

DOT/FAA/TC-18/24

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Adhesively Bonded Repairs to Metallic Fuselage Structure: Test 3, Effect of Environmental Conditions

June 2019

Final Report

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1. Report No. DOT/FAA/TC-18/24	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle ADHESIVELY BONDED REPAIRS TO METALLIC FUSELAGE STRUCTURE: TEST 3, EFFECT OF ENVIRONMENTAL CONDITIONS		5. Report Date June 2019	6. Performing Organization Code ANG-281
		8. Performing Organization Report No.	
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9. Performing Organization Name and Address William J. Hughes Technical Center Federal Aviation Administration Aviation Research Division Structures and Materials Section Atlantic City International Airport, NJ 08405		10. Work Unit No. (TRAIS)	11. Contract or Grant No.
		13. Type of Report and Period Covered Final Report	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration FAA Transport Airplane Directorate Airframe/Cabin Safety, ANM-115 1601 Lind Avenue SW Renton, WA 98057		14. Sponsoring Agency Code ANM-115	
		15. Supplementary Notes The FAA William J. Hughes Technical Center Aviation Research Division COR was John G. Bakuckas, Jr.	
16. Abstract In a joint effort, the FAA and The Boeing Company investigated the structural robustness and damage-resistance capabilities of adhesively bonded repair technology through the testing and analysis of metallic B727 fuselage panels at the FAA Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) lab. The program objectives were to characterize the durability and fatigue performance of boron/epoxy (B/Ep) and aluminum-bonded repairs under simulated service load conditions over the typical design service goal of an airplane (60,000 cycles for B727), and to investigate tools for evaluating and monitoring the repair integrity over the life of the part. In this study, the effects of environment on the durability and fatigue performance of bonded repairs to fuselage panels under simulated service load conditions were investigated using the FAA's FASTER facility. For this study, modifications were made to the fixture to apply synchronous mechanical, temperature, and humidity loading profiles. A hot-wet environmental condition with a temperature of 165°F and humidity of 85%, and a cold-dry environmental condition with a temperature of -25°F were applied to both B/Ep and aluminum-bonded repair patches installed on a B727 fuselage panel subjected to mechanical fatigue loads to at least one design service goal. Bonded repair patches were intentionally made deficient and contained defects to encourage damage growth. During all test phases, damage formation and growth of cracks and disbonds were monitored and recorded using a prototype structural health monitoring system and several nondestructive inspection methods, including visual inspections, eddy current, flash thermography, and resonance ultrasonic. In addition, strains in the vicinity of the repair patches were continuously recording, using strain gauges and the digital image correlation method. In total, 100,000 fatigue cycles have been completed for which representative results are summarized herein. In general, the overall fatigue performances of the repairs were reduced as the quality and condition of the repairs were degraded. In addition, environmental effects were a contributing factor to fatigue crack growth measured in the B/Ep repair patches for which the rates were typically slower under hot-wet conditions compared to ambient conditions. Elevated temperatures of the hot-wet condition apparently reduced the residual strains induced during the original curing process of the B/Ep patch installation. The cold-dry condition marginally increased the residual strains at the crack tips of the B/Ep patches. However, multi-site-damage formed during the cold-dry fatigue cycling, resulting in a 20-inch-long crack after 97,000 cycles. Because of stress redistribution, data analysis was terminated at that point. Data from this program will be used to assess tools and methods for evaluating and monitoring the repair integrity over the life of the part.			
17. Key Words Bonded repairs, Boron/epoxy, Disbond, Crack, Nondestructive inspection, Structural health monitoring inspection, Test, Analysis		18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 280	22. Price

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LIST OF ACRONYMS

B/Ep	Boron/epoxy
CD	Cold-dry
CRAS	Composite Repair of Aircraft Structures
DIC	Digital image correlation
EC	Eddy current
FASTER	Full-Scale Aircraft Structural Test Evaluation and Research
FE	Finite element
FEP	Fluorinated ethylene propylene
HFEC	High-frequency eddy current
HS	Hand sanded
JAA	Joint Aviation Authority
LFEC	Low-frequency eddy current
MSD	Multi-site-damage
NDI	Nondestructive inspection
NFOV	Narrow-field-of-view
PZT	Piezoelectric transducer
RA	Reference aluminum repair
RB	Reference Boron-epoxy repair
SGC	Strain gauge chain
SHM	Structural health monitoring
SIF	Stress intensity factor
SL	Service load
S8R	Six degrees of freedom
UA	Undersigned aluminum repair
UB	Undersigned Boron-epoxy repair
UDA	Underdesigned disband aluminum
UDB	Underdesigned disbond boron/epoxy
WFOV	Wide-field-of-view
WJHTC	William J. Hughes Technical Center

EXECUTIVE SUMMARY

In a joint effort, the FAA and The Boeing Company investigated the structural robustness and damage-resistance capabilities of adhesively bonded repairs through the testing and analysis of metallic B727 fuselage panels at the FAA William J. Hughes Technical Center in Atlantic City, NJ. The program objectives were to characterize through testing the durability and fatigue performance of boron/epoxy (B/Ep) and aluminum-bonded repairs under simulated service load (SL) conditions over the typical design service goal of an airplane (60,000 cycles for the B727), and to investigate methods and tools used for analysis and predictive performance of the repairs and those used for evaluating and monitoring the repair integrity during the life of the part. The damage scenario for the bonded repairs was primarily a center-bay crack. Normally, a crack is completely removed from the structure prior to a repair application. However, for the purpose of this research, the crack was not removed. Therefore, active damage (a crack that has not been stop-drilled or removed) is left under the repair patch to provide data necessary to support all of the objectives of the research. This approach is not advocating active damage be left under a repair in nonresearch-related applications.

In this portion of the study, the effects of environment on the durability and fatigue performance of bonded repairs to fuselage panels under simulated SL conditions are being investigated using the FAA's FASTER facility. For this study, modifications were made to the fixture to apply synchronous mechanical, temperature, and humidity loading profiles. A hot-wet environmental condition with a temperature of 165°F and a humidity of 85%, and a cold-dry environmental condition with a temperature of -25°F were applied to both B/Ep and aluminum-bonded repair patches installed on a B727 fuselage panel subjected to mechanical fatigue loads to at least one design service goal. Bonded repair patches were intentionally made deficient and contained defects to encourage damage growth. During all test phases, damage formation and growth of cracks and disbonds were monitored and recorded using a prototype structural health monitoring system and several nondestructive inspection methods, including visual inspections, eddy current, flash thermography, and resonance ultrasonic. In addition, strains in the vicinity of the repair patches were continuously recorded using strain gauges and the digital image correlation method. In total, 100,000 fatigue cycles were completed for which representative results are summarized herein.

In general, the overall fatigue performance of the repairs were reduced as the quality and condition of the repairs were degraded. In addition, environmental effects were a contributing factor to fatigue crack growth measured in the B/Ep repair patches in which the rates were typically slower under hot-wet conditions compared to ambient conditions. Elevated temperatures of the hot-wet condition apparently reduced the residual strains induced during the original curing process of the B/Ep patch installation. The cold-dry condition marginally increased the residual strains at the crack tips of the B/Ep patches. However, multi-site-damage formed during the cold-dry fatigue cycling resulting in a crack linkup to a 20-inch-long crack after 97,000 cycles. Because of stress redistribution, data analysis was terminated at that point. Data from this program will be used to assess tools and methods for evaluating and monitoring the repair integrity over the life of the part.

1. INTRODUCTION

There has been an extensive amount of research and development efforts regarding bonded repairs over the past three decades. Adhesively bonded repairs of aircraft structures are frequently used in military applications, especially with the Royal Australian Air Force, which has instituted this technology to maintain their aging fleet. A noteworthy reference that provides an outstanding summary of the advances and real-world applications of bonded repairs is a two-volume book edited by Baker, Rose, and Jones [1]. As part of a USAF-led effort, The Boeing Company developed an initial design tool for bonded repairs called Composite Repair of Aircraft Structures (CRAS).

Bonded repair technology has matured considerably and has been demonstrated to be a viable alternative to metallic fastened repairs. Obvious advantages are the aerodynamic and structural efficiency of bonded repairs and the ability to significantly reduce stress concentrations. Despite these advantages, commercial application of bonded repairs is quite limited because of the lack of confidence in bonding. In the past, bonded repairs on transport airframe structures were not always successful, resulting in unexpected bond failures. It is difficult to reliably determine and assure bond integrity. As such, credit is typically not provided for inhibiting crack initiation, slowing crack growth, and restoring strength. Consequently, the FAA issued a Policy Statement (PS-AIR-100-14-130-001) regarding bonded repairs to critical structures: "All critical structures must have a repair size limit no larger than a size that maintains limit load residual strength capability with the repair completely failed, or failed within arresting design structures." To expand the size limits of a given bonded repair, repair designs must have structural substantiation based on tests or analyses supported by tests. Additional data are required to qualify bonded material and process compatibilities, to demonstrate the proof of structure, and to establish reliable inspection procedures.

In a joint effort, the FAA and The Boeing Company are investigating the structural robustness and damage-resistance capabilities of adhesively bonded repair technology through the testing and analysis of metallic B727 fuselage panels at the FAA Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) lab. The program objectives are to characterize the durability and fatigue performance of boron/epoxy (B/Ep) and aluminum-bonded repairs under simulated service load (SL) conditions over the typical design service goal of an airplane (60,000 cycles for B727), and to investigate tools for evaluating and monitoring the repair integrity over the life of the part.

The damage scenario being addressed in this study primarily consisted of a center-bay crack in the fuselage skin. Center-bay cracks are not common; however, this approach simplified the analysis, repair installation, and inspection. Additionally, the accepted practice for repairing cracks is to cut out the crack before installing the repair. However, to achieve the objectives of the research, the simulated cracks in the fuselage skin were not removed prior to repair installation. This research required that the damage be left in place to gather the necessary data to show the ability of the repairs to slow damage growth, provide data for analysis tools correlation, and provide active damage that can be used to evaluate the ability of monitoring systems such as structural health monitoring (SHM) and nondestructive inspection (NDI) to detect any growth in damage size. It is emphasized that this research does not advocate leaving active damage (a crack that has not been stop-drilled or removed) under a repair in non-research related applications.

A phased approach was taken involving the testing and analysis of several panels containing B/Ep and aluminum-bonded patches. A variety of loading and environmental conditions, damage scenarios, and repair conditions were considered. The first panel tested provided baseline data and was completed in 2010 [1–4]. The results demonstrated that properly designed and installed bonded repairs can be durable under fatigue to at least one design service goal under SL conditions and to at least 20,000 cycles at elevated loads of 115% and 133% of the SL conditions. In addition, the repairs are capable of effectively containing significant damage (e.g., a 26-inch, two-bay notch in a lap joint with central stiffener severed) under severe static loads in excess of ultimate load requirements, 150% limit load.

The second follow-on test was completed in 2012, in which repair patches were intentionally made deficient and contained defects to permit damage growth [5–6]. In general, the capability to detect growing flaws under bonded patches and to monitor the effectiveness of the repairs was demonstrated using several NDI methods and a prototype piezoelectric-based SHM system. Model predictions were in good agreement with crack-growth test results for the majority of repair patch configurations. However, the test and analysis correlations revealed that further research is needed to better account for thermal residual stresses and thick patch configurations.

The two panels previously discussed were tested at laboratory temperature ambient conditions. In this current phase of the program, a third B727 panel is being used to assess the effects of environment on the durability and fatigue performance of B/Ep and aluminum-bonded repairs and to continue investigating tools to evaluate and monitor the repair bond integrity. Major modifications were made to fully integrate an environmental system with the FASTER fixture to apply synchronous mechanical, temperature, and humidity load profiles. With this new enhancement, fuselage panels can now be tested under a variety of operating environments, ranging from hot-wet (165°F and 85% to 95% humidity) to extremely cold (-25°F) conditions.

The primary focus of this study was to determine the effect of environment on the fatigue performance of adhesively bonded repairs to a metallic fuselage, including repairs made intentionally deficient to promote damage growth. This report summarizes the fixture modification for environmental fatigue testing, provides an overview of the test plan, and presents the results up to the 100,000 fatigue cycles for this third panel test. Repair configurations from the first two panel tests were generally retained for comparison purposes to assess the effects of hot-wet (165°F and 85% humidity) environmental conditions (80,000 cycles) and cold-dry (-15°F) environmental conditions (20,000 cycles) on repair performance. The effectiveness of an updated SHM system and several NDI methods, including visual inspections, eddy current (EC), flash thermography, and resonance ultrasonic, were studied throughout the test to monitor the growth of the cracks and disbonds.

In general, the overall fatigue performance of the repairs was correlated to the relative condition and quality of the repairs. Fatigue crack growth measured in the B/Ep composite repair patches was slower under hot-wet conditions than under ambient conditions. Mismatches in the thermal coefficient of expansion of the composite B/Ep patch and aluminum fuselage result in the development of residual stresses ahead of the notch during the initial patch-installation curing process. At elevated temperatures, tensile residual stresses are relaxed, contributing to slower crack growth. The cold-dry condition marginally increased the residual strains at the crack tips of the B/Ep patches. Results for the aluminum repair indicated limited effect of environment on the

fatigue crack growth because both the repair and the fuselage skin are made of aluminum. During fatigue testing multi-site-damage (MSD) developed along the lap joint of the B727 fuselage panel. At approximately 97,000 cycles, MSD crack linkup occurred, resulting in a 20-inch-long crack. Because of stress redistribution, data analysis was terminated at that point. This effort provides the data to calibrate and verify methodologies to assess the integrity of bonded repairs.

