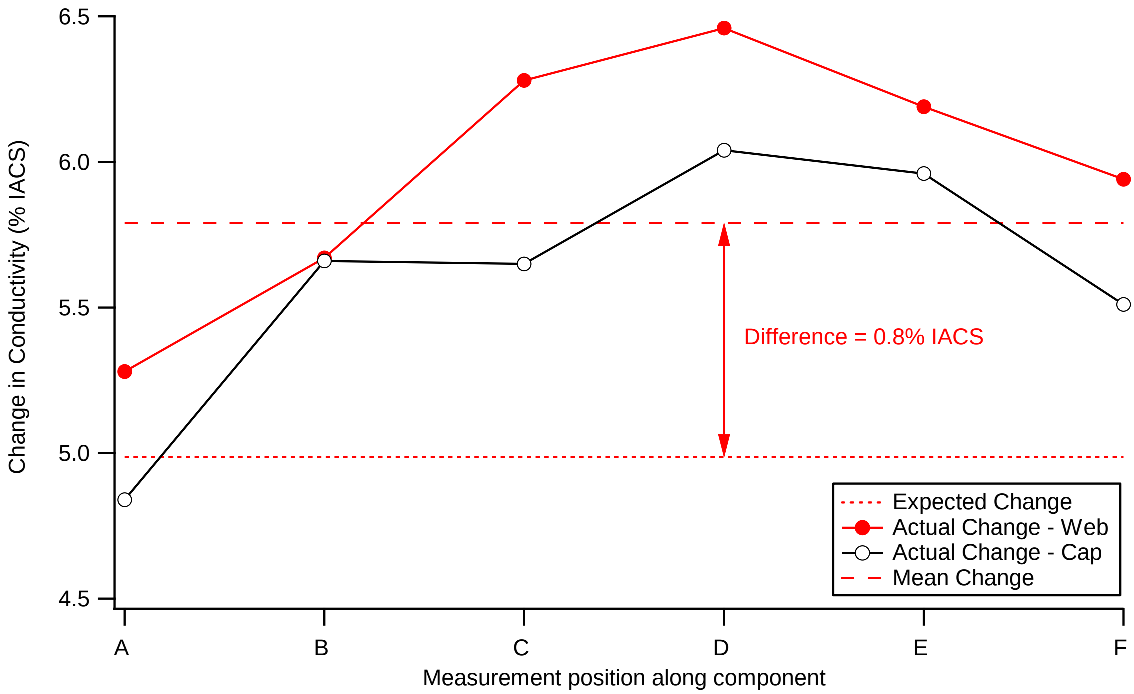


*Figure 35: Comparison for Component 1 between actual change in conductivity as a function of position on the component, expected change in conductivity and mean change in conductivity*

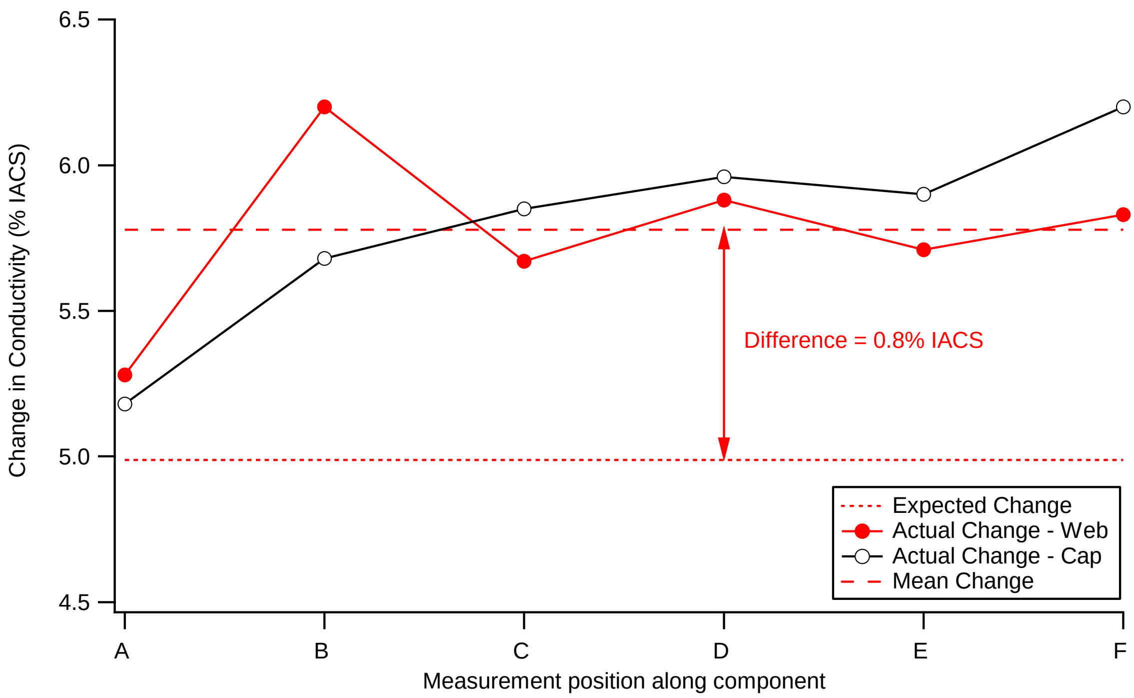


*Figure 36: Comparison for Component 2 between actual change in conductivity as a function of position on the component, expected change in conductivity and mean change in conductivity*

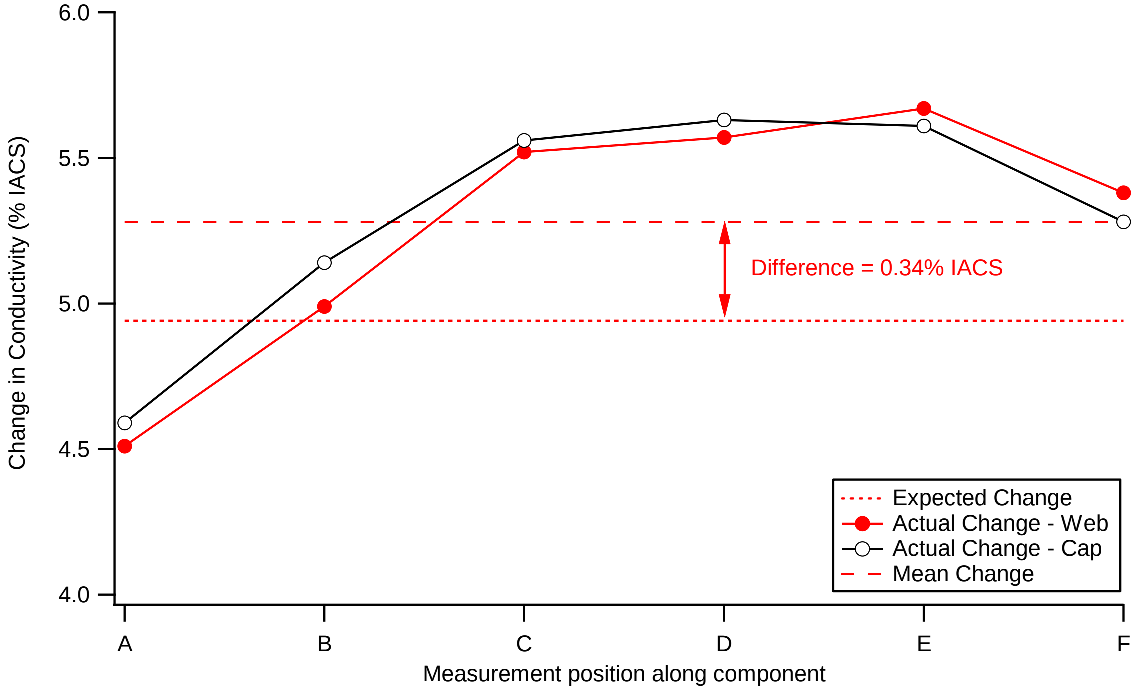


*Figure 37: Comparison for Component 5 between actual change in conductivity as a function of position on the component, expected change in conductivity and mean change in conductivity*

## 5.7 Comparative Metrology

Table 5 summarises the results of the metrological examination of the three components that underwent RRA treatment. The data in Table 5 shows the distortion of the components in terms of two values. The first of these is the change in overall length of the components. The second is the change in the mid-section Z height of the component (Figure 38). Examination of Table 5 shows that there is no obvious correlation between the change in the overall length of a component and the change in a component's height. These data are plotted as Figure 39.

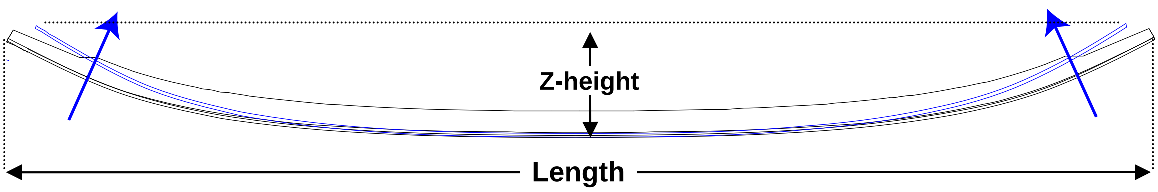


*Figure 38: Schematic drawing showing effect of deformation on the trial components, which was to slightly increase the curvature of the component. The definition of the length and mid-section Z-height are shown by arrows. The blue arrows show the direction of movement of the ends of the components, and the partial outline (blue) shows the final configuration of the cap (on an exaggerated scale). The web has not been illustrated in its final state for clarity.*

Figure 40 is a shaded contour plot showing the degree of deviation of the three components examined versus position along the component when viewed from below. This figure shows that the deformation of Components 1 and 2 was quite similar, while Component 5 showed less deformation. In all cases RRA slightly increased the curvature of the components, Figure 40.

*Table 5: Results of metrological examination of the trial components before and after RRA treatment*

| Component ID | Overall Length (mm) | | | Mid-Section Z Height (mm) | | |
|---|---|---|---|---|---|---|
| | Initial | Post-RRA | Change | Initial | Post-RRA | 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 |
| Average | 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 |

A calculation using simple elastic beam theory (Reference 15) showed that the mid-section Z height changes reported in Table 5 could be produced by applying a force of approximately 31 N to the ends of the component while holding the centre fixed in place. Such a force could easily be applied by hand and suggests that the observed deformation of the components due to RRA treatment might be considered negligible.

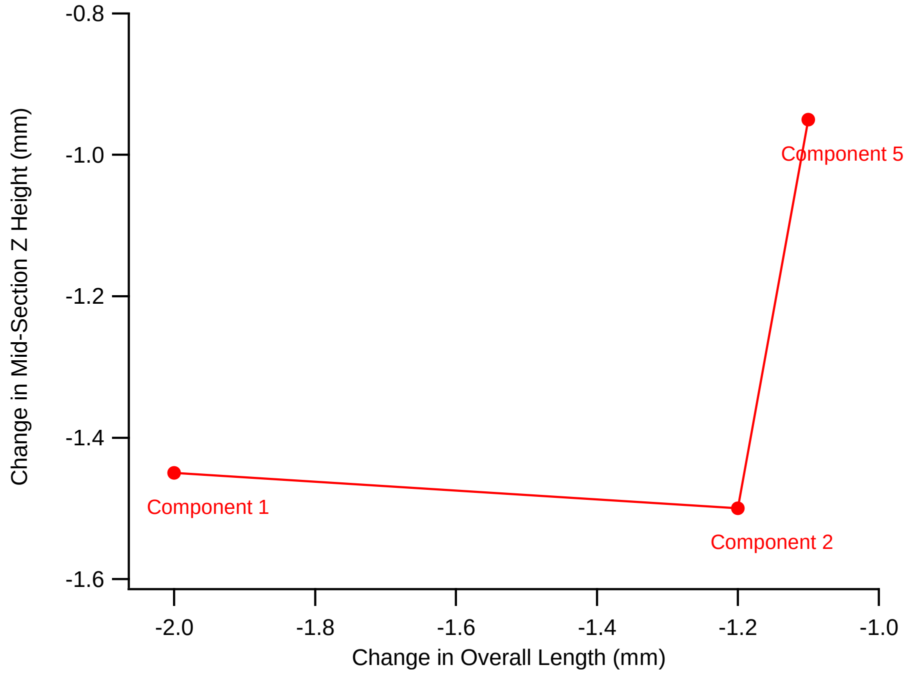


*Figure 39: Comparison of change in overall length of the components with the change in mid-section Z height. Note the lack of correlation between the two quantities. The codes next to the symbols indicate the component from which each data point came.*