2. EXPERIMENTAL PROCEDURE

This section provides information on the experimental procedure used for the full-scale test. First, the test fixture and fixture modifications are discussed. Next, a description of the test panel, including aircraft history, panel dimensions, materials, and panel preparation for the test are provided. Then, the test phases and the applied loads is provided. Finally, an overview of the inspection and monitoring methods employed is provided.

2.1 FASTER FIXTURE DESCRIPTION AND MODIFICATIONS

The FASTER fixture was used in this study, which is capable of testing full-scale aircraft fuselage panels under the simulated flight service loading conditions, as shown in figure 1. The FASTER fixture is located at the FAA William J. Hughes Technical Center (WJHTC). To gain a better understanding of the durability and damage-tolerance aspects of bonded-repair technology under environmental loading conditions, enhancements and modifications made to the FASTER fixture are discussed in this section.

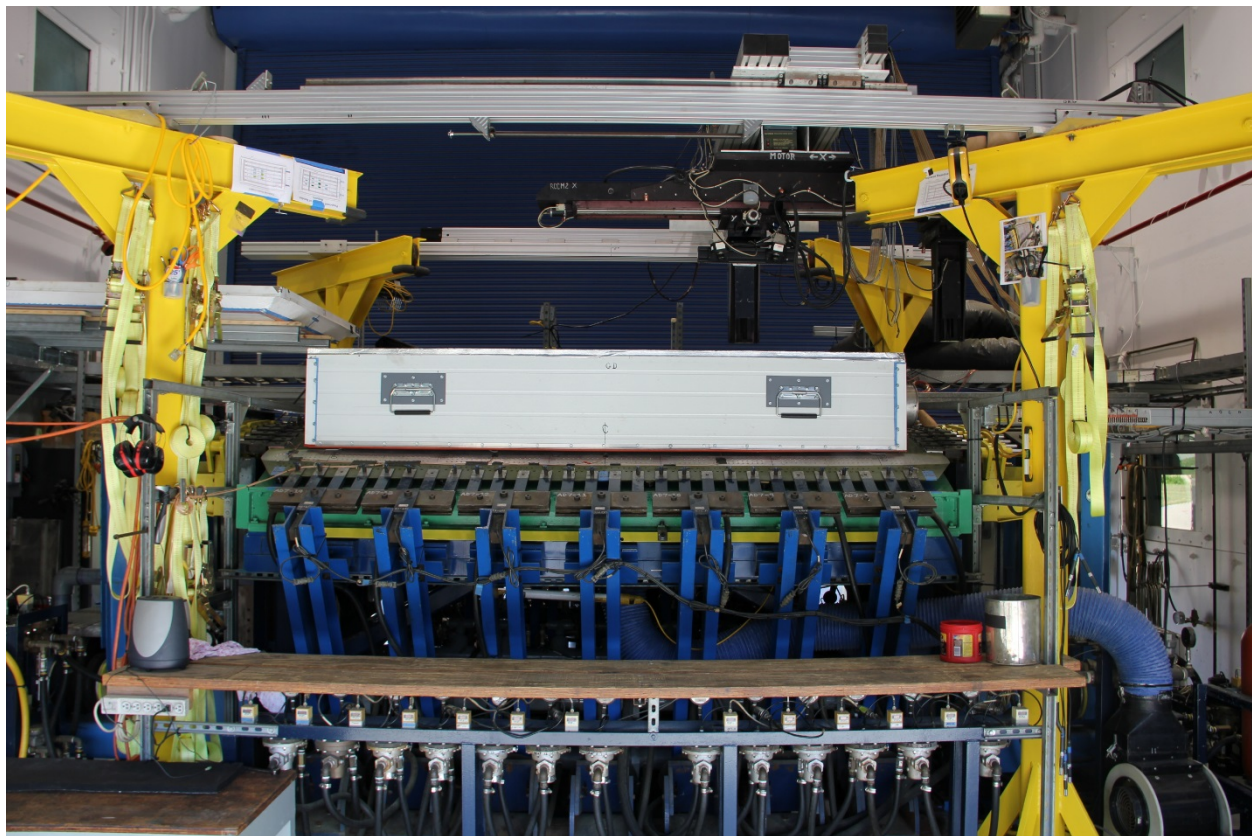


Figure 1. FASTER fixture configuration for environmental loading

The FASTER fixture was originally designed for accelerated fatigue studies of metallic fuselage structures. The fixture can apply combined internal pressure and axial load with appropriate hoop reactions to narrow-and-wide-body fuselage panels. Internal pressurization can be applied using water or air as the pressurization medium. The FASTER fixture uses two sets of four axial loaders at each end of the panel, two sets of seven hoop loaders along each straight edge of the panel, and two sets of six frame loaders connected directly to the frame ends. For the purpose of conducting the environmental test, a detailed description of the modification is provided below.

To apply synchronous mechanical and environmental loadings to the test panel, two components—an environmental chamber and a remote conditioner—were integrated with the existing mechanical loading fixture. Figure 2 shows the final configurations of the fixture modifications.

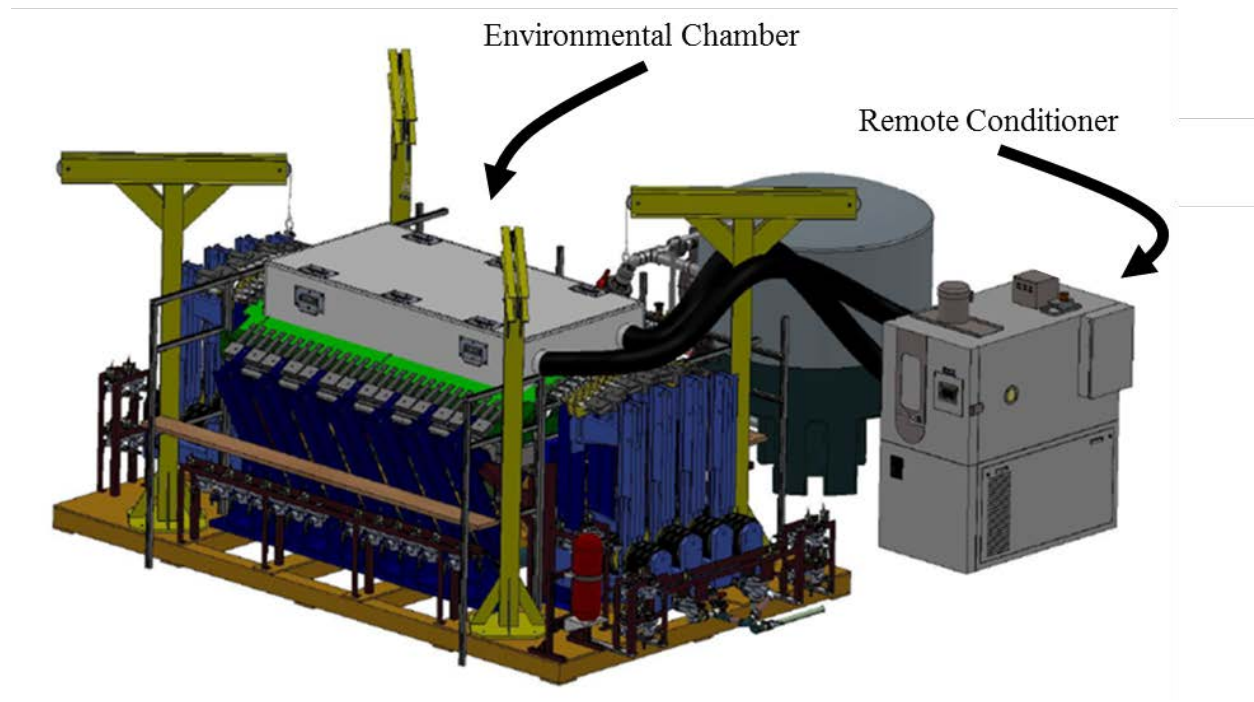


Figure 2. FASTER fixture integrated with environmental chamber and remote conditioner for synchronous mechanical, temperature, and humidity-loading profiles to fuselage panels

2.1.1 Environmental Chamber

An environmental chamber was designed to contain the temperature and humidity conditions outlined in table 1 to a 4-by-9-by-1-foot volume covering the outer surface of the fuselage panel, as shown in figure 3. The chamber was built using prefabricated insulated panels constructed with 4-inch-thick expanded polystyrene foam core insulation material having a thermal resistance rating of 4.17 per inch thickness, sandwiched between 26-gauge galvanized steel sheets. An airtight interface between the chamber and fuselage panel was accomplished using a double layer of rubber bulb seals and 1-inch-thick weather-resistant neoprene foam. The chamber was secured to the fuselage panel with mechanical straps.

Table 1. Temperature—humidity requirements

Condition	Temperature, °F	Relative Humidity, %
Operational Conditions:		
Hot-Dry	96	3–8
Hot-Wet	96	85–95
Cold	-25	Tending toward saturation
Test Capability:		
Hot-Dry	165	3–8
Hot-Wet	165	85–95
Cold	-50	Tending toward saturation

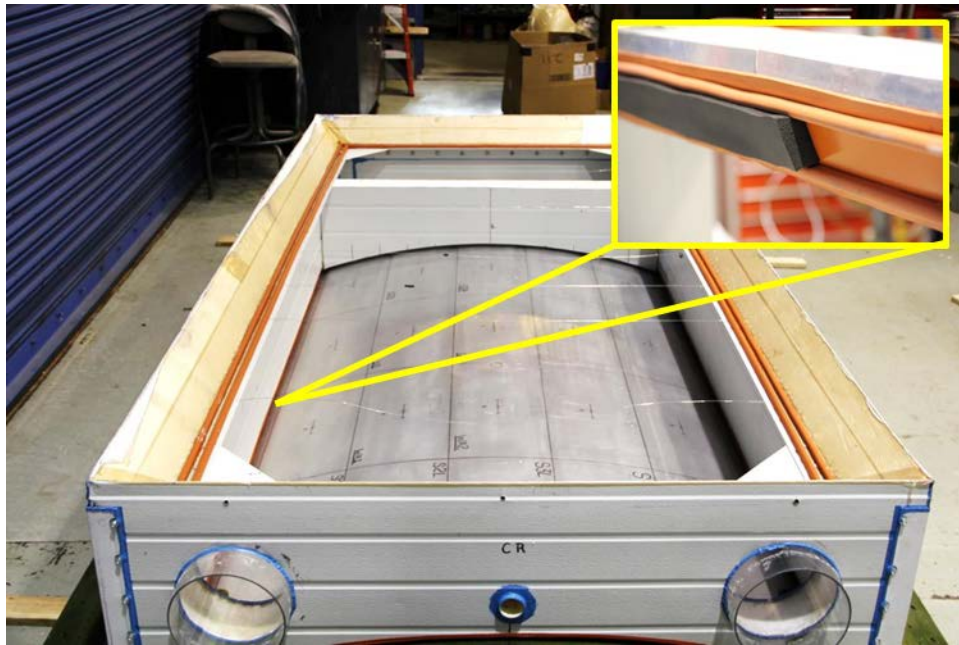


Figure 3. Environmental chamber with air-tight seal; insert shows the bottom seal consisting of rubber bulb seal and weather-resistant neoprene foam

2.1.2 Remote Conditioner

A remote conditioner was used to generate the temperature and humidity conditions in the environmental chamber to the specifications in table 1. For this, a commercially available unit was used, namely a Cincinnati Sub-Zero Z-plus remote conditioner (P/N Model ZPRCHS-816-6-6-SC/AC), which can be operated both locally and remotely. Locally, the unit has a built-in 30-inch³ volume chamber used to condition coupons and small components. Remotely, the unit is interfaced with the environmental chamber using a pair of 8-inch inside diameter insulated ducts, one inlet and one outlet, for a closed-loop environmental conditioned system. A control interface was added to the existing FASTER graphic user interface to allow for full operation of the remote conditioner,

including system startup, defining temperature and humidity profiles, adjusting set point values, and setting tolerances while running a fatigue test.

An acceptance test was conducted to verify the functionality of the integrated system. An array of sensors was used throughout the environmental chamber to measure the temperature and humidity distribution. The fully integrated system was run to verify that all conditions in table 1 were met (i.e., at steady state) and that both temperature and humidity were evenly distributed throughout the environmental chamber within $\pm 3^{\circ}\text{F}$ and $\pm 5\%$ RH, respectively.

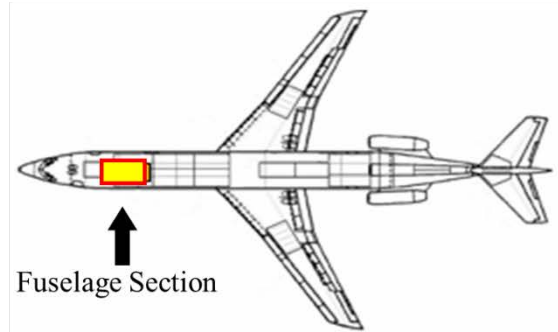
2.2 TEST PANEL DESCRIPTION

The fuselage panel used in this study was removed from a retired passenger service Boeing 727-225 aircraft with tail number N675MG and serial number 22553, as shown in figure 4. During service, the aircraft accumulated 48,579 flight hours and 29,821 flight cycles. A large section of the fuselage was removed from the crown of the aircraft from frame stations STA560 to STA660 and stringer stations S-3R to S-6L, intact with skin, frames, shear clips, stringers, a longitudinal skin splice joint, and a cutout and doubler pad up for an upper rotating beacon.

(a) Retired Boeing 727 airplane at salvage yard



(b) Location of fuselage section on airplane



(c) Fuselage section following removal from Boeing 727

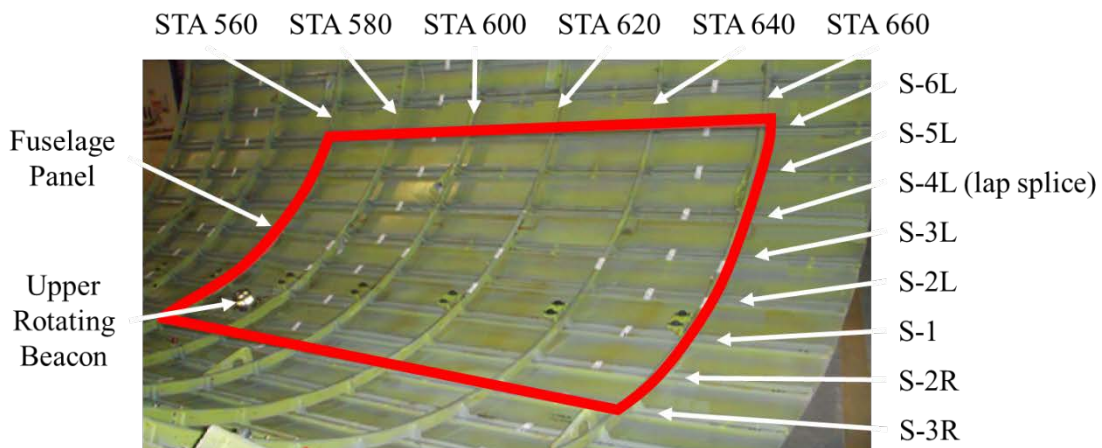


Figure 4. Highlights of B727 airplane and panel: (a) retired airplane in salvage yard, (b) location of panel section on airplane, and (c) internal view of removed panel section

After the panel was removed, detailed inspections were made to determine the condition of the panel test section and to repair the damaged structure. The panel was then cut to size to fit into the FASTER fixture. Reinforcing doublers were installed along the outer perimeter of the skin and to the frame ends for load attachment points of the fixture. Holes of 0.5-inch diameter were drilled along the reinforced doubler edge of the panel at a specific spacing for load introductions in the axial and hoop directions.

The final panel dimensions were 125 inches by 73 inches with a radius of 74 inches, as shown in figure 5. The skin thickness was 0.04 inch throughout the test section. The substructure included six stringers in the axial direction with 9.5-inch spacing and six frames in the hoop direction with 20-inch spacing. A longitudinal lap-joint was located along stringer S-4L. Appendix A of this document provides the fuselage panel engineering drawings.

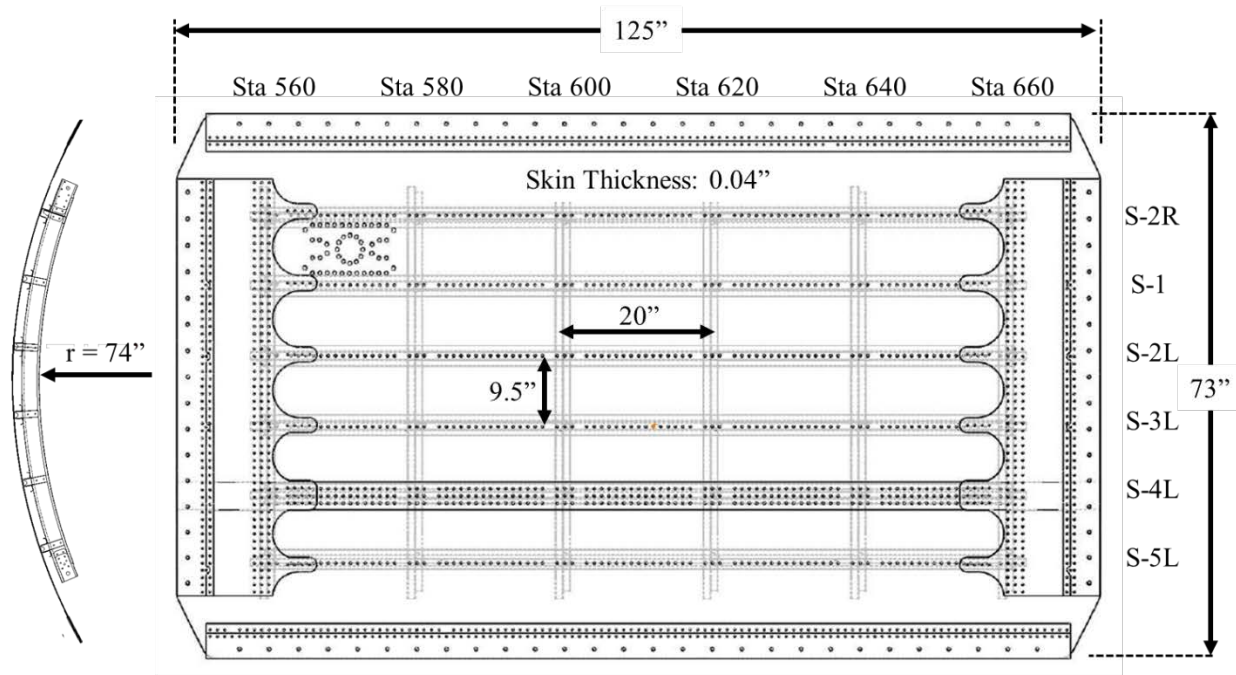


Figure 5. Panel configuration

2.3 PANEL LOAD HISTORY

The complete load history of the panel is shown in figure 6. During service, the aircraft accumulated 29,821 flight cycles. In this test program, two test phases were conducted for the extended fatigue test. In phase 1, the panel was tested at 100% simulated SL under the hot-wet (HW) environmental conditions for 80,000 cycles. In phase 2, the panel was tested at 100% SL under cold-dry (CD) environmental conditions for an additional 20,000 cycles. Accounting for the aircraft operational history the total number of SL cycles accumulated in the test panel was 129,831 cycles. During the fatigue cycling, MSD formed, resulting in a 20-inch-long crack after 97,000 cycles. Because of stress redistribution, data analysis and results are presented up to 90,000 cycles in this report. The details of the MSD are provided in section 4.

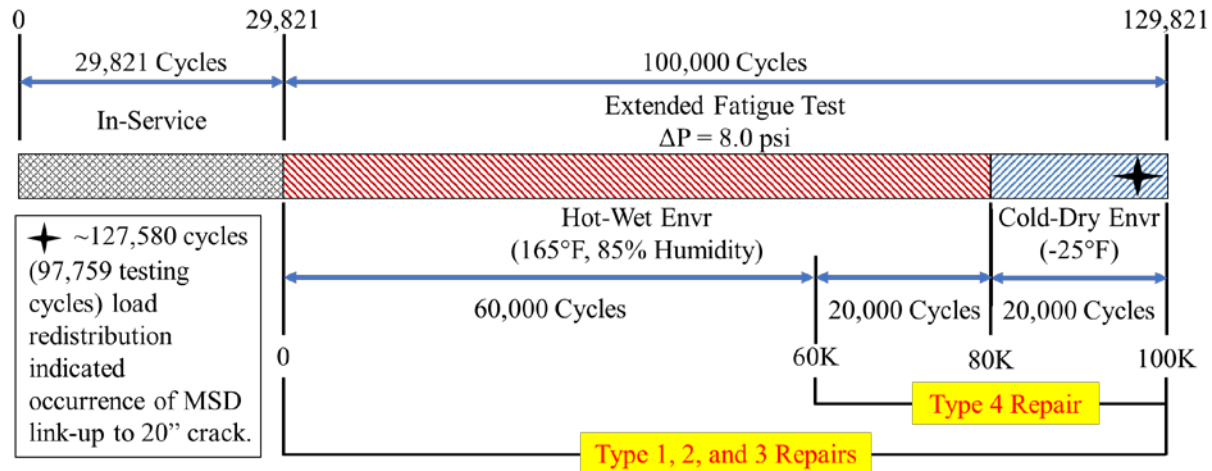


Figure 6. Entire loading history of panel 3

2.4 APPLIED LOADS

A summary of applied loads is shown in table 2. The loads used for the fatigue test simulated the SL conditions, including cabin pressurization (8.9 psi) and fuselage vertical bending, and were represented by an equivalent constant-amplitude spectrum. The magnitude of the applied loads used in the strain survey and fatigue pre-cracking to insert the initial damage was 75% of the SL conditions used for the fatigue test. For the baseline strain survey tests, quasi-static loadings were applied in 10 increments up to the maximum loads. For the pre-cracking and fatigue test, constant-amplitude loading was applied at a frequency of 0.033 Hz (resulting in two pressurization cycles per minute) with an *R* ratio (minimum to maximum load) of 0.1.

Table 2. Applied loads

Description	Maximum Mechanical Load					Constant Environmental Load
	Load Phase	Pressure (lb.)	Hoop (lb.)	Axial (lb.)	Frame (lb.)	
Strain Survey, 75% of SL	Quasi-static	6.7	7140	6675	1133	Ambient Hot-wet Cold-dry
Fatigue pre-cracking, 75% of SL	Cyclic, <i>R</i> = 0.1	6.7	7140	6675	1133	Ambient
Fatigue, 100% of SL	Cyclic, <i>R</i> = 0.1	8.9	9520	8900	1510	Hot-wet (80,000 cycles) Cold-dry (20,000 cycles)

2.5 INITIAL DAMAGE SCENARIO

The initial damage scenario for each repair consisted of 3-inch mid-bay through thickness cracks, as shown in figure 7. Damage was introduced in the form of a crack starter notch using a grind wheel and jeweler's saw, having a length of 2.8 inches and notch-tip width of 0.008 inch. Fatigue pre-cracking was conducted at an applied load of 75% of the SL conditions to generate natural cracks with sharp crack tips. As shown in figure 7, symmetric and colinear crack extension was obtained from the notch tips. The pre-cracking was continued until the natural cracks generated extended from the notches for a total length of 3 inches. Details of the damage scenarios and repair patches are provided in appendix B.

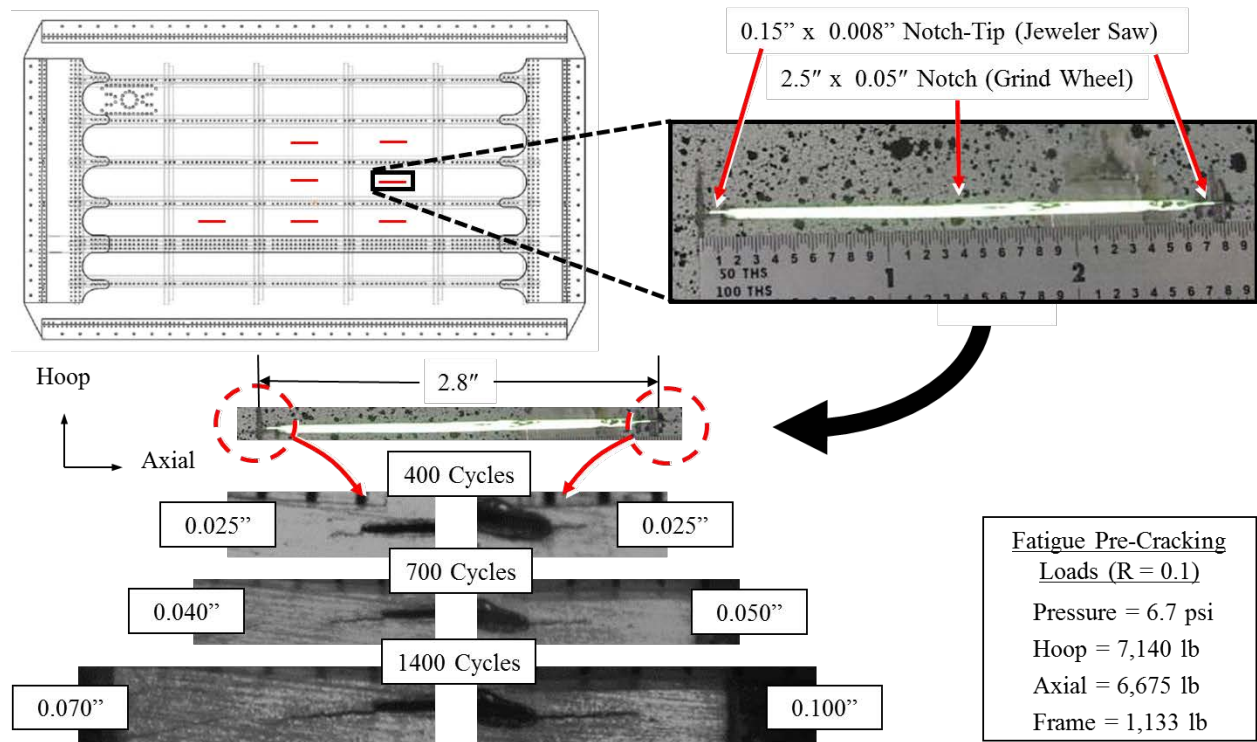


Figure 7. Photographs of crack growth from mid-bay notch during fatigue pre-cracking

2.6 TEST MATRIX AND REPAIR TYPES

Five repair types were considered in this program, as shown in table 3 and figure 8. Repairs were installed after the mid-bay crack length was approximately 3 inches, as shown in figure 7. A brief description of each repair type is included in this section and the details are provided in appendix B.