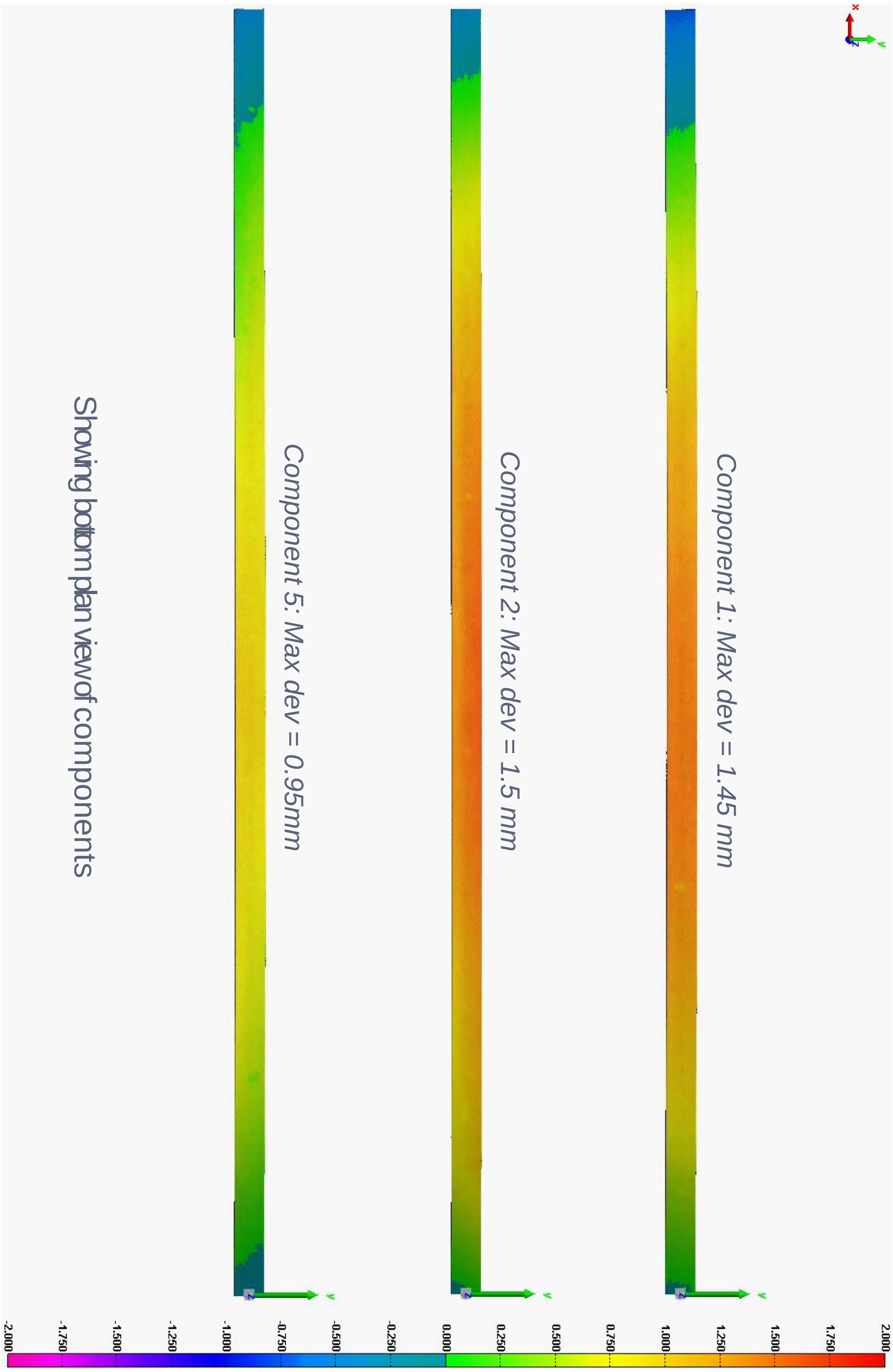


*Figure 40: Metrological (dimensional) comparison of the three FS737 Lower Cap components before and after RRA treatment. The colour of the bar at a given position is the displacement of that point relative to its position before RRA treatment. The displacement scale (colour bar) is in millimetres. Dimensional analysis shows a slight increase in the curvature of the components as a result of RRA treatment.*

# 6. Discussion

Three issues have arisen as a result of the reliability trials described in this report. These are:

1. Accounting for the measurement tolerances of the electrical conductivity meter,
2. The inconsistency of the acceptance criteria for initial and final electrical conductivity in the Stage III Process Specification (Reference 9), and
3. The reliability calculations that are the focus of the Stage III trial.

The effects of each of the above issues on the certification of RRA are discussed in separate sections below.

## 6.1 Tolerances of the Electrical Conductivity Meter

The RRA certification project has spanned a period of at least eight years. As a result much of the equipment used in the project has been replaced during the course of the project. In particular, the Foerster Sigmatest 2.068 D (Reference 23) electrical conductivity meter that was used in Stage I and the early part of Stage II of the RRA project was replaced - after it became faulty - by a Foerster Sigmatest 2.069 (Reference 24) electrical conductivity meter. The replacement meter was used for the remainder of Stage II and for Stage III.

The absolute accuracy and resolution of the two meters differed, and Table 6 summarises the data provided by Foerster on these quantities. At first glance it seems that the Sigmatest 2.069 has a better absolute accuracy than the Sigmatest 2.068D and this may indeed be the case given that it is a more recent design. However, the absolute accuracy of the Sigmatest 2.069 is qualified by the term 'Instrument Only' while that of the Sigmatest 2.068D has no such qualification. It is not known if this qualification reflects a more carefully written specification sheet or the exclusion of the effects of the conductivity probe on accuracy from the specification.

*Table 6: Comparison of absolute accuracy and resolution of the Sigmatest 2.068D and 2.069 electrical conductivity metres used in the RRA certification project*

| Quantity | Sigmatest 2.068 D | Sigmatest 2.069 |
|---|---|---|
| Absolute Accuracy | ±1% of measured value | N/A |
| Absolute Accuracy – Instrument Only | N/A | ±0.5% of measured value |
| Resolution @ 60 kHz | ±0.1% of measured value | |

The above issue is critical because the Stage III Process Specification allows for the tolerances of the electrical conductivity meter in determining if a RRA treatment has succeeded. Specifically, Paragraph 4.6.1 of the specification states (in part):

> *'…The treatment is considered successful if the final conductivity values are between 38 %IACS (minus the measurement tolerance of the conductivity meter) to 39 %IACS (plus the measurement tolerance of the conductivity meter)…'*

The tolerances were added to the Stage III Process Specification (Reference 9) after the Stage II trial (Reference 2) to minimise the unnecessary rejection of treated components for being outside the specified 38-39% IACS range. However, a situation could arise where a treated component would be deemed suitable when measured by one instrument, but unsuitable when measured by another even if the same value of electrical conductivity was recorded by both instruments, due to differences in the accuracy of the equipment. That is an unintended consequence of inserting the instrument tolerances into the Process Specification.

The different accuracy specification of the two Foerster electrical conductivity meters (Table 6) used by DSTO shows how such issues may arise. Moreover, the conductivity meter used by ALSPO for the purpose of their Process Proving Trial had a different absolute accuracy to the DSTO Foerster meters, which was stated by Mr J. Thomas of ALSPO to be 0.2% IACS (Reference 25). In addition, from discussions with Mr. Thomas (Reference 25) it became apparent that the wording of Paragraph 4.6.1 was not clear on the tolerance allowed on conductivity meter readings.

Given all of the above, DSTO proposes that the acceptance criteria for final electrical conductivity stated in Paragraph 4.6.1 should be revised to improve their clarity. The suggested replacement for Paragraph 4.6.1 of the Process Specification is:

> *'…The treatment is considered successful if the final conductivity values are between 37.62 %IACS and 39.39 %IACS. These values represent an acceptable range of 38 to 39% IACS, but also includes an instrument tolerance allowance of +/-1% …'*

The assumption of a blanket 1% of reading instrument tolerance is justified as follows:

1. The 38 to 39% IACS range was defined in Stage I of the RRA Certification Project using measurements of electrical conductivity made using the Foerster Sigmatest 2.068D electrical conductivity meter. This meter has a 1% of reading instrument accuracy.
2. Paragraph 3.5.3 of the Stage III Process Specification cites MIL-STD-1537C (Reference 26), which is the standard method for electrical conductivity measurement of aluminium alloys using eddy current equipment. This standard, which was published in 2002, states in Paragraph 3.6a that instrument accuracy should be better than 1% IACS.
3. In addition, MIL-STD-1537C states in Paragraph 4.2.1 that laboratory conductivity standards should be certified to ±0.35 % IACS or 1% of reading, whichever is less.
4. Finally, MIL-STD-1537C states in Paragraph 4.2.2 that instrument conductivity standards (i.e. the standards which are carried with the electrical conductivity meter) shall be certified to an accuracy of ±0.85% IACS.

Given the above, it is unreasonable to expect an accuracy of better than 1% of the reading on the conductivity meter. A tolerance of 1% of the measured value, which meets the requirements of MIL-STD-1537C paragraph 4.2.1, is considered to be suitably conservative while also helping to avoid the spurious rejection of RRA treated components.

## 6.2 Final Electrical Conductivity Measurement

During the analysis of the results from the Stage III Reliability Trials it was concluded that:

1. The Stage III Process Specification (Reference 9) has inconsistent criteria for acceptable values of initial and final electrical conductivities. Progressively more restrictive criteria for final electrical conductivity were introduced in successive revisions of the Process Specification, initially to deal with large variations in component temperature and from a desire to remain conservative. The new criteria were not compared to the criteria for the initial electrical conductivity to ensure consistency.
2. The statistical basis for an acceptable final electrical conductivity was unintentionally altered during Stage II of the RRA certification project and used in Stage III. This change was made in Stage II in an attempt to manage the effects of using the QDS Mascot furnace, which only had limited control capability, during the initial trials of the RRA process. The introduction of tightened criteria for control of furnace temperature for the Stage II and Stage III trials has removed this issue.

The combined effect of the two issues was to make it difficult to determine if two of the three components treated in Stage III Reliability Trials had been successfully treated or not. Specifically, Components 1 and 2 had mean final electrical conductivities within the allowed range but had individual measurements of final electrical conductivity that were outside the specified range, even when an allowance for instrument accuracy is included.

The inconsistency of the criteria for initial and final electrical conductivity is shown by a review of the relevant paragraphs in the Stage III Process Specification (Reference 9). PS§ 4.2.1 defines an acceptable initial electrical conductivity as follows:

> *'4.2.1. Electrical conductivity (% IACS) is to be measured before treatment, with the measurement being the average of at least six locations (refer paragraph 3.5.3.e). The conductivity of eligible components must be within the range of 31-35 % IACS,'*

While PS§ 4.6.1 and PS§4.6.2 defines an acceptable final electrical conductivity as follows:

> *'4.6.1. Confirmation of a successful RRA treatment is determined through a post-RRA electrical conductivity survey using the process described in Section 3.5. The treatment is considered successful if the final conductivity values are between 38 %IACS (minus the measurement tolerance of the conductivity meter) to 39 %IACS (plus the measurement tolerance of the conductivity meter). Electrical conductivity data are to be recorded in a manner consistent with the Quality Assurance procedures of the heat treating organisation.'*
>
> *'4.6.2. If any measured post-RRA electrical conductivity value falls outside the range specified in paragraph 4.6.1 then the RRA heat treatment was unsuccessful.*

*The component cannot undergo a second RRA heat treatment and the component must be considered unfit for service.'*

PS§4.2.1 defines an acceptable initial electrical conductivity as the mean of six readings between 31 and 35% IACS without any adjustment for the tolerances of the conductivity meter. In contrast, the final electrical conductivity is defined by PS§ 4.6.1 and PS§4.6.2 as acceptable when the maximum and minimum readings are within the 37.62 to 39.39% range, after adjusting for the meter's measurement tolerances[11].

In summary, the Stage III Process Specification defines an acceptable initial electrical conductivity as a mean within a given range which is not adjusted for the instrument tolerances, while inadvertently defining an acceptable final electrical conductivity as an extreme value (of either a location mean or reading) within a given range which is adjusted for instrument tolerances.

In addition the use of an extreme value is inconsistent with the certification basis proven in Stage I. In that stage the initial and final electrical conductivities were defined as the means of replicate measurements on a specimen. These measurements were often performed on the treated stock before specimen manufacture, or on the flat grip sections of specimens remote from the test locations. The mean measurements were then used to represent the properties of the entire specimen. Therefore, the certified final electrical conductivity range that was determined in Stage I, is defined in terms of mean values of electrical conductivity and not extreme values. This mean value was used as a metric to compare to the mechanical properties of the specimens. The variation in material properties was then accounted for in the statistical processes of determining the A-Basis allowables. It is therefore incorrect to use minimum or maximum values of electrical conductivity to infer these allowables.

A Monte Carlo simulation was created to examine the effect of using a maximum in place of a mean. PS§ 4.6.2 is ambiguous as a 'measured post-RRA electrical conductivity' could either be any single reading or the mean conductivity of a location on the component. Figure 41 shows that using either of these instead of the component mean will affect the apparent likelihood of a successful RRA treatment. This figure plots the results of the Monte-Carlo simulation as probability density functions (PDFs) of the component mean, maximum location mean and maximum reading. It assumes a normal distribution of conductivity values with a mean conductivity value of 38.5% IACS and a standard deviation of 0.26% IACS[12]. The PDFs in this figure have been normalised with respect to the component mean PDF. It can be seen that the mode of the maximum location mean PDF is higher than the component mean and the mode of the maximum reading PDF is higher again[13]. Using either of these values in place of the component mean will cause some components to be incorrectly classified as unserviceable after RRA treatment.

---

[11] The meter used in the current work had a 0.5% of the displayed value measurement tolerance.

[12] This is the approximate standard deviation for the initial conductivity measurements taken from a single material in Stage I

[13] Note that there are corresponding minimum distributions which show the same trend but in the opposite direction (i.e. the modes of the minimum distributions move towards zero).

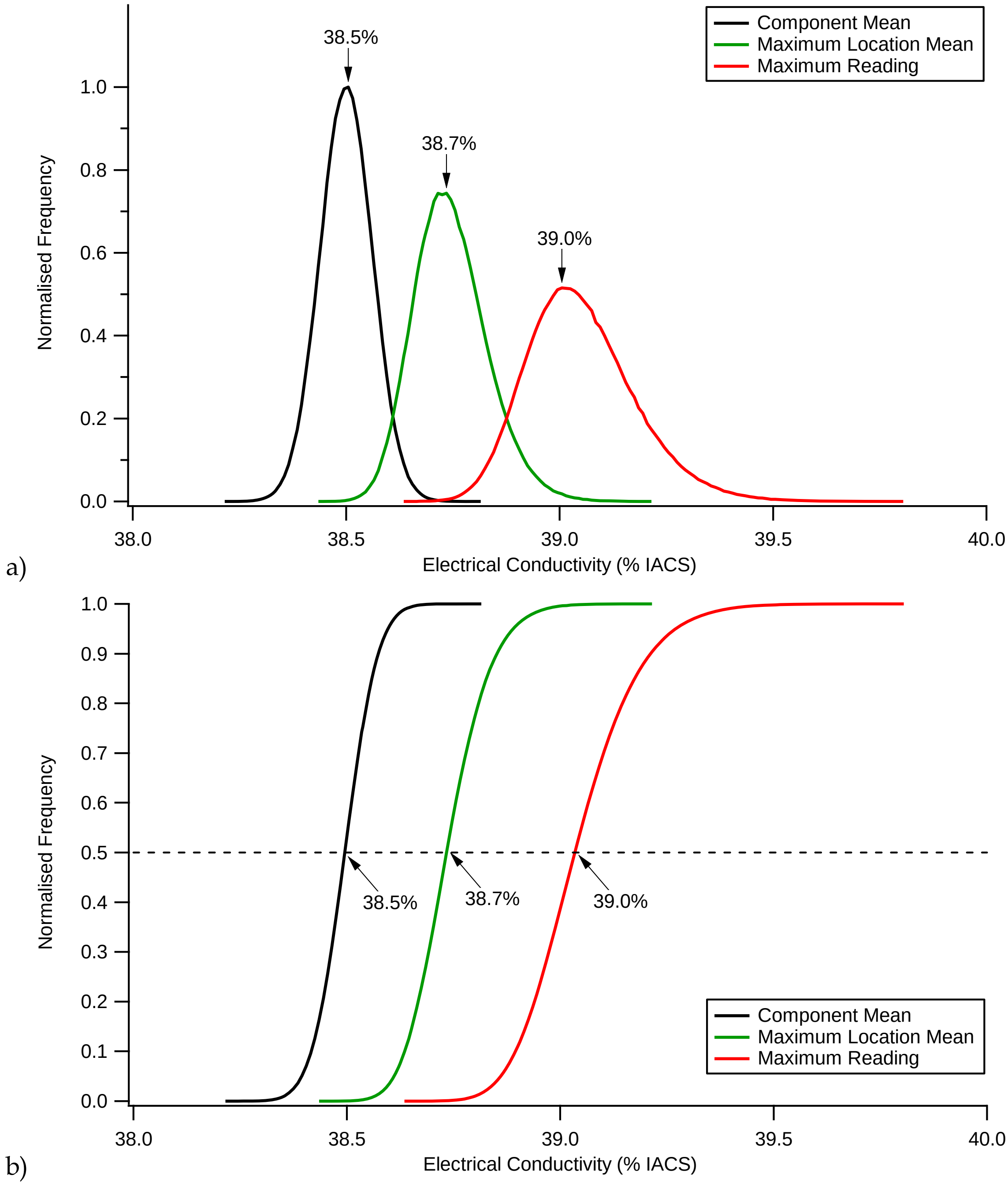


*Figure 41: Comparison of the (a) probability density functions with modes of each distribution marked and (b) cumulative density functions of the component mean, maximum location mean and maximum reading measures of electrical conductivity produced by a Monte-Carlo simulation intended to show the non-equivalence of the different measures.*

The Monte Carlo simulation also demonstrated that the maximum values increase with increasing standard deviation. Figure 42 plots the mode of three distributions against the standard deviation of the normal distribution. The mode of the component mean distribution is constant but the mode of the maximum value distributions increases linearly with the standard deviation.

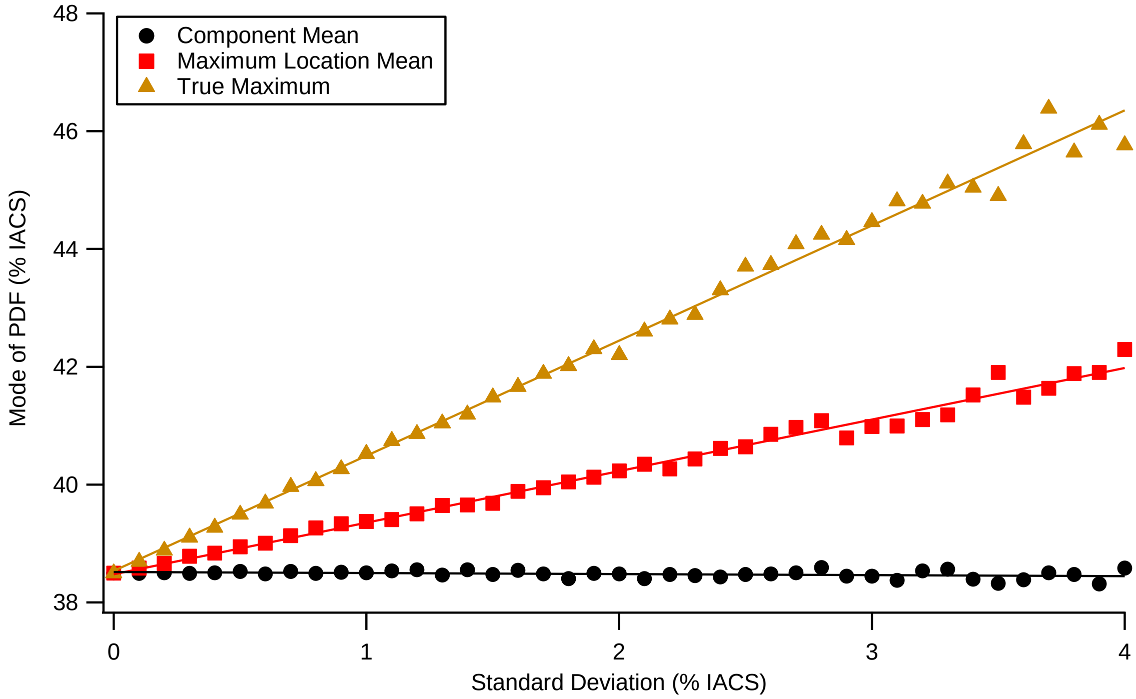


*Figure 42: Mode of component mean, maximum location mean and true maximum probability density functions*

A final demonstration on how, the use of a maximum value increases variability can be seen by having the final conductivity survey performed by a second operator. Figure 43 shows an example of this from the Stage III Reliability Trial. At Location B on Component 2 the change in electrical conductivity for the location mean was measured as 6.20% IACS by the initial NDI technician (Reference 27) and 5.66% IACS by a technician who repeated the measurements (Reference 28). This variation in itself could change a location mean from the target of 38.5% IACS to 39.04 % IACS. In contrast, the Component Mean changed by only 0.08% IACS. This demonstrates how maximum values are over sensitive to measurement error and therefore could lead to components being incorrectly classed as being incorrectly treated.

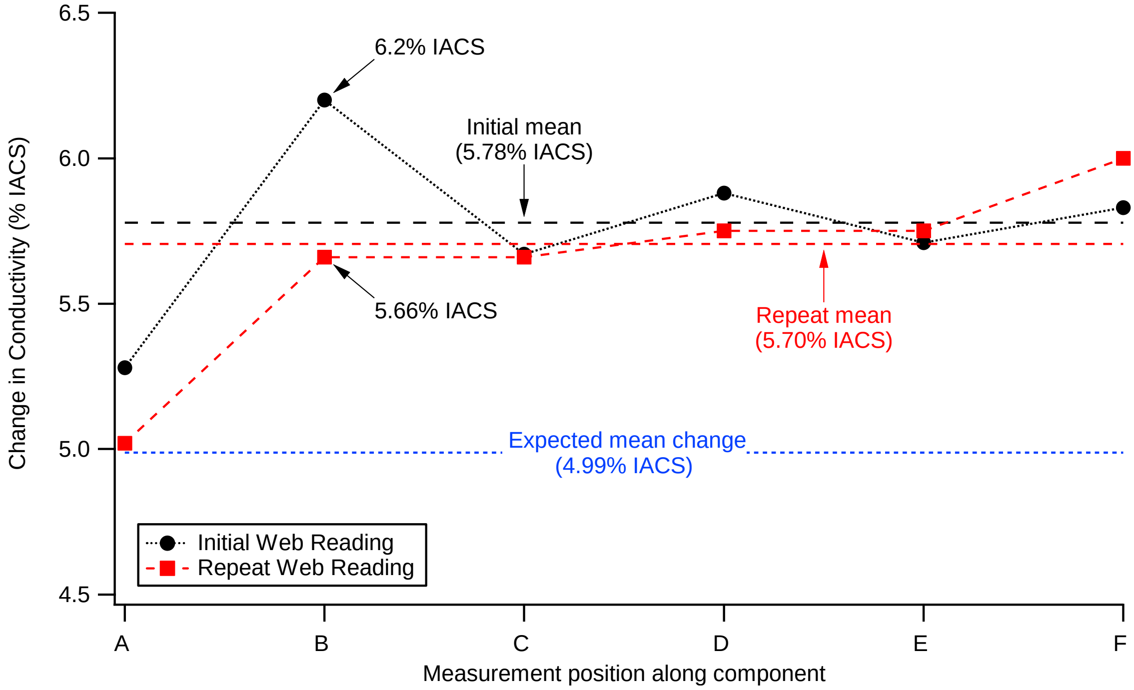


*Figure 43: Comparison of multiple surveys of change in Final Electrical Conductivity for Component 2*

## 6.3 Reliability Estimates

The Stage III DDP, in §4.6 (Reference 3) requested a process by which the repeatability and reliability of the RRA process could be estimated. Three options for demonstrating the repeatability of the RRA process were proposed by QinetiQ to ALSPO (Reference 29). ALSPO selected the third option proposed (Reference 21).