Table 3. Test matrix and repair types

Repair Type	Description	Designation
Type 1: Reference repairs	Introduced at the beginning of the test. Fatigue at SL under hot-wet conditions for 80,000 cycles and then under cold-dry conditions for additional 20,000 cycles.	RA, RB
Type 2: Under-designed repairs	Introduced at the beginning of the test. Fatigue at SL under HW conditions for 80,000 cycles and then under CD conditions for additional 20,000 cycles.	UA, UB
Type 3: Under-designed & partial disbond repairs	Introduced at the beginning of the test. Fatigue at SL under hot-wet conditions for 80,000 cycles and then under CD conditions for addition 20,000 cycles.	UDA, UDB
Type 4: Hand sanded	Introduced at 60,000 cycles. Fatigue at SL under HW conditions for 20,000 cycles and then under CD conditions for 20,000 cycles.	HS

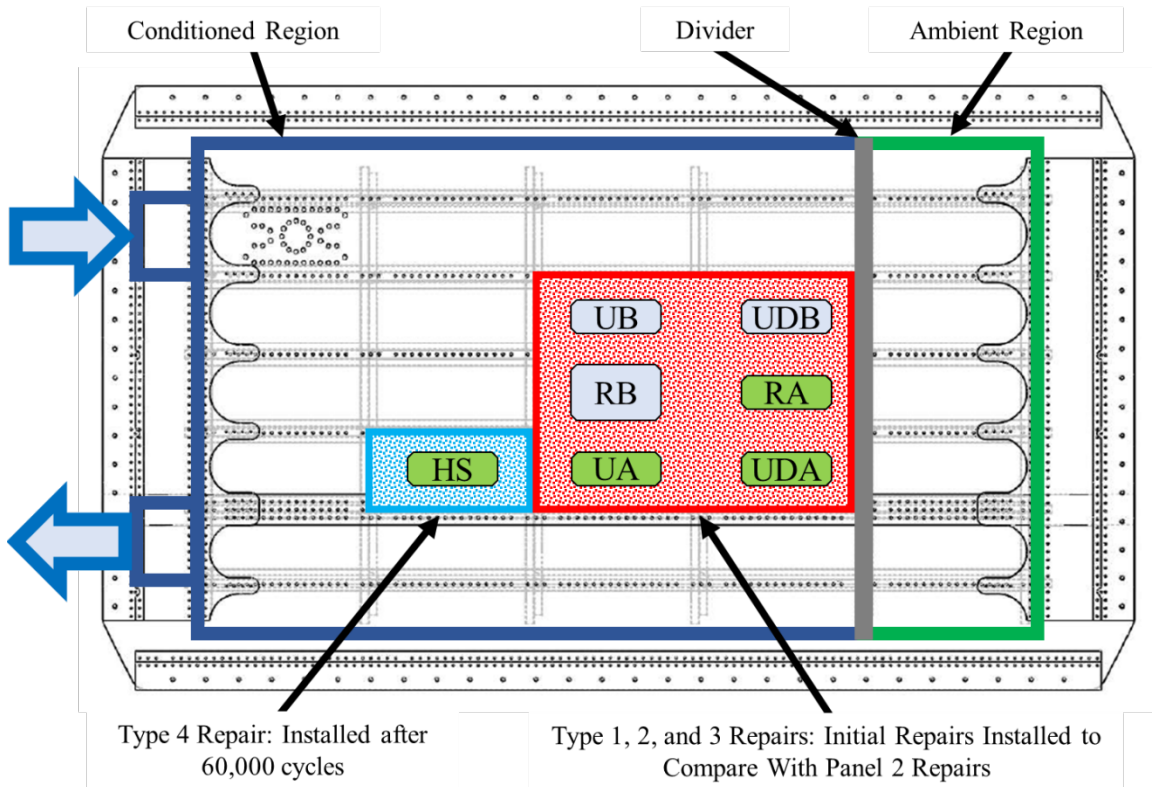


Figure 8. Locations of all four types of repair patches tested in this program

Type 1: Reference Repairs

The reference repair patches included a nine-ply B/Ep patch and a three-layer aluminum patch over a 3-inch mid-bay crack (see figure 9). The reference B/Ep repair was tested in panel 2 and provided a baseline performance for all the other bonded repairs, and were designed to contain damage and withstand one design service goal (60,000 cycles). The reference B/Ep repair patch had an octagon shape footprint approximately 8 inches in the axial direction by 5 inches in the hoop direction and consisted of nine plies ($20^\circ/-20^\circ/20^\circ/-20^\circ/0^\circ/-20^\circ/20^\circ/-20^\circ/20^\circ$) with a taper ratio of 20:1 in which the 0° fiber direction was perpendicular to the crack (see figure 9a). The reference aluminum patch also had an octagon shape footprint approximately 8 inches in the axial direction by 3 inches in the hoop, consisting of three 0.02-inch-thick aluminum doublers with a taper ratio of 20:1 (see figure 9b).

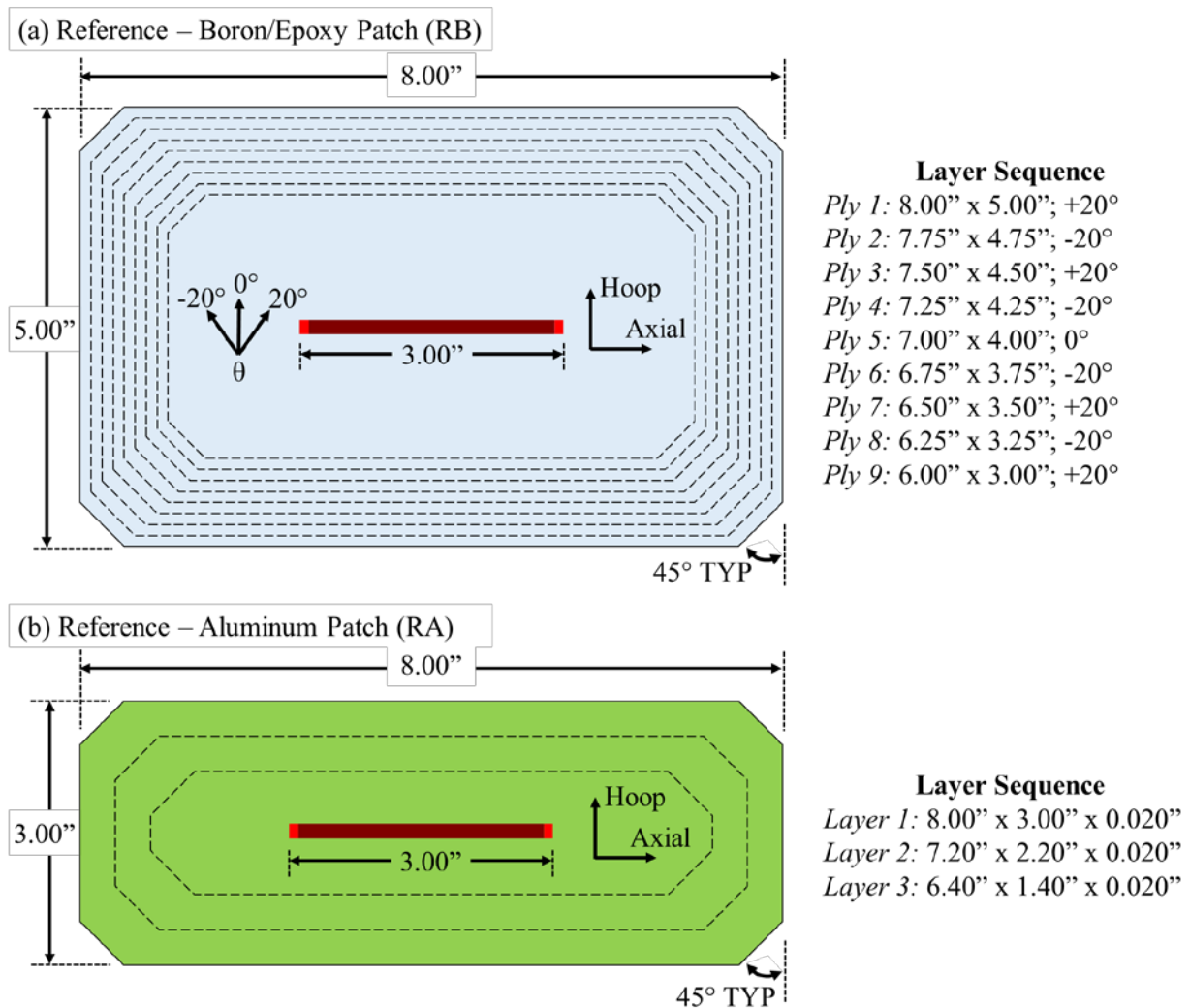


Figure 9. Reference repair configuration: (a) B/Ep patch, RB; (b) aluminum patch, RA

Type 2: Under-Designed Repairs

Type-2 repair patches included a B/Ep patch and a two-layer aluminum patch over a 3-inch mid-bay crack (see figure 10). These repairs were intentionally under-designed by reducing the number of reinforcing B/Ep plies and aluminum doublers and reducing the patch footprint in the hoop direction of the B/Ep repair only. The under-designed B/Ep repair had an octagon shape footprint approximately 8 inches in the axial direction by 3 inches in the hoop direction and consisted of five plies ($20^\circ/-20^\circ/0^\circ/-20^\circ/20^\circ$) with a taper ratio of 20:1. The approximate thickness of each B/Ep ply was 0.0057 inch in which the 0° fiber direction was perpendicular to the crack (see figure 10a). The under-designed aluminum patch had the same footprint (8-by-3 inch) consisting of two 0.02-inch-thick aluminum doublers with a taper ratio of 20:1 (see figure 10b).

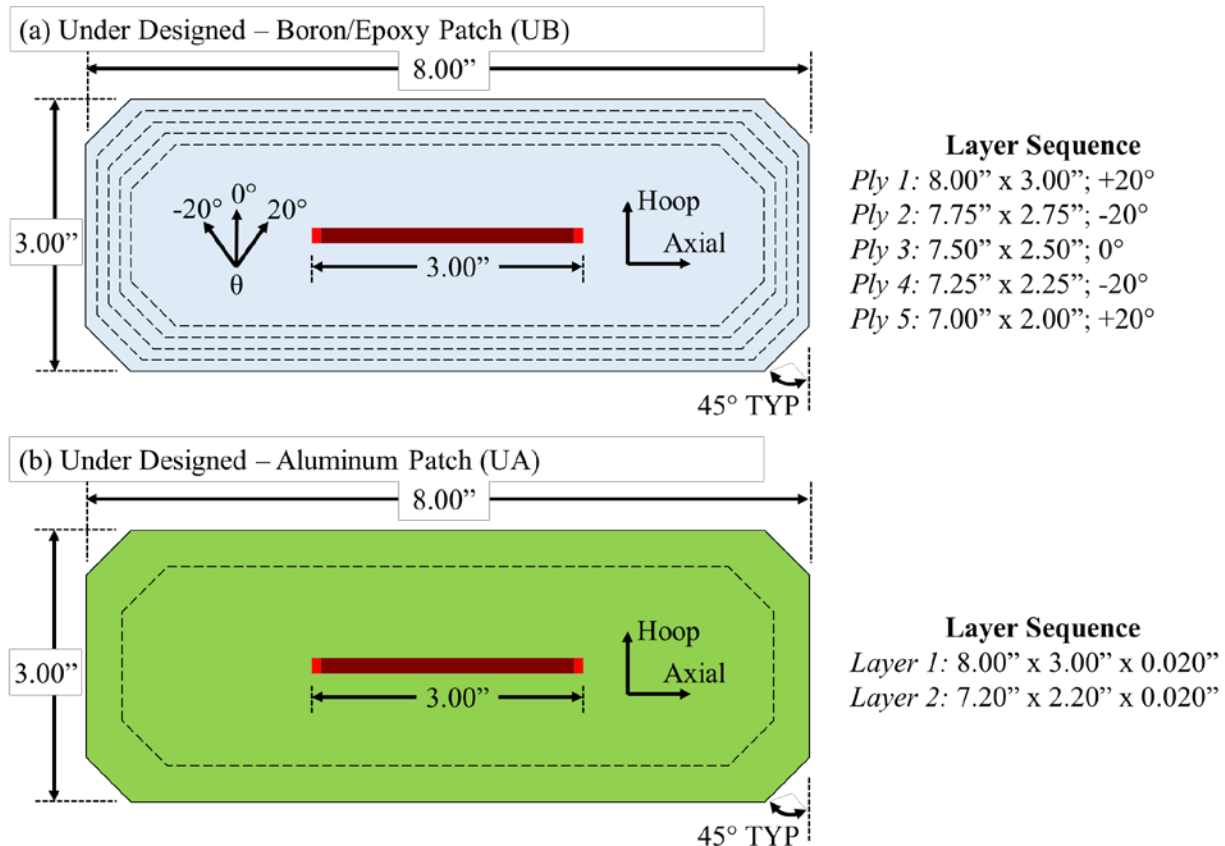


Figure 10. Type-2 repair configuration: (a) B/Ep composite repair, UB; (b) aluminum patch repair, UA

Type 3: Partial Disbond Repairs

Type-3 repair patches included a B/Ep patch and a two-layer aluminum patch over a 3-inch mid-bay crack (see figure 11). The repairs included engineered disbonds, which were introduced using fluorinated ethylene propylene (FEP) inserts and aluminum shims (coated with mold release agent). During the curing process, FEP inserts were installed around the crack region between the fuselage skin and adhesive, and the aluminum shims were located at the edge of the patch. After curing, the aluminum shims were removed. The patch dimensions and designs for both the B/Ep

and aluminum patches were identical to the type-2 repair configurations. Figure 11 shows the disbond size, shapes, and locations in the repair patches.

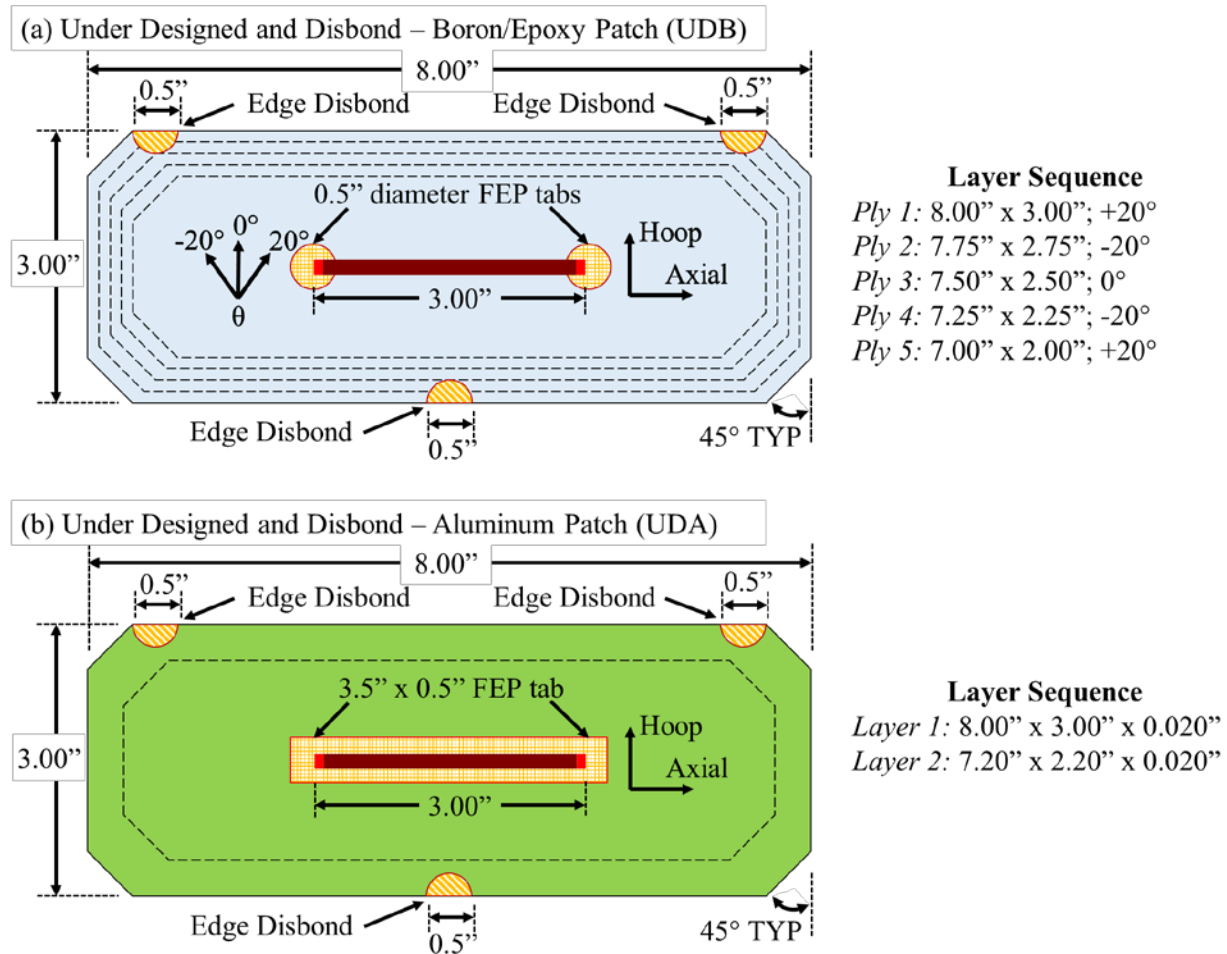


Figure 11. Type-3 repair configuration: (a) B/Ep composite repair, UDB; (b) aluminum patch repair, UDA

Type 4: Hand-Sand Repairs

Similarly, the patch dimensions and design for the type-4 aluminum patch were identical to the type-2 aluminum repair configuration. Normally, the outer skin of the panel was deoxidized using grit blast before repairs were bonded. However, instead of using grit blast to deoxidize the surface of the panel, the skin of the panel was hand sanded (HS). The repair designated HS was bonded normally using film adhesive.

2.7 INSPECTION METHODS

Periodic inspections were made every 10,000 cycles. Several NDI methods were used to monitor and record damage formation, crack propagations, and patch disbonds. Two methods were used for disbond and delamination detection—flash thermography and resonance ultrasonics. For crack detection, visual inspections and EC techniques were used. Visual inspections were made on the

inner and outer surfaces of the skin using high-magnification cameras, which could be remotely controlled during the test. Low-frequency eddy current (LFEC) was used on the outer surface to inspect for cracks in the skin underneath the B/Ep composite repair patches. High-frequency eddy current (HFEC) was used on the inner surface of the skin. Thermography, resonance-ultrasonic, and EC were conducted in a laboratory environment under no load conditions. Digital image correlation (DIC) data were collected in a laboratory environment under strain survey loads, and strain gauges data were collected under three environmental conditions (i.e., ambient, hot-wet, and cold-dry). A brief description of each inspection method is provided in table 4. Details of these inspection techniques can be found in the DOT/FAA/AR-11/4 [4].

Table 4. Inspection methods

Method	Inspection	Interval	Conditions
High-magnification visual from interior surface	Crack growth monitored at inner surface under all patches	Continuous	No load/ambient
HFEC from internal surface	Crack growth monitored at inner surface under all patches	10,000 cycles	No load/ambient
LFEC from external surface of patch	Crack growth monitored from outer surface of B/Ep patches	10,000 cycles	No load/ambient
Flash thermography from exterior surface of patch	Disbonding of all patches	10,000 cycles	No load/ambient
Resonance ultrasonic from exterior surface of patch	Disbonding of all patches	10,000 cycles	No load/ambient
DIC from external surface of the panel	Full-field strain variation and displacement	10,000 cycles	Strain survey load/ambient

Flash Thermography

The flash thermography system was used for disbond detections. The system sends a pulse of light to heat the structure and measures the surface temperature as the sample cools. Defects such as disbands trap the heat flow, resulting in a temperature gradient on the surface, which outlines the disbond region.

Resonance Ultrasonic

The resonance ultrasonic technique using the Olympus BondMaster[®] was used to detect disbands. The methodology relies on deviation of the resonance frequency response curve measured on a specimen with a crack/defect and on an identical non-cracked specimen. The detection criteria include: 1) shift of the peak position, 2) increase of the bandwidth, and 3) reduction of the amplitude.

EC

EC was used to detect cracks. EC is an electromagnetic testing method to detect and characterize surface and sub-surface flaws in conductive materials. ECs flow in closed loops within conductors, and they can be induced within nearby stationary conductors by a time-varying magnetic field created by an AC electromagnet. When the probe approaches to a defect, the EC changes in phase and amplitude.

2.8 STRAIN MEASUREMENTS

With these inspection methods, the strain gauges and DIC method were used to monitor strains throughout the tests.

2.8.1 Strain Gauge Monitoring

The panel was instrumented with approximately 200 strain gauges to monitor strains throughout the test. Strains were monitored at various locations, including the inner and outer surface of the skin, frames, and stringers (see figure 12). For each repair patch, strain gauges were placed along the boundaries on the inner and outer skin surfaces, at the patch outer surface, and along the notch-tip. Typically, each repair patch included eight strain gauges (see figure 13). For the selected patches, the local notch-tip strain field was measured using the strain gauge chain to capture a higher resolution of the strain distribution at 80,000 cycles (see figure 14).

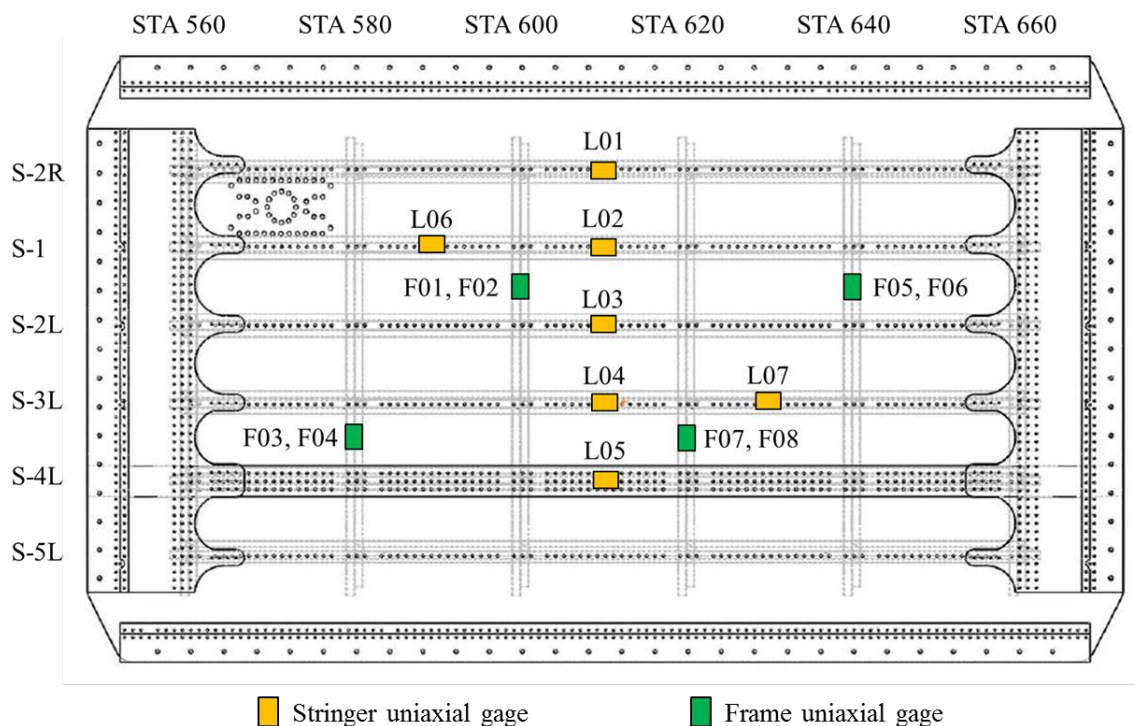


Figure 12. Strain gauge locations for substructures

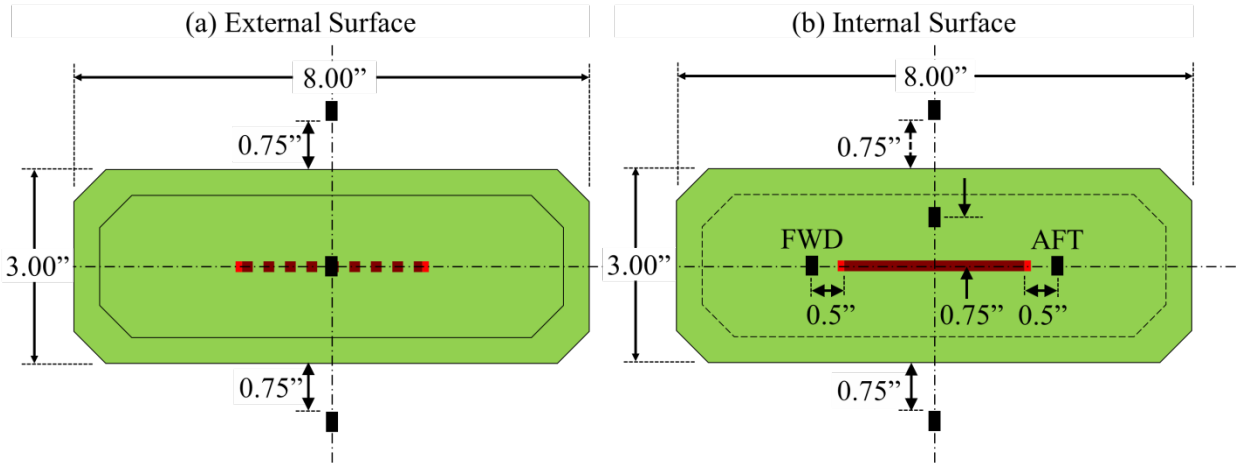


Figure 13. The typical strain gauge layout on the panel: (a) external surface, and (b) internal surface

In this supplementary study, the objective of using a strain gauge chain was to examine whether a single gauge is sufficient to accurately determine the stress intensity factor (SIF) for a curved panel with bonded repairs. The strain gauge chain was installed right in front of the crack tip (see figure 14). Details of the strain gauge layout and strain gauge chains are provided in appendix C.