The underpinning strategy was to utilise a statistical analysis of the final conductivity ($\sigma_{RRA}$) of the three trial components as well as the laboratory trials used in developing the retrogression time chart (Reference 11). For completeness, the results from the Process Proving Trial conducted by ALSPO (Reference 30) are also to be included. These data cover all of the completed heat treatments that have used retrogression times recommended in the Stage III Process Specification (Reference 9). Table 7 summarises the relevant final conductivity results.

The statistical method chosen will determine the confidence using a non-parametric prediction interval that includes the limits of the final electrical conductivity (Reference 3). A non-parametric investigation utilises the sample mean, $\overline{X}_n$, and sample standard deviation, $s_n$ rather than the population mean and population standard deviation. This statistical method assumes that the data are normally distributed to allow it to determine the probability that a random sample from the same population will fall outside a given range. This is in contrast to predictive confidence intervals in which the population mean and population standard deviation are estimated with a given confidence and then used to make predictions of future sampling. A non-parametric method was used since the population mean and standard deviation of the parent distribution of the data are unknown.

*Table 7: Final conductivity data for all samples or components that used the recommended retrogression times in the Stage III Process Specification (Reference 9 )*

| Specimen | $\sigma_{RRA}$ (% IACS) | Reference |
|---|---|---|
| C401 | 38.55 | 11 |
| C402 | 38.44 | 11 |
| C403 | 38.27 | 11 |
| C404 | 38.89 | 11 |
| C405 | 38.44 | 11 |
| C406 | 38.50 | 11 |
| C407 | 38.81 | 11 |
| C408 | 38.05 | 11 |
| C409 | 38.64 | 11 |
| C410 | 38.63 | 11 |
| C411 | 38.36 | 11 |
| C1 | 39.03 | 27 |
| C2 | 39.29 | 27 |
| C5 | 38.84 | 27 |
| Process Proving | 37.80 | 30 |
| Sample Mean ( $\overline{X}_n$ ) | 38.57 | |
| Sample Standard Deviation ( $s_n$ ) | 0.379 | |

The probability *p*, of the next observed sample $X_{n+1}$ falling within an interval can be defined in terms of the sample mean and sample standard deviation as follows (Reference 31):

$$\Pr\left[\overline{X}_n - T_\alpha s_n\left(1+\frac{1}{n}\right)^{\frac{1}{2}} \leq X_{n+1} \leq \overline{X}_n + T_\alpha s_n\left(1+\frac{1}{n}\right)^{\frac{1}{2}}\right] = p \qquad (2)$$

where $T_\alpha$ is the $100((1 + p)/2)^{th}$ percentile of a Student's t-distribution with $n - 1$ degrees of freedom.

From this:

$$\overline{X}_n \pm T_\alpha s_n\left(1+\frac{1}{n}\right)^{\frac{1}{2}} \qquad (3)$$

are the endpoints of a 100*p* % prediction interval for the next sample to be drawn ($X_{n+1}$). i.e. an interval centred on the sample mean can be predicted that will include a given percentage of subsequent samples.

As $\overline{X}_n$ = 38.57 % IACS, this prediction interval will first fall outside of the allowed range of 37.63 to 39.39 % IACS when:

$$T_{\alpha} s_{n} \left(1 + \frac{1}{n}\right)^{\frac{1}{2}} = 39.39 - 38.57 = 0.82 \qquad (4)$$

Substituting $s_n$ = 0.379 and $n$ = 15 into equation (4) yields a $T_a$ of 2.098.

As $T_a$ is the 100((1 + $p$)/2)$^{th}$ percentile of a Student's t-distribution with $n$ − 1 degrees of freedom:

$$(1+p)/2 = 0.9727^{14} \qquad (5)$$

$$\text{and } p = 0.945 \qquad (6)$$

Where $p$ is the probability of a final conductivity ($\sigma_{RRA}$) falling within the allowed range. As a result, the confidence in (i.e. reliability) of the RRA process is approximately 95%.

# 7. Compliance of Trials with the Reliability Trials Compliance Matrix

## 7.1 Process Element – Aircraft Component – Generic

### 7.1.1 PID 1.1: Initial Component Condition

The trial components were purchased new from QDS, and were assessed by DSTO as having not been in-service. This assessment was supported by the observation that the trial components lacked the machined holes that would be required to mount them on an aircraft. Additionally, no evidence of surface treatments to induce beneficial residual stresses (e.g. shot peening) were evident on any of the components. This property is assessed as being '**Compliant**'.

### 7.1.2 PID 1.2: Alloy Identification and Initial Temper

The trial components were extruded T-sections of AA7075-T6 as per SAE AMS-QQ-A-200/11 (Reference 32). The part numbers of the components were verified by inspection of the invoice received from QDS upon receipt of the components. The alloy identification and initial temper of this part number was verified by inspection of Lockheed Martin drawing 356251 (Reference 33). This property is assessed as being '**Compliant**'.

[14] Values for student's t statistic are typically determined from tables. Mathematica 8.0 enables direct calculation and the string `'CDF[StudentTDistribution[14], 2.098]'` was used to evaluate a $T_\alpha$ of 2.098.

### 7.1.3 PID 1.3: As-Extruded Short Transverse Thickness

A new FS737 Lower Cap has a specified thickness of 7.92 mm (0.312 inch) on the cap and 6.35 mm (0.25 inch) on the web. These values are less than the maximum 1.0 inch thickness allowed and equal to or greater than the minimum of 6.35mm (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 33), which was provided to DSTO by the DMO Air Lift Systems Program Office (ALSPO). This property is assessed as being '**Compliant**'.

### 7.1.4 PID 1.4: Initial Electrical Conductivity

The Stage III Process Specification requires in PS§4.2 that the mean initial electrical conductivity of the components be in the range of 31 to 35% IACS. The electrical conductivity measurements for all components are reported in NDI Report NDT/GEN/15/10 (Appendix C.1) and complied with the Stage III Process Specification (Reference 9) as summarised in §4.4. This property is assessed as being '**Compliant**'.

### 7.1.5 PID 1.5: Final Electrical Conductivity

Two of the three components tested in this trial did not fall within the range of final electrical conductivities allowed by the Stage III Process Specification. This property can therefore not been assessed as being 'Compliant'. However, examination of the results indicated that:

1. the criteria for acceptable final electrical conductivity in the Stage III Process Specification were inconsistent with those for initial electrical conductivity (§6.2),
2. the Stage III Process Specification used a maximum value rather than a mean, which is inconsistent with the definition of the allowable range of final electrical conductivity from Stage I (§6.2), and
3. a different electrical conductivity meter with an apparently improved tolerance was used for the Stage III trials (§6.1).

After examining each of these effects it was decided that the results of all three trials were non compliant with this item but acceptable given the changes required in the Process Specification. This property is therefore assessed as being '**Non-Compliant (Acceptable)**'.

### 7.1.6 PID 1.6: Dimensions

The dimensions of all three components were measured before and after RRA treatment. The data collected was then compared to determine the effect of RRA treatment on the original (as manufactured) shape of the components. It was found that there was only minor deformation which could be reversed by the application of approximately 30 N force. As there was no authoritative standard available to compare the results against it was not possible to rate this property as 'Compliant'. However, the small deformations observed and the minor load required to reverse these were considered negligible. This property is assessed as being '**Non-Compliant (Acceptable)**'.

## 7.2 Process Element – Heat Treatment Organisation – Generic

### 7.2.1 PID 2.1: AMO Status

The AMO status of BACR was confirmed in an email from OIC CMSA3 - DAVCOMP (Directorate Air Vehicle Compliance) on 9/4/09 in which DSTO was provided copies of the Letter of Maintenance Authority (LMA) (Reference 34) and Maintenance Authority Certificates (MAC) for BACR (Reference 35). This property is assessed as being '**Compliant**'.

### 7.2.2 PID 2.2: Authority to Heat Treat Aluminium Alloys

The LMA and MAC (References 34 and 35) for BACR do not include the heat treatment of aluminium alloys. However:

1. BACR are approved by Civil Aviation Safety Authority (CASA) for the processing of composite aircraft components and the requirements for the thermal treatment of composites are similar to those for treating aluminium alloys; and
2. 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 Process Specification with the required level of control (Reference 9). BACR's CASA Certificate of Approval is reproduced in the PSCR (Reference 13).

Discussions held at the Stage II Critical Design Review (CDR) concluded that while the above measures were sufficient justification for trials, they would not be sufficient for generic use of RRA technology on RAAF aircraft components (Reference 36).This property is assessed as being '**Non-Compliant (Acceptable)**'.

### 7.2.3 PID 2.3: Furnace Calibration

A calibration certificate for the BACR oven used for the Stage III RRA trial was issued by Australian Calibrating Services on 10/05/2010 and is valid for six months with the date of the next calibration being scheduled for 10/11/2010 (Reference 18). The reliability trials were conducted between 17/08/2010 and 24/08/2010 and fell within the calibration period. The calibration report provided by BACR is NATA compliant. The measured temperature variation at 180 °C was 7.51 °C. The internal dimensions of the 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'**.

### 7.2.4 PID 2.4: Furnace Assessment

According to the Stage III Process Specification an assessment of the capability of the furnace to perform a RRA treatment must be made for each type of component. The assessment was performed on the BACR furnace using QA specimens during Stage II of RRA certification. The furnace was assessed at that time as being capable of performing RRA treatment on the basis of Figure 4 in Reference 13. The maximum variation was within the 10 °C specified by the Stage III Process Specification (Reference 9). The property is assessed as being **'Compliant'**.

#### 7.2.5 PID 2.5: Thermocouple Calibration

Four DSTO thermocouples and two BACR thermocouples were used in the trial. A thermocouple with serial number 5358 was inserted in the quench bath while thermocouple number 5359 was attached to the component at position A. These thermocouples were calibrated by FastLab Calibration Laboratory on 13/11/2008, (Reference 37). The remaining thermocouples were calibrated by a secondary calibration using thermocouples 5358 and 5359 (Reference 13). This property was assessed as being **'Non-Compliant (Acceptable)'**.

#### 7.2.6 PID 2.6: Data Device Calibration

The BACR furnace calibration certificate was issued by Australian Calibrating Services on 10th of May 2010 and is valid for six months with the next calibration scheduled for 10th of November 2010. The calibration report is NATA Compliant and was supplied to DSTO via e-mail (Reference 18). The BACR furnace Controller Measured Temperature calibration data 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. This property was assessed as being **'Compliant'**.

### 7.3 RRA Treatment Temperature Profile

#### 7.3.1 PID 3.1: Temperature Profile – Retrogression

The requirements for successful retrogression profile were derived from PS§4.3.1.a, PS§4.3.1.d and PS§4.3.1.e of the Stage III Process Specification (Reference 9) and are summarised in §4.6.1 of this report. These requirements were assessed for all three components in §5.5 of this report. The three requirements were:

1. Initial heating rate as determined from the set-point temperature data. This was reported in §5.5.1.1 as 1.96 °C/min for all three components, within the range of 2.0 ± 0.1 °C/min required by PS§4.3.1.d.
2. Retrogression temperature was determined from the furnace set-point values and reported in §5.5.1.2 as 195 °C for all three components. This is the value required by PS4.3.1.d.
3. Temperature variation as measured by the maximum difference in temperature across the three thermocouples placed evenly along the length of the component. This was reported in §5.5.1.3 as 4.5 °C for Component 1, 3.6 °C for Component 2 and 6.7 °C for Component 5. These are within the 10 °C allowed in PS§4.3.1.a.

Additionally, while retrogression times are recommended by the process specification, they are not used as a success criterion. These were measured from temperature data taken from three locations along the component (Figure 4) and were the time that any part of the component was above 181 °C. From Table 2, these were 23:20, 23:45 and 22:40 minutes for Component 1, Component 2 and Component 5 respectively.

The retrogression temperature profile is therefore assessed as being '**Compliant**'.