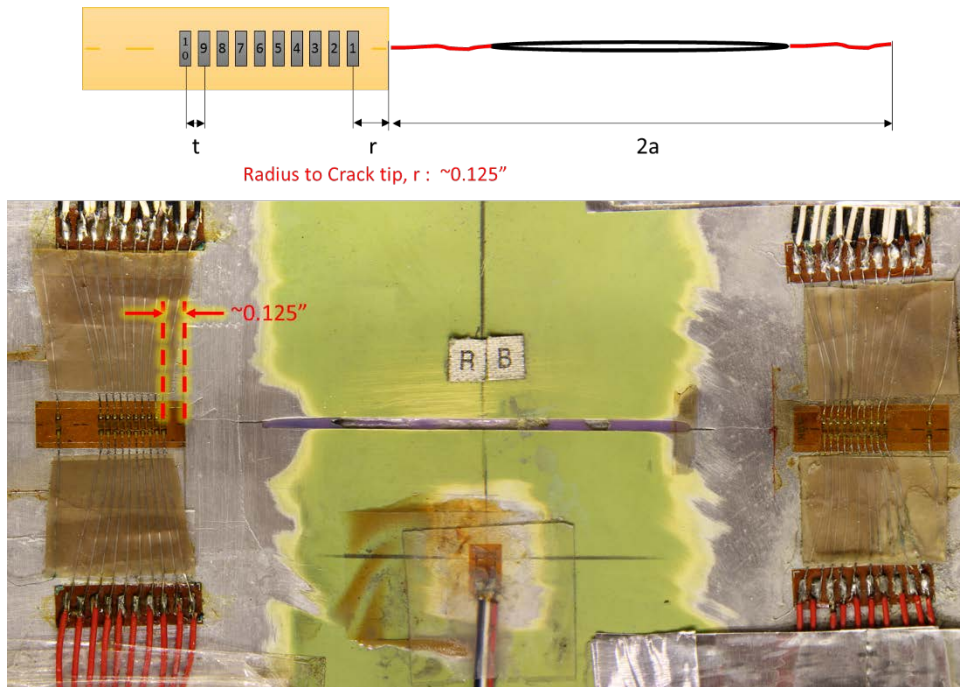


Figure 14. Typical setup of the strain gauge chain

2.8.2 DIC Monitoring

DIC was used to measure displacement and strain fields. The DIC is an optical method that tracks changes in images. The system consists of two digital cameras triangulating on top of the

specimen. The specimen is painted with a speckle pattern. By measuring the relative displacements of the speckle pattern, the DIC method resolved full field measurements of the strain and displacement.

It should be noted that the DIC data can be collected only in a laboratory environment under strain survey loads. It was limited by the size of the environmental chamber. The details of the inspection methods and strain monitoring methods are provided in references [7].

2.9 DESCRIPTION OF SHM SYSTEM

2.9.1 Approach

The SHM system in this study consisted of a network of surface-mounted piezoelectric actuators and sensors at two repair locations and the associated hardware for collecting data. The two patches monitored included the underdesigned boron patch and the underdesigned boron patch with disbonds.

The SHM actuators were excited by a short hanning windowed voltage signal, which in turn propagated ultrasonic waves throughout the structure via the electromechanical coupling intrinsic in piezoelectric transducers (PZT) material. The surrounding sensors responded mechanically and outputted a voltage signal that is collected by a data acquisition unit. A variety of signal characteristics that correspond to each wave path were used to train a linear regression model to understand crack length. The trained model was then used to predict crack length and compared to truth data provided by NDI and visual inspection to validate the SHM system.

The baseline plan for this test was to determine the survivability of the SHM sensors by assessing the ability to provide acceptable signal quality under the environmental conditions for the first 20,000 cycles. The goal was to develop and implement an SHM system that can withstand the environmental conditions outlined in this test plan, and then identify damage locations and sizing for the subsequent cycles of the test.

The network of piezoelectric ultrasonic transducers was used to assess the integrity of each bonded repair via wave propagation signals that correlate to crack and disbond growth. The locations of the transducers relative to the bonded repair were the same locations as for the previously tested panel 2 and are described in figures 15–16. Two types of transducers were used for this test:

1. Acellent SMART Layer (SML-SP-1/4-0) PZT Transducers on the inner surface of the panel
 - 0.25-inch diameter by 0.010-inch-thick PZT
 - Size = 0.45-by-1.5-by-0.030 inch
 - Flexible circuit: copper transmission lines sandwiched in polyimide layers
 - Removable wiring via standard Molex connector
2. Boeing Prototype SHM Environmental PZT Transducers on the outer surface of the panel, inside the environmental chamber
 - 0.25-inch diameter by 0.010-inch-thick PZT

- Size = 0.50-by-1-by-0.030 inch
- Flexible circuit: copper transmission lines etched in polyimide layer
- Potted for hermetic seal on all edges and wiring terminations with BMS 5-37, electrical potting compound

Transducers were bonded to both surfaces of the panel. Data cabling for the Acellent transducers was removable, but were installed with the intent to keep them connected at the transducer throughout the test. Data cabling for the Boeing transducers was permanent. Transducer locations and cables were routed as to not interfere with strain gauges or NDI inspection areas. Transducers were connected to a data acquisition unit and data were recorded during the periodic inspections of the test article.

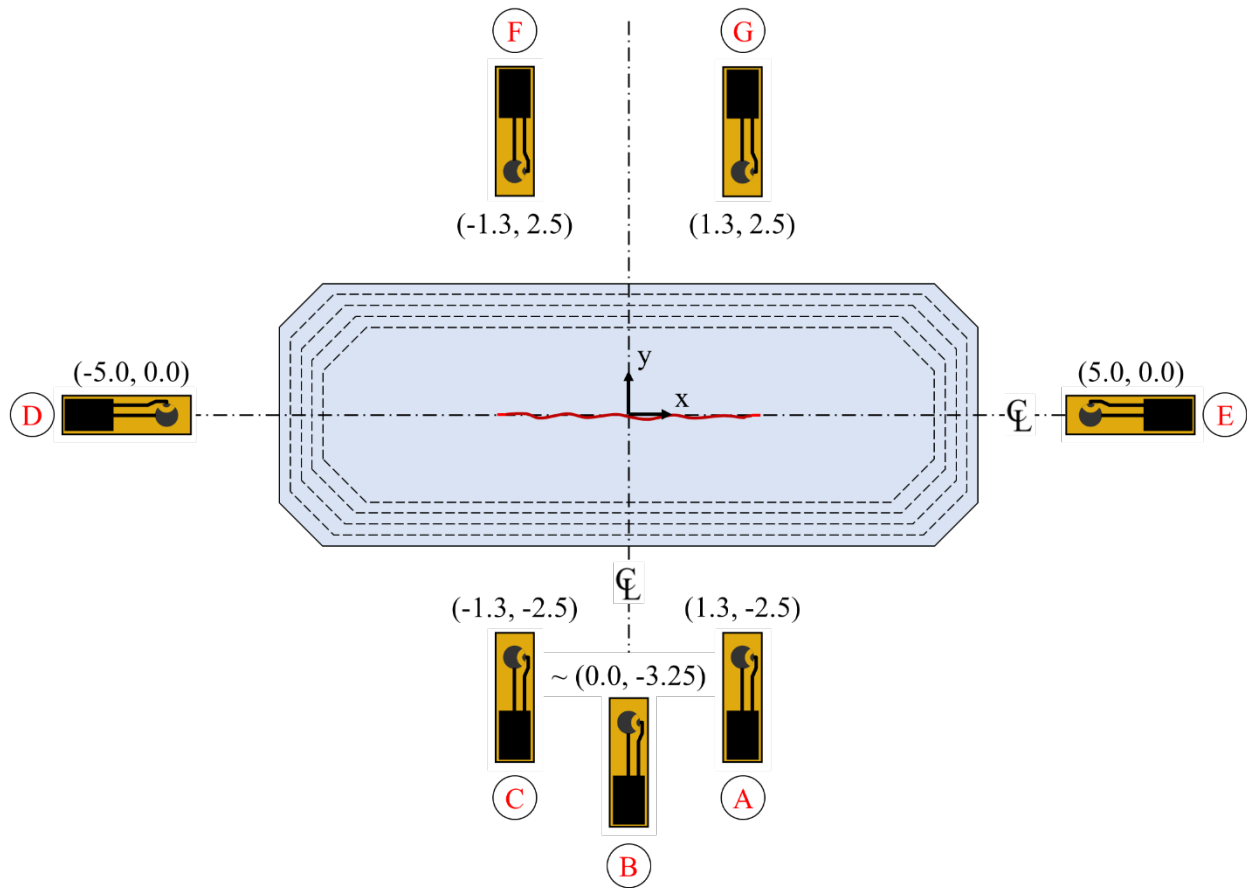


Figure 15. Piezoelectric transducer locations for the IML side at both UB and UDB patches

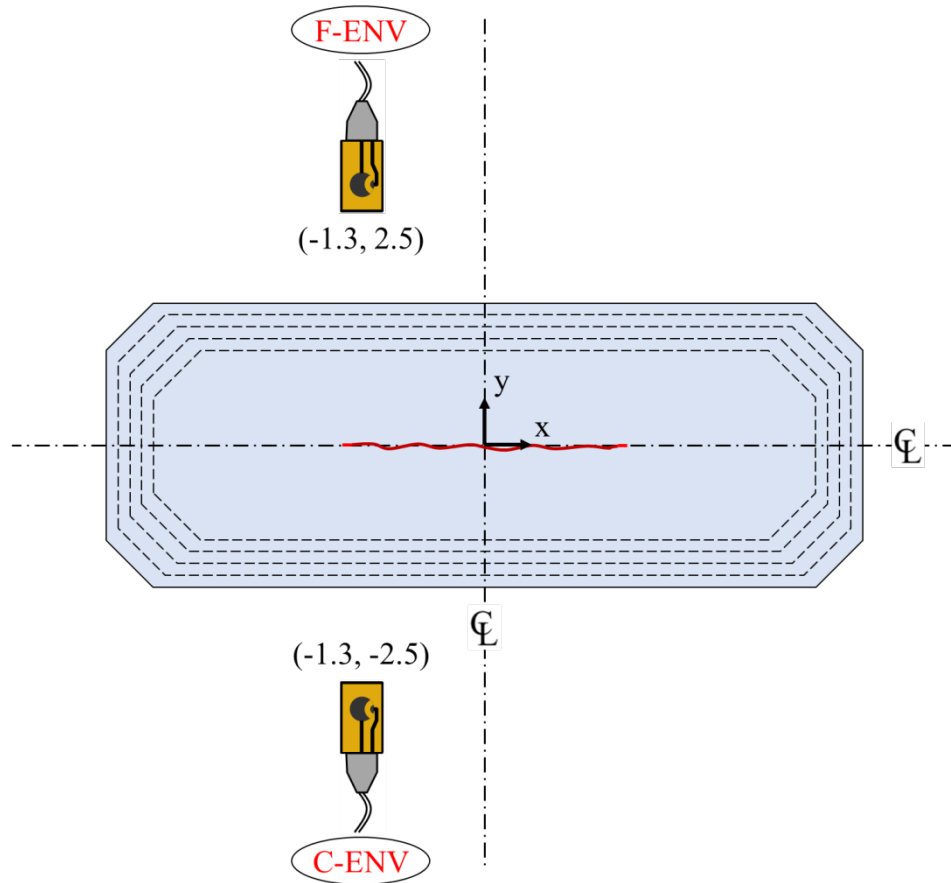


Figure 16. Piezoelectric transducer locations for the OML side exposed to the environmental test conditions at both UB and UDB patches

2.9.2 SHM System Requirements

2.9.2.1 Stay-out Zones

Regions of the test article must remain clear for NDI and ARAMIS strain mapping. An integrated instrumentation map was created to ensure all measurement techniques do not interfere. Additionally, piezoelectric transducers can experience significant performance degradation when exposed to strains over 1500 microstrain. Preliminary strains were used to determine areas unsuitable to bond transducers and ARAMIS strain survey data were checked before SHM instrumentation was bonded to the structure.

2.9.2.2 Data Collection

Boeing traveled to the site to install and set up the SHM systems. When the testing was stopped periodically for inspection, in accordance with the test procedures, SHM data were collected by FAA WJHTC personnel. Boeing trained FAA personnel on how to collect the data and transmit that data back to Boeing using the Boeing-approved encrypted data transfer system. An electronic copy of all recorded signal data, including transducer excitations and responses, was provided to all SHM team members. File format was CSV or MATLAB binary. Fixed length headers were

affixed to the files. Sample rate information was provided in the header or by other documentation. Each excitation and response was identified with a run number that corresponds with cycle number and the optically measured crack length. SHM data collection was performed using a Metis Design Intelli-Connector MD7 system. The data-collection equipment consists of a standalone hub with a power supply and a high-speed digital sensor node with a breakout board. Figure 17 shows a notional wiring diagram of this system.