### 7.3.2 PID 3.2: Post-Retrogression Quenching

The requirements for successful retrogression profile were derived from the Process Specification (Reference 9) in PS§4.3.1.f and PS§4.3.1.g and are summarised in §4.6.2 of this report. These requirements were then assessed for all three components in §5.5.2. The four requirements were:

1. Quenching Time as determined from the temperature readings of the three thermocouples attached along the length of the component and reported in §5.5.2. This showed that the quench time for Component 2 and Component 5 was 40 seconds, while Component 1 had a quench time of 45 seconds. These were within the 180 seconds limit given in PS§4.3.1.f.
2. Initial Quench Bath temperature was measured directly by a thermocouple placed within the quench bath. This value was reported in Table 3 as 12.9 °C for Component 1, 15 °C for Component 2 and 13.6 °C for Component 3. All values were below the maximum initial quench bath temperature given in PS§4.3.1.g as 32 °C.
3. Maximum Quench Bath Temperature was measured directly by a thermocouple placed within the quench bath. This maximum allowed value was calculated from initial quench bath temperatures (PS§4.3.1.g) and reported in Table 3 along with the final quench bath temperatures for all three components. The final quench bath temperatures for Components 1, 2 and 5 respectively were 15.0 °C, 16.9 °C and 15.9 °C. The corresponding maximum acceptable final quench bath temperatures were 26.9 °C, 29 °C and 27.6 °C.
4. Dwell Duration is the time between completion of quench and start of re-ageing. This was taken from the time-stamps of the temperature datasets for retrogression and for re-ageing. This was reported in Table 3 as 12.7 minutes, 15.5 minutes and 11.4 minutes for Components 1, 2 and 5 respectively. All three components had dwell times less than the 30 minute maximum given in PS§4.4.1.

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

### 7.3.3 PID 3.3: Temperature Profile – Re-ageing

The requirements for successful re-ageing profile were derived from the Process Specification (Reference 9) in PS§4.3.1.a, PS§4.5.1.a and PS§4.5.1.d and are summarised in §4.6.3 of this report. These requirements were then assessed for all three components in §5.5.3. The five requirements were:

1. Initial Furnace Temperature was measured from the thermocouples measuring furnace air temperature and was reported in Table 4 as being less than 120 °C as required in PS§4.5.1.a for all three components.

2. Re-ageing Ramp Rate as determined from the set-point temperature data. This was reported in §5.5.3 (Table 4) as 1.96 ºC/min for all three components, within the range of 2.0 ± 0.1 ºC/min required by PS§4.5.1.d.
3. Re-ageing Temperature was determined from the furnace set-point values and reported in §5.5.3 (Table 4) as 120 ºC for all three components. This is the value required by PS§4.5.1.a. The mean Re-ageing temperature as measured from the thermocouples attached to the component was reported as 121 º C.
4. Re-ageing Duration was determined directly from the set-point values for the furnace as 24.0 hours for all components as required by PS§4.5.1.d.
5. Temperature Variation as measured by the maximum difference in temperature across the three thermocouples placed evenly along the length of the component. This was reported in §5.5.3 (Table 4) as 1.4 ºC for Component 1, 1.5 ºC for Component 2 and 2.5 ºC for Component 5. These are within the 10 ºC allowed in PS§4.3.1.a.

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

# 8. Recommended Revisions to the Process Specification

The §4.6.5 of the Stage III DDP (Reference 3) prescribes that any modifications resulting from the Stage III Reliability and Process Proving trials should be incorporated into a fourth revision of the Process Specification. The following paragraphs summarise the lessons learnt through the trials described in this report and the corresponding revisions recommended for incorporation into the fourth revision of the Process Specification:

1. The acceptance criteria for final conductivity in the Stage III Process Specification (PS§4.6) has led to ambiguities in interpreting the results of the conductivity measurements. These definitions, introduced in Stage II, unintentionally differed from the original certification basis of the RRA process as defined in the Stage I MPDR (Reference 6). This issue was discussed in §6.2 above.
2. Discussions with ALSPO prior to the Process Proving Trials showed that the use of a tolerance range from the electrical conductivity (PS§4.6.1) meter was unclear and caused difficulties in interpretation for both the Process Proving and Reliability trials. This issue was addressed in §6.1 above. The revised wording of the PS§4.6.1[15] should read:

   > *'The treatment is considered successful if the mean of the final conductivity for all measured locations is between 37.62-39.39 %IACS. This includes a 1% tolerance in the measured value of the mean conductivity of the component as specified in MIL-STD-1537C.'*

3. Prescribing the removal of the thermocouples following quenching (PS§4.3.1.f) caused difficulties for the Process Proving trials (Reference 25). This should be changed to

[15] Section numbers in this discussion refer to sections in the Stage III Process Specification (Reference 9). Corresponding sections in subsequent issues of the Process Specification may have different numbers.

allow more freedom for different heat treating facilities. This should be added as PS§4.3.j:

> *'The thermocouples may be removed before quenching following retrogression and may then be re-attached for re-ageing'.*

4. The acceptance criterion for the temperature control during the re-ageing stage was missing. This should be added to the Process Specification as PS§4.5.1 as (e) and should be worded to be consistent with the temperature control for the retrogression stage as follows: 'A maximum temperature variation 10 °C between the readings for any thermocouples attached to the component is considered acceptable'.

5. PS§3.4.3 and PS§4.3.1.e of the Stage III Process Specification contain potentially contradictory requirements for temperature variation. PS§3.4.3 states:

   > *'…the furnace must be capable of maintaining a surface temperature variation along a component of no more than 10 °C….'*

   In contrast, PS§4.3.1.e states:

   > *'…a temperature variation of ±10 °C between the readings for any thermocouples attached to the component is considered acceptable.'*

   A temperature variation of ±10 °C might be viewed by a reader as allowing a 20 °C range in temperature. Specifically, the '±' symbol is ambiguous and should be removed. The revised sentence in PS§4.3.1.e will therefore be:

   > *'…a maximum temperature variation of 10 °C between the readings for any thermocouples attached to the component is considered acceptable.'*

   'Maximum' has been added to this sentence to make it clear that this temperature variation cannot exceed 10 °C.

6. With the focus given to the error in measurement for electrical conductivity, an additional inclusion is recommended to prevent additional errors from the use of different conductivity meters for pre-RRA and post-RRA measurements. The revised wording of PS§4.6.1 should read:

   > *'Confirmation of a successful RRA treatment is determined through a post-RRA electrical conductivity survey using the process described in Section 3.5, using the same conductivity meter. . . '*

7. Although PS§3.5.3 specifies that conductivity measurements are to be taken in accordance with Reference 26 (MIL-STD-1537C), the requirement for using qualified personnel according to this standard is not set out specifically. It is suggested that the first sentence of PS§3.5.3 should be revised to read:

   > *'The electrical conductivity survey is to be carried out **by suitably qualified personnel** using a suitable conductivity meter. '*

   The words added to the sentence in PS§3.5.3 of the Process Specification are shown in bold.

# 9. Conclusions

This report describes a trial of the Stage III RRA Process Specification on three real aircraft components using industrial equipment. The trial has demonstrated that:

1. The trial has shown that the RRA process as defined in the Stage III RRA Process Specification can be reliably applied to an aircraft component in an industrial environment.
2. Estimates of the reliability of the process based on the results of these trials exceeded 95%.
3. All properties described by items in the compliance matrix received recommended ratings of either **'Compliant'** or **'Non-Compliant (Acceptable)'**. Of the 15 items in the compliance matrix only four were rated **'Non-Compliant (Acceptable)'**.
4. The trials revealed a significant deficiency in the Stage III Process Specification relating to the final electrical conductivity. This was the reason for the Non-Compliant (Acceptable) rating of P.I.D. 1.5. The change in certification basis and increase in measurement error for final conductivity will be rectified through a revision of the Process Specification. This will ensure that the final conductivity measurement retains the same basis for certification as was used in the Material Qualification.

# 10. Acknowledgements

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# Appendix A: Reliability Trials 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 III RRA Process Specification and C-130H and J SRM (References 38 and 39) | 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 for any nicks, dents or scratches that exceed SRM limits and accompanying documentation.<br>No evidence of treatments to induce residual stresses was found by examination by DSTO staff.<br>No nicks/dents or scratches were found by DSTO staff. | Compliant | §7.1.1 |
| | 1.2 | Alloy Identification and Initial Temper | SAE AMS-QQ-A-200/11 (Reference 32) | The parent extrusion of the component must comply with SAE AMS-QQ-A-200/11 | Inspection | N/A | Direct verification | Compliant | §7.1.2 Lockheed Martin Drawings (Reference 33) |
| | 1.3 | As-extruded short transverse thickness | Stage III RRA Process Specification Section 2 (Reference 9) | 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. | Compliant | §7.1.3 Lockheed Martin Drawings (Reference 33) |
| | 1.4 | Initial Electrical Conductivity | Stage III RRA Process Specification Section 4 (Reference 9) | The candidate (pre-RRA) component's electrical conductivity must be within the range 31-35% IACS | Test | ASTM E1004-02 (Reference 40) | Verification via direct measurement. Values must be within specified range for compliance. | Compliant | §7.1.4 |
| | 1.5 | Final Electrical Conductivity | Stage III RRA Process Specification Section 4 (Reference 9) | The post-RRA electrical conductivity of the component must be within the range 38-39 % IACS | Test | ASTM E1004-02 (Reference 40) | Verification via direct measurement. Values must be within specified range for compliance.<br>The criteria for acceptable final conductivity was found to be inconsistent with that for initial electrical conductivity and inconsistent with the certification basis used in Stage I (§6.2). Additionally, the inclusion of conductivity meter tolerances is not consistent with the tolerances for MIL-STD-1537 C (Reference 26) which is the basis of the conductivity measurement method contained in the Process Specification (Reference 9). Given the recommended changes to final conductivity measurement in the Process Specification, this property is assessed as non-compliant acceptable. | Non-Compliant Acceptable | §7.1.5<br>§6.1<br>§6.2<br>MIL-STD-1537 C (Reference 26)<br>NDT Reports (References 27 and 28) |

| Process Element | ID | Property | Requirement Specification | Requirement | Compliance Method | Compliance Specification | Compliance Method Justification/Comments | Compliance Result | Reference to Documentary Evidence |
|---|---|---|---|---|---|---|---|---|---|
| | 1.6 | Dimensions | Manufacturing Specification (if available) otherwise DAR requirement | Component dimensions and shape should not change beyond levels allowed by manufacturing specification. | Test | NATA approved metrology | Dimensional stability was not conclusively demonstrated in Stage II. Attempts to obtain dimensional tolerances from Lockheed Martin failed.<br><br>In lieu of the manufacturing specification, metrology should be conducted on the Stage III reliability trial components before and after RRA treatment. This will allow the variations in dimensions due to RRA to be compared with the variation in manufactured dimensions. If the variation due to RRA is less than that intrinsic in the manufacture of the components it can be considered negligible.<br>As there was no authoritative standard available to compare the results against it was not possible to rate this property as 'Compliant'. Dimensional analysis of all three components, before and after RRA treatment concluded that only minor deformation occurred which could be reversed by the application of approximately 30 N force. These deformations were consequently considered negligible. | Non-Compliant Acceptable | §7.1.6<br>Stage II Metrology report (Reference 20)<br>Stage III Metrology report (Reference 15) |
| Heat Treatment Organisation - Generic | 2.1 | AMO Status | TAMM Reg. 4.1.1.a and/or ALSPO SI (LOG) 02-08 (References 41 and 42) | The heat treatment organisation must be an Authorised Maintenance Organisation (AMO) with authority to heat treat aircraft components for use of ADF aircraft. | Inspection | TAMM (Reference 41) | 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 (TMA).<br><br>The organisation must be considered suitable for issuing of a TMA by documentation review if a TMA has not been issued.<br>AMO Status of BACR Confirmed:<br>Letter of Maintenance Authority (LMA) and Maintenance Authority Certificates (MAC) held by BACR. | Compliant | §7.2.1<br><br>LMA (Reference 34)<br><br>MAC (Reference 35) |
| | 2.2 | Authority to Heat Treat Aluminium Alloys | TAMM Reg. 4.1.1.d and/or ALSPO SI (LOG) 02-08 (References 41 and 42) | The heat treatment organisation's AMO or equivalent certification must include the ability to conduct heat treatments on aluminium alloy components | Inspection | TAMM (Reference 41) | As for AMO Status<br><br>DSTO assessed the BACR facility as capable of holding authority to 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. | Non-Compliant Acceptable | §7.2.2<br><br>LMA (Reference 34)<br><br>MAC (Reference 35) |
| | 2.3 | Furnace Calibration | Stage III RRA Process Specification Section 3 (Reference 9) | The furnace, its control system and associated thermocouples must have a current calibration | Inspection | NATA or similar | Review calibration records for furnace prior to heat treatment. If calibration is not current it must be renewed. | Compliant | §7.2.3 (Reference 18) |

| Process Element | ID | Property | Requirement Specification | Requirement | Compliance Method | Compliance Specification | Compliance Method Justification/Comments | Compliance Result | Reference to Documentary Evidence |
|---|---|---|---|---|---|---|---|---|---|
| Heat Treatment Organisation – Generic (cont'd) | 2.4 | Furnace Assessment | Stage III RRA Process Specification Section 3. (Reference 9) | Furnace assessed as capable of maintaining a temperature differential of less than 14 ºC. | Test | N/A | Furnace classification alone is not enough to verify the capability of the furnace to perform a RRA heat treatment. Different furnaces have different capabilities in terms of heat-up rate. As such it is necessary to adapt the length of the retrogression phase to ensure accurate heat-treatment for each component type. Unless suitable data are already available, this will be achieved by conducting furnace trials to determine the temperature distribution and rate of heating in the furnace. | Compliant | §7.2.4 (Reference 13) |
| | 2.5 | Thermocouple Calibration | Stage III Process Specification Section 3 (Reference 9) | The thermocouples used in the most critical location of the component should have a traceable and current calibration certificate. | Inspection | OEM or NATA | Obtain calibration certificate for sufficient thermocouples to record temperatures in critical component locations. Thermocouples in non-critical locations only require secondary calibrations. | Non-Compliant (Acceptable) | §7.2.5 |
| | 2.6 | Data Device Calibration | Stage III RRA Process Specification Section 3 (Reference 9) | The data acquisition system used to record temperature data from the thermocouples attached to the component or QA specimens must have a current calibration | Inspection | OEM specification | Review currency of calibration certificate of data acquisition system and renew if needed. Note that the data acquisition device can either be integrated into the furnace controller or be an independent unit. | Compliant | §7.2.6 |
| RRA Treatment Temperature Profile | 3.1 | Temperature Profile - Retrogression | Stage III RRA Process Specification Section 4 (Reference 9) | Temperature ramp rate, maximum temperature and retrogression time specific are to be as defined in the Stage III Process Specification. | Test | N/A | The temperature-time data recorded during retrogression shall be examined against the specific criteria of the process specification. These criteria are:<br>1. Temperature Ramp Rate<br>2. Maximum temperature<br>3. Retrogression Time<br>The results are to be recorded in the work order and verified from data-files. | Compliant | §7.3.1<br><br>(References 16, 17 and 18) |
| | 3.2 | Post-Retrogression Quenching | Stage III RRA Process Specification Section 4 (Reference 9) | Quench | Test | N/A | Quench to be carried out within three minutes of completion of retrogression. Quenchant temperature, maximum temperature and maximum temperature change should conform with the requirements of Stage III RRA Process Specification Paragraph 4.3.2.g | Compliant | §7.3.2<br><br>(References 16, 17 and 18) |
| | 3.3 | Temperature Profile – Re-ageing. | Stage III RRA Process Specification Section 4 (Reference 9) | Temperature ramp rate, maximum temperature and re-ageing time specific are to be defined in the Stage III Process Specification. | Test | N/A | The temperature-time data recorded shall be examined against the specific criteria of the process specification. These criteria are:<br>1. Temperature Ramp Rate<br>2. Maximum temperature<br>3. Re-ageing Time<br>The results are to be recorded in the work order and verified from data-files. | Compliant | §7.3.3<br><br>(References 16, 17 and 18) |

# Appendix B: Work Order Supplied To Boeing Australia Component Repairs

## Work Order for RRA Treatment of FS737 Lower Cap

**Notes:**
1. This work order will enable a heat treatment organisation to follow Sections 4.1 to 4.6 of the Stage III Process Specification for Retrogression and Re-ageing of 7075-T6.
2. These sections of the Process Specification refer to the heat treatment of a component through a short duration retrogression at 195 °C and a long duration (24 hours) re-ageing at 120 °C.
3. The following tables should be completed by the operator during the heat treatment process except where specified.

**Table 1: Retrogression and Quenching Process Steps**

| Step | Description | Completed |
|---|---|---|
| **1** | Confirm that required equipment is present<br>• *From Section 3.1.3 of Stage III Process Specification*<br>1. FS737 component<br>2. Water quench tank (filled to appropriate level)<br>3. Six K-type thermocouples with certificates of traceable calibration.<br>• *Four with minimum 10 metre length and capable of attachment to the component. Supplied by DSTO.*<br>4. Data acquisition system<br>• *Minimum: 6 channels*<br>• *Minimum: 0.2 Hz (12/minute)*<br>• *Capable of real time simultaneous monitoring and recording of six channels*<br>• *This system can be part of the furnace controller.*<br>5. Personal protective equipment<br>• *Minimum: High temperature gloves and safety glasses.*<br>6. Trolley for holding the component<br>7. Timer<br>• *Minimum: Capable of 2 hours countdown at 1 second intervals.* | |
| **2** | Record component ID: | |
| **3** | Record initial conductivity of component<br>• *Provided by DSTO*<br><br>Initial Conductivity: | Operator:<br><br>Howard Morton |
| **4** | Calculate Retrogression Time in minutes and seconds<br>• from Figure A1 of Stage III Process Specification.<br><br>Retrogression Time:- | |

1 of 3

*Work Order for RRA Treatment of FS737 Lower Cap*

| Step | Description | Completed |
|---|---|---|
| **5** | 1. Attach three thermocouples to the cap (thickest section) of the component so that the temperature within 150 mm of the ends and of the centre of the component can be monitored.<br>2. Place two thermocouples within the control zone of the furnace to monitor the air temperature.<br>3. Place one thermocouple in the quench tank.<br>• *The quench tank thermocouple may be placed any time prior to Step10 below if quench tank cannot be positioned earlier.* | |
| **6** | Position the component on the trolley provided. | |
| **7** | Place the trolley with the component on it within the control zone of the furnace | |
| **8** | Start recording all thermocouples at 12 samples per minute (0.2 Hz sampling frequency) or greater. | |
| **9** | Ramp the **furnace** from room temperature at 2±0.1 °C per minute to 195 °C. | |
| **10** | Start the timer as soon as the temperature of any of the thermocouples on the **component** exceeds 181 °C. | |
| **11** | Record initial **quench water** temperature.<br>• *Must be below 32 °C*<br><br>Initial quench water temperature: | |
| **12** | Hold the component in the furnace until the retrogression time recorded at Step 4 above. | |
| **13** | Remove the trolley from the furnace and quench the component into the quench tank within three minutes of retrogression completion.<br>• *To quench: Position the trolley over the water tank and release the drop-pins that hold the component.*<br>• *Quench is complete when the component temperature drops below 50 °C.* | |
| **14** | Record final **quench water** temperature:<br>• *Must remain below 38 °C*<br>• *Must not exceed initial temperature by more than 14 °C*<br>• *If the temperature peaks and then drops record the peak temperature.*<br><br>Quench water final temperature: | |
| **15** | Stop recording thermocouples. | |
| **16** | Dry the component and trolley. | |

2 of 3

*Work Order for RRA Treatment of FS737 Lower Cap*

**Table 2: Re-ageing Process Steps**

| Step | Description | Completed |
|---|---|---|
| **1** | Purge the furnace.<br>• Ensure that the air temperature in the furnace drops below 120 °C. | |
| **2** | Within 30 minutes of the start of Retrogression Step 13, position the component on the trolley and place this combination within the control zone of the furnace.<br>• Initial temperature of furnace is not critical but must be below 120 ºC. | |
| **3** | Start recording all thermocouples (except quench water) at 1 sample per minute (0.0167 Hz sampling frequency) or greater. | |
| **4** | Ramp the furnace from below 120 °C to a set point of 120 ºC at 2±0.1 ºC per minute. | |
| **5** | Hold at 120 ºC for 24 hours. | |
| **6** | Air-cool the component to room temperature. | |
| **7** | Remove the thermocouples from the component. | |
| **8** | Interrogate the data recorder and confirm the variation of the temperature of the three locations on the component during retrogression was less than 10 ºC. | |
| **9** | Provide copies of calibration certificates for<br>• Furnace,<br>• 6 thermocouples, and<br>• Data acquisition system *(if separate from Furnace calibration)* | |
| **10** | Provide copy of test data to DSTO<br><br>File name: | |

**Table 3: Confirm Successful Heat treatment**

| | |
|---|---|
| **Operator** | |
| **Signature** | |
| **Date** | |

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# Appendix C: Initial Electrical Conductivity NDI Reports

## C.1 Report NDT/GEN/15/10 (Howard Morton)

**Australian Government**
**Department of Defence**
Defence Science and
Technology Organisation

**Air Vehicles Division**
506 Lorimer St
Fishermans Bend 3207

*Report No.*
**NDT/GEN/15/10**

*Non-Destructive Testing Report.*

| *Parent Equipment:* | *Area Inspected:* | *Requested by:* | *Ref:* |
|---|---|---|---|
| RRA C130 Beams | As requested | C Loader | Verbal |

*Inspection Method/Procedure:*

Conductivity test.

| *Instrument Make:* | *Serial No.:* | *Probe No.:* |
|---|---|---|
| Sigmatest 2.069 | 742 669 | p/n 9068074 s/n 472 |

*Instrument Set-up/Exposure Details:*

Calibration as per manual. Using three reference standards.
52.00% IACS p/n 9080350 s/n 41
29.80 % IACS p/n 9080317 s/n 36 (set of three).
19.10 % IACS p/n 9080317 s/n 388.
Instrument was calibrated prior to use and was checked prior to and after each beam.

*Results/Comments:*

**Test Method.**

Beams were numbered 1, 2, 3 &5 by means of notches at one end.
Measurements were taken in 6 positions: 300 mm in from the notched end of the Beam and at 5 equidistant locations (519 mm spacing) along the beam. Letters A through F were engraved on the edge of the cap where the measurements were taken.
At each of these positions, on the cap 12 mm from the web surface and on the web 12mm from the cap surface (Beam #1 B-E 20 mm from cap surface), 3 conductivity readings were taken and averaged. All measurements were taken on the engraved side.

**Test Restrictions:**
The tested Cap section of the beam has a slight concavity. However, the results suggest this has not influenced the measured values.

The surface finish (sand blasted) was measured and found to exceed the recommended maximum of 165RMS for conductivity measurement (RAAF NDT General Procedures. Section 5, Chapter 3). Conductivity measurements were taken on Beam #2, Cap at position A. The area was polished and the measurements re-taken. The variation was within the measuring accuracy of the instrument, all other measurements were taken without polishing.

**Results**

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| *Results/Comments:* |
|---|
| See attached table. |

| | | | |
|---|---|---|---|
| *Method of Recording Data:* | Hardcopy/softcopy. | | |
| *Data Location:* | Folder: NDT General Part 3 Softcopy:I:\NDT GENERAL | | |
| *Entered into Database by:* | H Morton | | *Date:* 6 July 2010 |

| *Inspectors Name:* | *Signature:* | |
|---|---|---|
| H Morton | | 6 July 2010 |
| *Independent Inspectors Name:* | *Signature:* | |
| | | *Date:* |

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Average conductivity measurements in % IACS.

| Beam | Position | Check | Cap | Web | | Position | Check | Cap | Web |
|---|---|---|---|---|---|---|---|---|---|
| #1 | Check | 29.80 | | | | | | | |
| | A | | 33.15 | 33.03 | | | | | |
| | B | | 33.63 | 33.25 | | | | | |
| | C | | 33.89 | 33.59 | | | | | |
| | D | | 33.73 | 33.77 | | | | | |
| | E | | 33.45 | 33.73 | | | | | |
| | F | | 33.51 | 33.43 | | | | | |
| | Check | 29.76 | | | | | | | |
| | | | | | | | | | |
| #2 | Check | 29.78 | | | | | | | |
| | A | | 33.79 | 33.62 | | | | | |
| | B | | 33.66 | 33.72 | | | | | |
| | C | | 33.57 | 33.52 | | | | | |
| | D | | 33.64 | 33.27 | | | | | |
| | E | | 33.31 | 33.10 | | | | | |
| | F | | 33.55 | 33.39 | | | | | |
| | Check | 29.77 | | | | | | | |
| | | | | | | | | | |
| #3 | Check | 29.78 | | | | | | | |
| | A | | 34.02 | 34.16 | | | | | |
| | B | | 34.00 | 34.02 | | | | | |
| | C | | 34.12 | 33.98 | | | | | |
| | D | | 34.19 | 33.94 | | | | | |
| | E | | 34.15 | 33.95 | | | | | |
| | F | | 34.06 | 34.18 | | | | | |
| | Check | 29.84 | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| #5 | Check | 29.81 | | | | | | | |
| | A | | 33.65 | 33.37 | | | | | |
| | B | | 33.41 | 33.44 | | | | | |
| | C | | 33.66 | 33.44 | | | | | |
| | D | | 33.65 | 33.40 | | | | | |
| | E | | 33.65 | 33.66 | | | | | |
| | F | | 33.67 | 33.61 | | | | | |
| | Check | 29.83 | | | | | | | |
| | | | | | | | | | |

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# Appendix D: Final Electrical Conductivity NDI Reports

## D.1 Report NDT/GEN/20/10 (Howard Morton)

Australian Government
Department of Defence
Defence Science and
Technology Organisation

Air Vehicles Division
506 Lorimer St
Fishermans Bend 3207

*Report No.*
**NDT/GEN/20/10**

*Non-Destructive Testing Report.*

| *Parent Equipment:* | *Area Inspected:* | *Requested by:* | *Ref:* |
|---|---|---|---|
| RRA C130 Beams<br>Post Heat Treatment | As requested | B Crawford | Email 27/8/10 |

*Inspection Method/Procedure:*

Conductivity test.

| *Instrument Make:* | *Serial No.:* | *Probe No.:* |
|---|---|---|
| Sigmatest 2.069 | 742 669 | p/n 9068074 s/n 472 |

*Instrument Set-up/Exposure Details:*

Calibration as per manual. Using three reference standards.