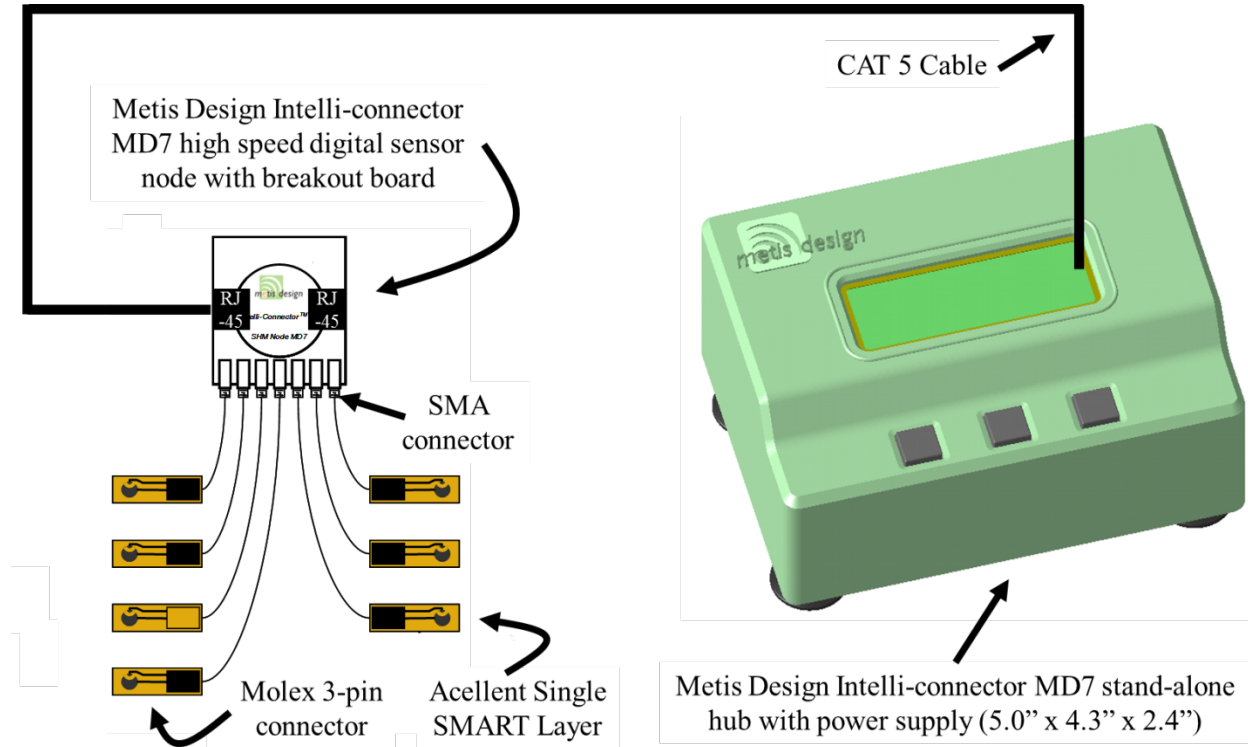


Figure 17. SHM data-collection system wiring diagram

2.9.2.3 Transducer Installation

Installing SHM transducers is similar to bonding a strain gauge in terms of surface preparation and time required. Note that SHM sensors were bonded to the structure after the successful application of the bonded repair. Boeing provided detailed transducer installation instructions.

2.9.2.4 Data to be Collected

The SHM system collected data as required to meet damage evaluation requirements. Boeing provided detailed data-acquisition instructions. To ensure that usable data were collected, the following safeguarding steps were followed:

1. The sensor system designs minimized noise and cross talk. Design features that performed this function were shielding for wiring on the sensor layer and separate ultrasonic actuation and sensing circuits.
2. After sensor installation, preliminary assessments were made to validate proper operation of the systems. Baseline data were collected after specimen installation in the test fixture but before fatigue cycling began. The data were analyzed to ensure proper bonding and to verify that the system was operating as expected.
3. Multiple datasets were collected for each data-collection cycle.

2.9.2.5 Time to Collect Data

SHM data collection required approximately 30 minutes.

2.9.2.6 Damage Detection and Evaluation Goals

The damage-evaluation systems determined the presence, location, extent, and type of damage in the specimen, as defined in table 5.

Table 5. Damage-detection goals

Category	Goal/Requirement
Presence	The damage-evaluation system must detect crack growth that is at least 0.2 inch from the initial cut or a disbond size of 1 inch ² .
Type	The damage-evaluation system must distinguish damage as either crack growth or patch disbond. The type of damage must be reported in a descriptive sense, such as “crack growth detected.”
Location	The system must report the location of damage in the specimen. The location of detected damage must be reported by the damage-evaluation system in a quantitative manner using engineering units (mm, cm, in.). Coordinate systems may be defined and used for reporting damage location. Alternatively, graphics may be used to show damage location.
Extent	The system must report the extent of the damage in the specimen. At a minimum, the system should report the length of a crack or the area of a disbond in a quantitative manner using engineering units. Coordinate systems may be defined and used for reporting the extent of damage. Alternatively, graphics may be used to show damage location.

Results reported from the damage evaluation systems were compared to the crack lengths and disbond information recorded by visual inspection and NDI.

3. ANALYTICAL PROCEDURE TO VERIFY TEST SETUP

3.1 INTRODUCTION

The pristine global finite element (FE) model was built and analyzed prior to panel testing to verify the test setup and applied loads. The global FE analysis provided predictions of the stress/strain full-field measurements. Stress and strain distributions obtained from the global FE model of the curved panel were compared with strain gauge data and digital image correlation results.

3.2 MODEL DETAILS

The global FE structural analysis of the Boeing 727 panel 3 was conducted using the commercial code ABAQUS. The model contained the major geometric details and dimensions of the panel, including detailed dimensions of the skin, the substructures (frames, stringers, and shear clips), and the reinforced doublers. The pristine panel was modeled using quadratic shell elements with six degrees of freedom (S8R). Multi-point-constraint tie constraints were used between substructures to replicate the behavior of rivets in the structure. The mesh was defined predominantly with quadrilateral elements with a size of approximately 1 inch on the skin, and 0.5 inch on the substructures.

To save computation time and deliver results more efficiently, certain degrees of simplification were made. It was assumed that the reinforced doublers were perfectly bonded to the panel and disbonding or structural failure was not expected. Following this assumption, five layers of reinforced doublers were merged to be represented by a single shell. By assigning various cross section properties (i.e., section thickness) to the shell, the essential features of the reinforced doublers were still taken into consideration. Moreover, approximately 20,000 elements could be reduced by merging five layers of reinforced doublers into a single shell. Similarly, the lap joint and tear straps could be simplified using the same approach while keeping the essential characteristics of the detailed structure. Finally, the entire model includes 39,129 S8R elements. Figure 18a shows the full assembly of the panel with the frame and stringer substructure and the skin. Figure 18b shows the shell section thickness in color code. The dark blue color shows the thinnest area (0.04 inch) in all mid-bay locations; the red color shows the thickest area (0.292 inch) in the regions of the attached reinforced doublers. The material properties used in the analysis are listed in table 6 for various structural components of a curved panel, stringers, frames, and clips.

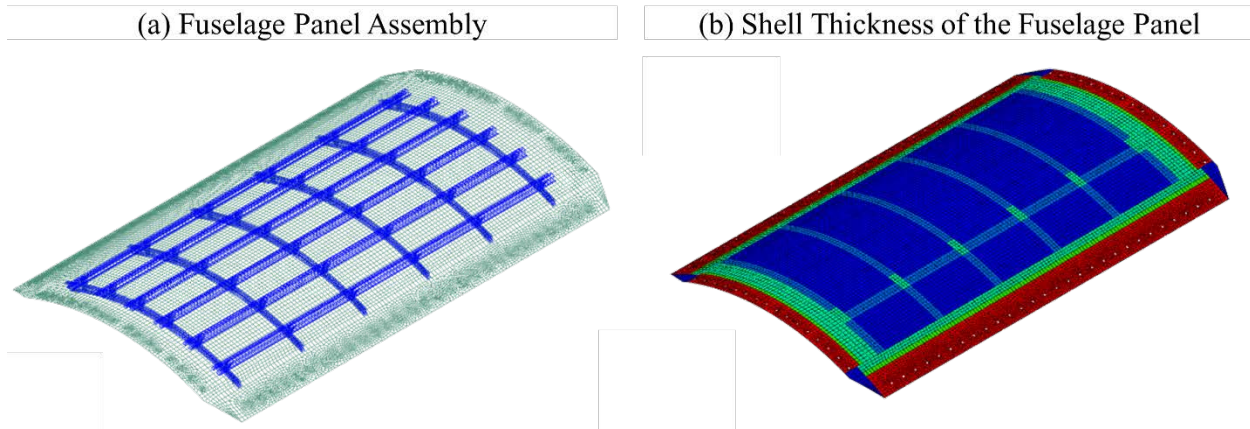


Figure 18. (a) Panel assembly; (b) shell section thickness of the panel

Table 6. Material properties of various structural components of the panel

Skin	
Material Type	2024-T3 Clad sheet, LT
Young's Modulus, E	1.05E+07 psi
Poisson's Ratio	0.3
Tensile Yield	39,000 psi (A-basis)
Tensile Ultimate	59,000 psi (A-basis)
Coefficient of Thermal Expansion, α	1.25E-05 in/°F
Frame and Stringer	
Material Type	7075-T76511 Extrusion
Young's Modulus	1.03E+07 psi
Poisson's Ratio	0.3
Tensile Yield	69,000 psi (A-basis)
Tensile Ultimate	79,000 psi (A-basis)
Coefficient of Thermal Expansion	1.25E-05 in/°F

3.3 LOADING CONDITIONS AND BOUNDARY CONDITIONS

Table 7 shows a load case representing 75% of the simulated service load. The mechanical loading conditions include internal cabin pressurization, longitudinal load, hoop load, and frame load. Figure 19 shows the final loading conditions, including the 14 simulated hoop loaders, eight simulated axial loaders, 12 simulated frame loaders, and the internal pressurization of the panel. Each loader consists of a whiffletree with four load-attached points. Because the whiffletree distributes load uniformly between all load-attached points, concentrated force will be applied directly to the panel, and the force value is equivalent to $\frac{1}{4}$ of each load transducer reading at the FASTER facility. Therefore, there is a total of 28 load-attached points along the hoop reinforced doublers and 16 load-attached points along the hoop reinforced doublers. This technique allows the model to simulate realistic applied loading conditions without modeling the whiffletree

structure of the loaders. The same methodology was used to apply the longitudinal and frame loads. Note that the radial links of the frame loaders were modeled to provide extra flexibility when the panel deformed. A single beam element was used to model each radial link, with the bottom of the links pinned to constrain the radial and the hoop displacements. Finally, the midpoint of each edge was constrained to prevent rigid body motion.

Table 7. Strain survey loading conditions

Description	Maximum Mechanical Load					Constant Environmental Load	
	Load Phase	Pressure (lb)	Hoop (lb)	Axial (lb)	Frame (lb)	Temperature (°F)	Humidity (%)
Strain Survey, 75% of SL	Quasi-static	6.7	7140	6675	1133	Ambient	Ambient

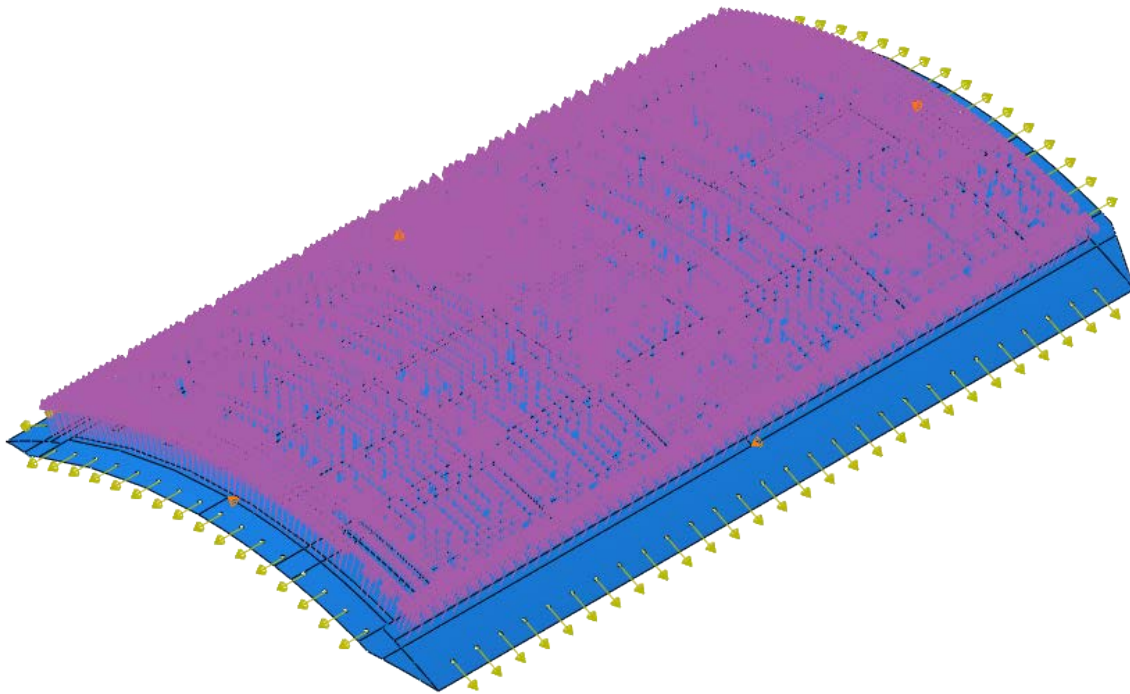


Figure 19. Final configurations of the simulated loaders (yellow) and internal pressurization (purple)

3.4 RESULTS AND COMPARISONS

Results predicted by the FE model of the pristine panel were compared to those measured during strain surveys. Figure 20 shows the strain gauge location on the external and internal skin of the panel. The test and simulation was conducted under 75% simulated service load at an ambient

environmental condition. The strain results were compared at various locations at the maximum strain survey loads.