52.00% IACS p/n 9080350 s/n 41

29.80 % IACS p/n 9080317 s/n 36 (set of three).

19.10 % IACS p/n 9080317 s/n 388.

Instrument was calibrated prior to use and was checked on the 29.80% IACS standard prior to and after testing each beam.

*Results/Comments:*

**Test Method.**

Beams were numbered 1, 2 &5 by means of notches at one end.
Measurements were taken in 6 positions: 300 mm in from the notched end of the Beam and at 5 equidistant locations (519 mm spacing) along the beam. Letters A through F were engraved on the edge of the cap where the measurements were taken.
3 conductivity readings were taken and averaged at each of these positions: on the cap 12 mm from the web surface (Beam #1 20 mm from web surface) and on the web 12mm from the cap surface. All measurements were taken on the engraved side.

**Test Restrictions:**
The tested Cap section of the beam has a slight concavity. However, the results suggest this has not influenced the measured values.

The surface finish (sand blasted) was measured and found to exceed the recommended maximum of 165RMS for conductivity measurement (RAAF NDT General Procedures. Section 5, Chapter 3).
Conductivity measurements were taken on Beam #2, Cap at position A. The area was then

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| *Results/Comments:* |
|---|
| polished and the measurements re-taken. The variation was within the measuring accuracy of the instrument, all other measurements were taken without polishing.<br>**Results**<br>See attached table. |

| | | |
|---|---|---|
| *Method of Recording Data:* | Hardcopy/softcopy. | |
| *Data Location:* | Folder: NDT General Part 3 Softcopy:I:\NDT GENERAL | |
| *Entered into Database by:* | H Morton | *Date:* 3 Sep 2010 |

| *Inspectors Name:* | *Signature:* | |
|---|---|---|
| H Morton | [signature] | 3 Sep 2010 |

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Cnductivity measurements in % IACS.

| Beam | Position | Check | Cap | Web | | Position | Check | Cap | Web |
|---|---|---|---|---|---|---|---|---|---|
| #1 | Check | 29.78 | | | | | | | |
| | A | | 37.99 | 38.31 | | | | | |
| | B | | 39.29 | 38.92 | | | | | |
| | C | | 39.54 | 39.87 | | | | | |
| | D | | 39.77 | 40.23 | | | | | |
| | E | | 39.41 | 39.92 | | | | | |
| | F | | 39.02 | 39.37 | | | | | |
| | Check | 29.92 | | | | | | | |
| | | | | | | | | | |
| #2 | Check | 29.81 | | | | | | | |
| | A | | 38.97 | 38.90 | | | | | |
| | B | | 39.34 | 39.92 | | | | | |
| | C | | 39.42 | 39.19 | | | | | |
| | D | | 39.60 | 39.15 | | | | | |
| | E | | 39.21 | 38.81 | | | | | |
| | F | | 39.75 | 39.22 | | | | | |
| | Check | 29.81 | | | | | | | |
| | | | | | | | | | |
| #5 | Check | 29.78 | | | | | | | |
| | A | | 38.24 | 37.88 | | | | | |
| | B | | 38.55 | 38.43 | | | | | |
| | C | | 39.22 | 38.96 | | | | | |
| | D | | 39.28 | 38.97 | | | | | |
| | E | | 39.26 | 39.33 | | | | | |
| | F | | 38.95 | 38.99 | | | | | |
| | Check | 29.76 | | | | | | | |
| | | | | | | | | | |

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## D.2 Report NDT/GEN/21/10 (Greg Surtees)

**Australian Government**
**Department of Defence**
Defence Science and
Technology Organisation

**Air Vehicles Division**
506 Lorimer St
Fishermans Bend 3207

*Report No.*
**NDT/GEN/21/10**

*Non-Destructive Testing Report.*

| *Parent Equipment:* | *Area Inspected:* | *Requested by:* | *Ref:* |
|---|---|---|---|
| RRA C130 Beams<br>Pre & Post Heat Treatment | As requested | B Crawford | Email 8/09/10 |

| *Inspection Method/Procedure:* |
|---|
| Conductivity test. |

| *Instrument Make:* | *Serial No.:* | *Probe No.:* |
|---|---|---|
| Sigmatest 2.069 | p/n 9066500 s/n 742 | p/n 9068074 s/n 472 |

*Instrument Set-up/Exposure Details:*

Calibration as per manual. Using two reference standards.
29.80 % IACS p/n 9080708 s/n 36 (from a set of three).
44.39 % IACS p/n 9080708 s/n 36 (from a set of three).
Instrument was calibrated prior to use and checked after testing each beam.

*Results/Comments:*

**Test Method.**

RRA C130 beams numbered 2 & 3 (identified by means of notches at one end) were re-tested for conductivity results.
Measurements were taken in 6 positions: 300 mm in from the notched end of the Beam and at 5 equidistant locations (519 mm spacing) along the beam. Letters A through F were engraved on the edge of the cap where the measurements were taken.

Three conductivity readings were taken and averaged at each of these positions: on the cap 12 mm from the web surface and on the web 12mm from the cap surface. All measurements were taken on the engraved side.

**Test Restrictions/Notes:**

The test area surface finish was in the sand blasted condition.
The surface finish at Beam #2, position A (Cap area) was in the polished condition.

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| *Results/Comments:* |
| --- |
| **Results**<br>See attached table. |

| | | |
| --- | --- | --- |
| *Method of Recording Data:* | Hardcopy/softcopy. | |
| *Data Location:* | Folder: NDT General Part 3 Softcopy:I:\NDT GENERAL | |
| *Entered into Database by:* | Mr G Surtees | *Date:* 9 Sept 2010 |

| *Inspectors Name:* | *Signature:* | |
| --- | --- | --- |
| Mr Greg Surtees | | 9 Sep 2010 |

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Conductivity measurements in % IACS.

| Beam | Position | Check | Cap | Web | | Position | Check | Cap | Web |
|---|---|---|---|---|---|---|---|---|---|
| #2 | A | | 38.90 | 38.64 | | | | | |
| | B | | 39.30 | 39.38 | | | | | |
| | C | | 39.50 | 39.18 | | | | | |
| | D | | 39.62 | 39.02 | | | | | |
| | E | | 39.18 | 38.85 | | | | | |
| | F | | 39.64 | 39.39 | | | | | |
| | | | | | | | | | |
| #3 | A | | 34.07 | 34.12 | | | | | |
| | B | | 33.97 | 33.96 | | | | | |
| | C | | 33.98 | 33.92 | | | | | |
| | D | | 34.08 | 33.83 | | | | | |
| | E | | 34.00 | 33.88 | | | | | |
| | F | | 33.92 | 34.10 | | | | | |
| | | | | | | | | | |

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# Appendix E: Completed Work Order Supplied To Boeing Australia Component Repairs

Trial 1 Component #1 17-8-2010

## Work Order for RRA Treatment of FS737 Lower Cap

**Notes:**

1. This work order will enable a heat treatment organisation to follow Sections 4.1 to 4.6 of the Stage III Process Specification for Retrogression and Re-ageing of 7075-T6.
2. These sections of the Process Specification refer to the heat treatment of a component through a short duration retrogression at 195 °C and a long duration (24 hours) re-ageing at 120 °C.
3. The following tables should be completed by the operator during the heat treatment process except where specified.

**Table 1: Retrogression and Quenching Process Steps**

| Step | Description | Completed |
|---|---|---|
| 1 | Confirm that required equipment is present<br>• *From Section 3.1.3 of Stage III Process Specification*<br>1. FS737 component<br>2. Water quench tank (filled to appropriate level)<br>3. Six K-type thermocouples with certificates of traceable calibration.<br>• *Four with minimum 10 metre length and capable of attachment to the component. Supplied by DSTO.*<br>4. Data acquisition system<br>• *Minimum: 6 channels*<br>• *Minimum: 0.2 Hz (12/minute)*<br>• *Capable of real time simultaneous monitoring and recording of six channels*<br>• *This system can be part of the furnace controller.*<br>5. Personal protective equipment<br>• *Minimum: High temperature gloves and safety glasses.*<br>6. Trolley for holding the component<br>7. Timer<br>• *Minimum: Capable of 2 hours countdown at 1 second intervals.* | [initials] |
| 2 | Record component ID: #1 | [initials] |
| 3 | Record initial conductivity of component<br>• *Provided by DSTO*<br>Initial Conductivity: 33.51 | Operator:<br>Howard Morton |
| 4 | Calculate Retrogression Time in minutes and seconds<br>• from Figure A1 of Stage III Process Specification.<br>Retrogression Time: 22 min 48 sec. | [initials] |

1 of 3

*Work Order for RRA Treatment of FS737 Lower Cap*

| Step | Description | Completed |
|---|---|---|
| **5** | 1. Attach three thermocouples to the cap (thickest section) of the component so that the temperature within 150 mm of the ends and of the centre of the component can be monitored.<br>2. Place two thermocouples within the control zone of the furnace to monitor the air temperature.<br>3. Place one thermocouple in the quench tank.<br>• *The quench tank thermocouple may be placed any time prior to Step10 below if quench tank cannot be positioned earlier.* | |
| **6** | Position the component on the trolley provided. | |
| **7** | Place the trolley with the component on it within the control zone of the furnace | |
| **8** | Start recording all thermocouples at 12 samples **per thermocouple** per minute (0.2 Hz sampling frequency) or greater. | |
| **9** | Ramp the **furnace** from room temperature at 2±0.1 °C per minute to 195 °C. | |
| **10** | Start the timer as soon as the temperature of any of the thermocouples on the **component** exceeds 181 °C. | |
| **11** | Record initial **quench water** temperature.<br>• *Must be below 32 °C*<br><br>Initial quench water temperature: 13°C | |
| **12** | Hold the component in the furnace until the retrogression time recorded at Step 4 above. | |
| **13** | Remove the trolley from the furnace and quench the component into the quench tank within three minutes of retrogression completion.<br>• *To quench: Position the trolley over the water tank and release the drop-pins that hold the component.*<br>• *Quench is complete when the component temperature drops below 50 °C.* | |
| **14** | Record final **quench water** temperature:<br>• *Must remain below 38 °C*<br>• *Must not exceed initial temperature by more than 14 °C*<br>• *If the temperature peaks and then drops record the peak temperature.*<br><br>Quench water final temperature: 14°C | |
| **15** | Stop recording thermocouples. | |
| **16** | Dry the component and trolley. | |

2 of 3

*Work Order for RRA Treatment of FS737 Lower Cap*

**Table 2: Re-ageing Process Steps**

| Step | Description | Completed |
|---|---|---|
| **1** | Purge the furnace.<br>• Ensure that the air temperature in the furnace drops below 120 °C. | [signature] |
| **2** | Within 30 minutes of the start of Retrogression Step 13, position the component on the trolley and place this combination within the control zone of the furnace.<br>• Initial temperature of furnace is not critical but must be below 120 °C. | [signature] |
| **3** | Start recording all thermocouples (except quench water) at 1 sample **per thermocouple** per minute (0.0167 Hz sampling frequency) or greater. | [signature] |
| **4** | Ramp the furnace from below 120 °C to a set point of 120 °C at 2±0.1 °C per minute. | [signature] |
| **5** | Hold at 120 °C for 24 hours. | [signature] |
| **6** | Air-cool the component to room temperature. | [signature] |
| **7** | Remove the thermocouples from the component. | [signature] |
| **8** | Interrogate the data recorder and confirm the variation of the temperature of the three locations on the component during retrogression was less than 10 °C. | [signature] |
| **9** | Provide copies of calibration certificates for<br>• Furnace,<br>• 6 thermocouples, and<br>• Data acquisition system *(if separate from Furnace calibration)* | [signature] |
| **10** | Provide copy of test data to DSTO<br>File name: Trial 1 retrogression.xls<br>Trial 1 re-ageing.xls | [signature] |

**Table 3: Confirm Successful Heat treatment**

| | |
|---|---|
| **Operator** | DENNIS TAM |
| **Signature** | [signature] |
| **Date** | 18-8-2010 |

19-8-2010

Trial 2 Component #2

# Work Order for RRA Treatment of FS737 Lower Cap

**Notes:**

1. This work order will enable a heat treatment organisation to follow Sections 4.1 to 4.6 of the Stage III Process Specification for Retrogression and Re-ageing of 7075-T6.
2. These sections of the Process Specification refer to the heat treatment of a component through a short duration retrogression at 195 °C and a long duration (24 hours) re-ageing at 120 °C.
3. The following tables should be completed by the operator during the heat treatment process except where specified.

**Table 1: Retrogression and Quenching Process Steps**

| Step | Description | Completed |
|---|---|---|
| **1** | Confirm that required equipment is present<br>• *From Section 3.1.3 of Stage III Process Specification*<br>1. FS737 component<br>2. Water quench tank (filled to appropriate level)<br>3. Six K-type thermocouples with certificates of traceable calibration.<br>• *Four with minimum 10 metre length and capable of attachment to the component. Supplied by DSTO.*<br>4. Data acquisition system<br>• *Minimum: 6 channels*<br>• *Minimum: 0.2 Hz (12/minute)*<br>• *Capable of real time simultaneous monitoring and recording of six channels*<br>• *This system can be part of the furnace controller.*<br>5. Personal protective equipment<br>• *Minimum: High temperature gloves and safety glasses.*<br>6. Trolley for holding the component<br>7. Timer<br>• *Minimum: Capable of 2 hours countdown at 1 second intervals.* | [initials] |
| **2** | Record component ID: #2 | [initials] |
| **3** | Record initial conductivity of component<br>• *Provided by DSTO*<br><br>Initial Conductivity: 33.51 | Operator:<br><br>Howard Morton |
| **4** | Calculate Retrogression Time in minutes and seconds<br>• from Figure A1 of Stage III Process Specification.<br><br>Retrogression Time: 22 min 48 sec. | [initials] |

1 of 3

*Work Order for RRA Treatment of FS737 Lower Cap*

| Step | Description | Completed |
|---|---|---|
| **5** | 1. Attach three thermocouples to the cap (thickest section) of the component so that the temperature within 150 mm of the ends and of the centre of the component can be monitored.<br>2. Place two thermocouples within the control zone of the furnace to monitor the air temperature.<br>3. Place one thermocouple in the quench tank.<br>• *The quench tank thermocouple may be placed any time prior to Step10 below if quench tank cannot be positioned earlier.* | JW |
| **6** | Position the component on the trolley provided. | JW |
| **7** | Place the trolley with the component on it within the control zone of the furnace | JW |
| **8** | Start recording all thermocouples at 12 samples **per thermocouple** per minute (0.2 Hz sampling frequency) or greater. | JW |
| **9** | Ramp the **furnace** from room temperature at 2±0.1 °C per minute to 195 °C. | JW |
| **10** | Start the timer as soon as the temperature of any of the thermocouples on the **component** exceeds 181 °C. | JW |
| **11** | Record initial **quench water** temperature.<br>• *Must be below 32 °C*<br>Initial quench water temperature: 13 °C | JW |
| **12** | Hold the component in the furnace until the retrogression time recorded at Step 4 above. | JW |
| **13** | Remove the trolley from the furnace and quench the component into the quench tank within three minutes of retrogression completion.<br>• *To quench: Position the trolley over the water tank and release the drop-pins that hold the component.*<br>• *Quench is complete when the component temperature drops below 50 °C.* | JW |
| **14** | Record final **quench water** temperature:<br>• *Must remain below 38 °C*<br>• *Must not exceed initial temperature by more than 14 °C*<br>• *If the temperature peaks and then drops record the peak temperature.*<br>Quench water final temperature: 14 °C | JW |
| **15** | Stop recording thermocouples. | JW |
| **16** | Dry the component and trolley. | JW |

2 of 3

*Work Order for RRA Treatment of FS737 Lower Cap*

**Table 2: Re-ageing Process Steps**

| Step | Description | Completed |
|---|---|---|
| **1** | Purge the furnace. <br>• Ensure that the air temperature in the furnace drops below 120 °C. | [illegible] |
| **2** | Within 30 minutes of the start of Retrogression Step 13, position the component on the trolley and place this combination within the control zone of the furnace. <br>• Initial temperature of furnace is not critical but must be below 120 °C. | [illegible] |
| **3** | Start recording all thermocouples (except quench water) at 1 sample **per thermocouple** per minute (0.0167 Hz sampling frequency) or greater. | [illegible] |
| **4** | Ramp the furnace from below 120 °C to a set point of 120 °C at 2±0.1 °C per minute. | [illegible] |
| **5** | Hold at 120 °C for 24 hours. | [illegible] |
| **6** | Air-cool the component to room temperature. | [illegible] |
| **7** | Remove the thermocouples from the component. | [illegible] |
| **8** | Interrogate the data recorder and confirm the variation of the temperature of the three locations on the component during retrogression was less than 10 °C. | [illegible] |
| **9** | Provide copies of calibration certificates for <br>• Furnace, <br>• 6 thermocouples, and <br>• Data acquisition system *(if separate from Furnace calibration)* | [illegible] |
| **10** | Provide copy of test data to DSTO <br>File name: Trial 2 retrogression.xls <br>Trial 2 re-ageing.xls | [illegible] |

**Table 3: Confirm Successful Heat treatment**

| | |
|---|---|
| **Operator** | DENNIS TAM |
| **Signature** | [illegible] |
| **Date** | 20-8-2010 |

3 of 3

Trial #3 Component #5 23-8-2010

# Work Order for RRA Treatment of FS737 Lower Cap

**Notes:**

1. This work order will enable a heat treatment organisation to follow Sections 4.1 to 4.6 of the Stage III Process Specification for Retrogression and Re-ageing of 7075-T6.
2. These sections of the Process Specification refer to the heat treatment of a component through a short duration retrogression at 195 °C and a long duration (24 hours) re-ageing at 120 °C.
3. The following tables should be completed by the operator during the heat treatment process except where specified.

**Table 1: Retrogression and Quenching Process Steps**

| Step | Description | Completed |
|---|---|---|
| **1** | Confirm that required equipment is present<br>• *From Section 3.1.3 of Stage III Process Specification*<br>1. FS737 component<br>2. Water quench tank (filled to appropriate level)<br>3. Six K-type thermocouples with certificates of traceable calibration.<br>• *Four with minimum 10 metre length and capable of attachment to the component. Supplied by DSTO.*<br>4. Data acquisition system<br>• *Minimum: 6 channels*<br>• *Minimum: 0.2 Hz (12/minute)*<br>• *Capable of real time simultaneous monitoring and recording of six channels*<br>• *This system can be part of the furnace controller.*<br>5. Personal protective equipment<br>• *Minimum: High temperature gloves and safety glasses.*<br>6. Trolley for holding the component<br>7. Timer<br>• *Minimum: Capable of 2 hours countdown at 1 second intervals.* | |
| **2** | Record component ID: #5 | |
| **3** | Record initial conductivity of component<br>• *Provided by DSTO*<br><br>Initial Conductivity: 33.55 | Operator:<br><br>Howard Morton |
| **4** | Calculate Retrogression Time in minutes and seconds<br>• from Figure A1 of Stage III Process Specification.<br><br>Retrogression Time: 21 min 47 sec. | |

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*Work Order for RRA Treatment of FS737 Lower Cap*

| Step | Description | Completed |
|---|---|---|
| **5** | 1. Attach three thermocouples to the cap (thickest section) of the component so that the temperature within 150 mm of the ends and of the centre of the component can be monitored.<br>2. Place two thermocouples within the control zone of the furnace to monitor the air temperature.<br>3. Place one thermocouple in the quench tank.<br>• *The quench tank thermocouple may be placed any time prior to Step10 below if quench tank cannot be positioned earlier.* | JM |
| **6** | Position the component on the trolley provided. | JM |
| **7** | Place the trolley with the component on it within the control zone of the furnace | JM |
| **8** | Start recording all thermocouples at 12 samples **per thermocouple** per minute (0.2 Hz sampling frequency) or greater. | JM |
| **9** | Ramp the **furnace** from room temperature at 2±0.1 °C per minute to 195 °C. | JM |
| **10** | Start the timer as soon as the temperature of any of the thermocouples on the **component** exceeds 181 °C. | JM |
| **11** | Record initial **quench water** temperature.<br>• *Must be below 32 °C*<br><br>Initial quench water temperature: 13 °C | JM |
| **12** | Hold the component in the furnace until the retrogression time recorded at Step 4 above. | JM |
| **13** | Remove the trolley from the furnace and quench the component into the quench tank within three minutes of retrogression completion.<br>• *To quench: Position the trolley over the water tank and release the drop-pins that hold the component.*<br>• *Quench is complete when the component temperature drops below 50 °C.* | JM |
| **14** | Record final **quench water** temperature:<br>• *Must remain below 38 °C*<br>• *Must not exceed initial temperature by more than 14 °C*<br>• *If the temperature peaks and then drops record the peak temperature.*<br><br>Quench water final temperature: 14 °C | JM |
| **15** | Stop recording thermocouples. | JM |
| **16** | Dry the component and trolley. | JM |

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*Work Order for RRA Treatment of FS737 Lower Cap*

**Table 2: Re-ageing Process Steps**

| Step | Description | Completed |
|---|---|---|
| **1** | Purge the furnace.<br>• Ensure that the air temperature in the furnace drops below 120 °C. | [signature] |
| **2** | Within 30 minutes of the start of Retrogression Step 13, position the component on the trolley and place this combination within the control zone of the furnace.<br>• Initial temperature of furnace is not critical but must be below 120 °C. | [signature] |
| **3** | Start recording all thermocouples (except quench water) at 1 sample **per thermocouple** per minute (0.0167 Hz sampling frequency) or greater. | [signature] |
| **4** | Ramp the furnace from below 120 °C to a set point of 120 °C at 2±0.1 °C per minute. | [signature] |
| **5** | Hold at 120 °C for 24 hours. | [signature] |
| **6** | Air-cool the component to room temperature. | [signature] |
| **7** | Remove the thermocouples from the component. | [signature] |
| **8** | Interrogate the data recorder and confirm the variation of the temperature of the three locations on the component during retrogression was less than 10 °C. | [signature] |
| **9** | Provide copies of calibration certificates for<br>• Furnace,<br>• 6 thermocouples, and<br>• Data acquisition system *(if separate from Furnace calibration)* | [signature] |
| **10** | Provide copy of test data to DSTO<br>File name: Trial 3 retrogression.xls<br>Trial 3 re-ageing.xls | [signature] |

**Table 3: Confirm Successful Heat treatment**

| | |
|---|---|
| **Operator** | DENNIS TAM |
| **Signature** | [signature] |
| **Date** | 24-8-2010 |

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Retrogression and Re-ageing, RRA, aluminium alloy, heat treatment, certification

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 reliability trials, conducted at Boeing Australia Component Repairs (BACR) in August 2010, with the requirements of the compliance matrix in the Stage III Design Development Plan and, by extension, the Stage III Process Specification for RRA. All properties described by items in the compliance matrix received recommended ratings of either 'Compliant' or 'Non-Compliant (Acceptable)'. Of the 15 items in the compliance matrix only four were rated 'Non-Compliant (Acceptable)'.The trials demonstrated that the RRA process as defined in the Stage III Process Specification can be reliabily applied to an aircraft component in an industrial environment with a reliability exceeding 95%.