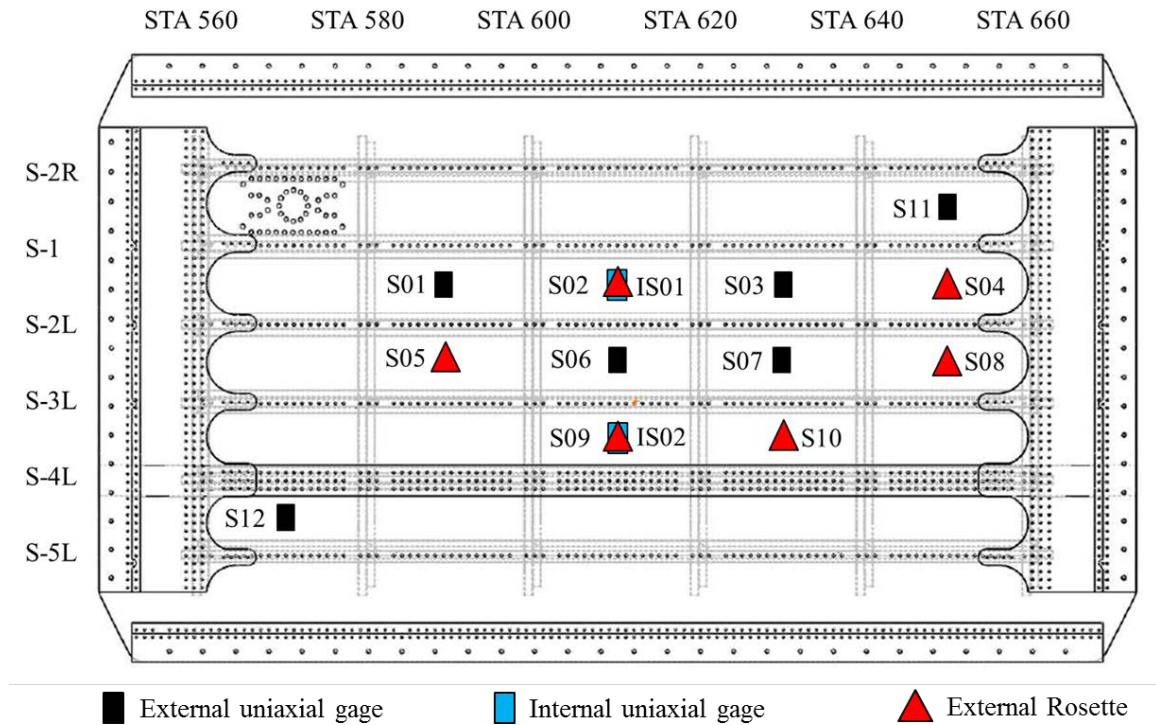


Figure 20. Strain gauge locations on the panel

Figure 21 shows the comparison between FE analysis prediction and the strain survey results of the pristine panel. Results indicated that both hoop and axial strain predictions from the FE model agreed very well with the strain survey results. The accuracy of the FE model ranged between 91% and 99% at all measured locations.

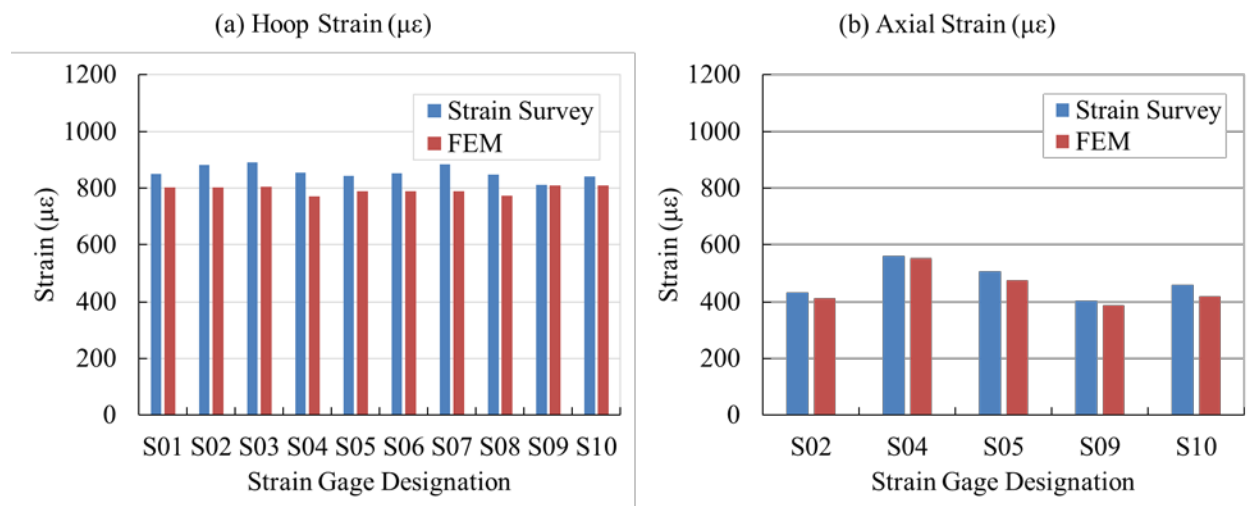


Figure 21. Comparison between fem and strain survey: (a) hoop strain, (b) axial strain

Further comparisons have been made showing the strain history as a function of internal pressure at the midbays next to the lap joint. Both hoop and axial strain were compared to three different strain surveys. Figure 22 shows the representative results of the comparisons compared with strain gauge S05, S09, and S10. Strain gauge S05 was installed on the external surface of the panel as shown in the green box. Strain gauges S09 and S10 were installed on the external surface and next to the lap joint, and are shown in the red and blue boxes. With panel pressurization, secondary bending occurred and introduced additional tension to the external surface of the lower side of the panel adjacent to the lap-joint because of local skin bulging. Therefore, a concave down tensile strain was observed at S09 and S10 locations. Overall the comparison of FE results and strain gauge results showed good agreement, verifying the test setup and applied loads.

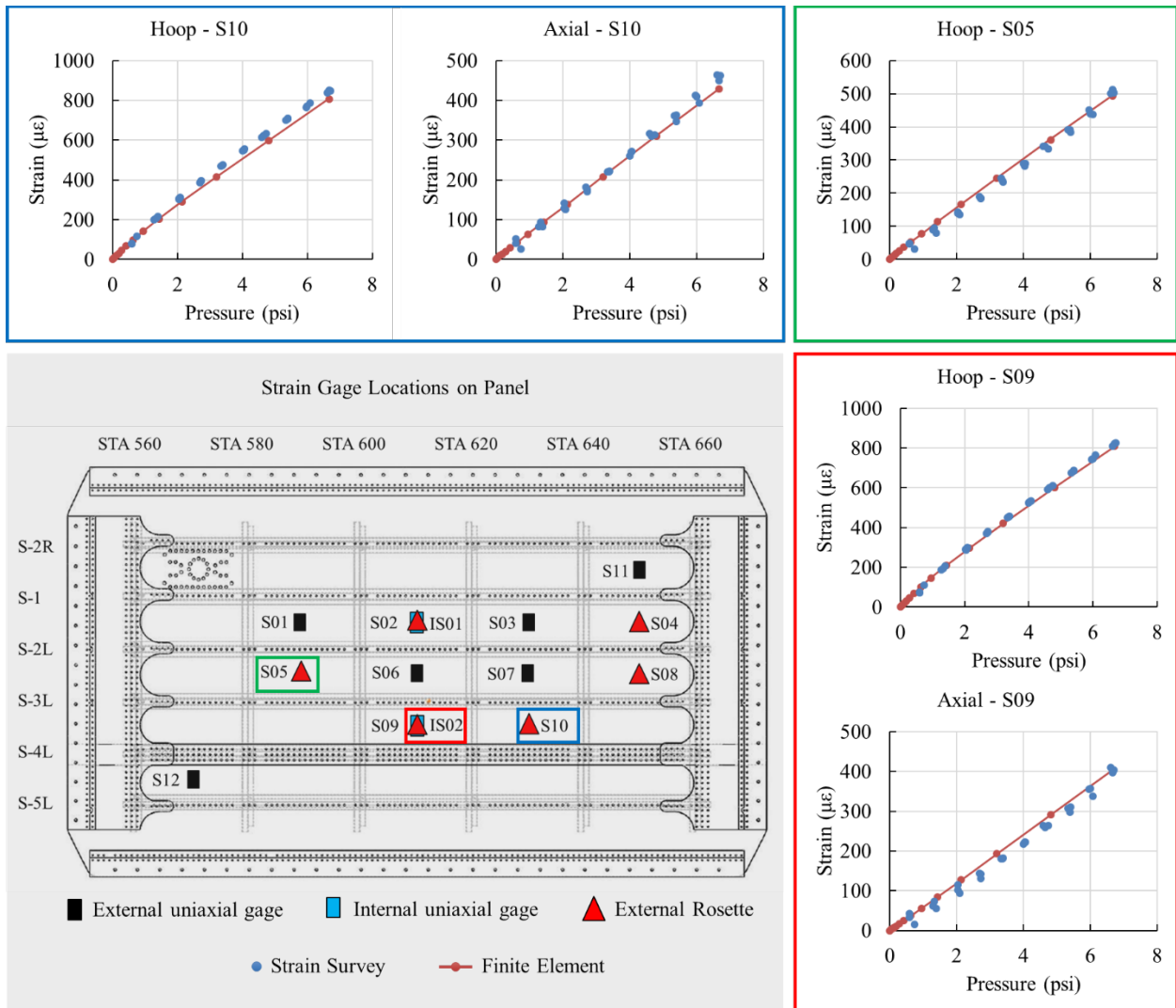


Figure 22. Strain ($\mu\epsilon$) as a function of internal pressure at S05, S09, and S10 locations

4. RESULTS AND DISCUSSION

Tests were performed to study fatigue performance of bonded repairs subjected to environmental conditions. The overall loading profile included mechanical fatigue loading simulated service

loads synchronized with temperature and humidity profiles. Representative results of strain survey, fatigue crack growth, and NDI are described in the subsequent sections.

4.1 UNEXPECTED MSD FORMATION

MSD unexpectedly formed during fatigue cycling, which evolved into a 20-inch-long crack (see figure 23). This was discovered during the 100,000-cycle inspection. As shown in the figure, MSD linkup is evident from the saw-tooth cracking pattern observed visually.

The MSD linkup was also manifested by the sudden change in strain distribution in all patches (see figure 24). The greatest change occurred in the hoop strain gauge data in the patch nearest to the MSD (the type 2 aluminum patch, UA), showing a sudden decrease in hoop strain ahead of both crack tips, as shown in figure 24d. The crack-tip strain dropped by approximately $500 \mu\epsilon$. The sudden drop in strain indicates that the MSD was linked up at approximately 97,800 cycles. Hoop-strain redistribution in the remote repair patches was also observed, as shown in all patches in figure 24. Unlike the UA patch, which is located right above the MSD region, other repair patches showed only a slight increase in the hoop strain. Because of the large strain redistribution near the repairs, results can be compared only up to the last inspection, which occurred prior to MSD linkup (i.e., 90,000 cycles).

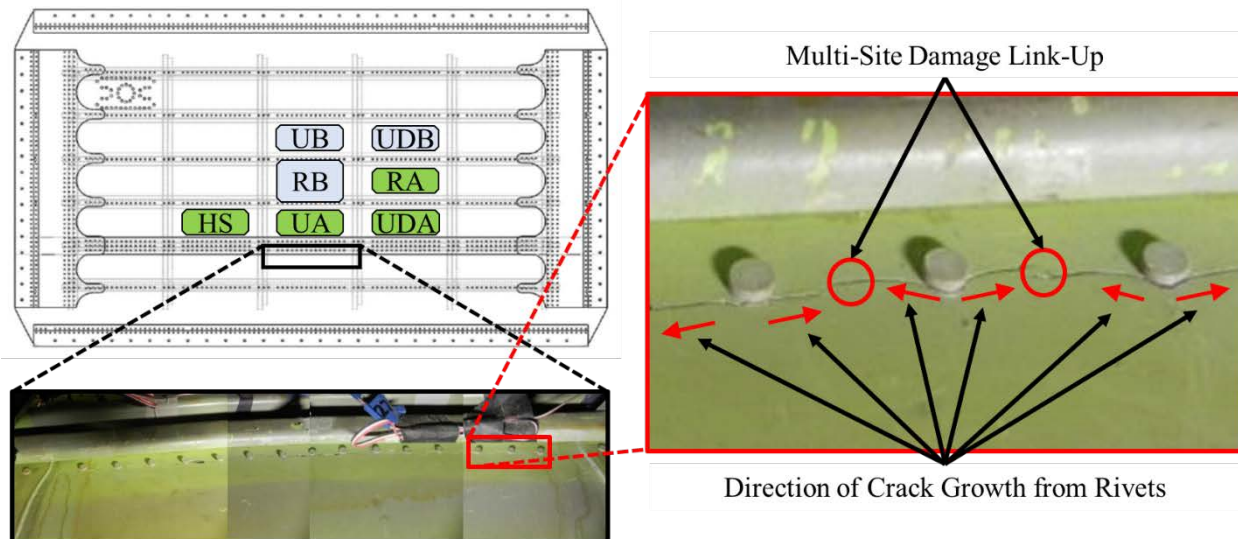


Figure 23. MSD on the internal surface of the skin

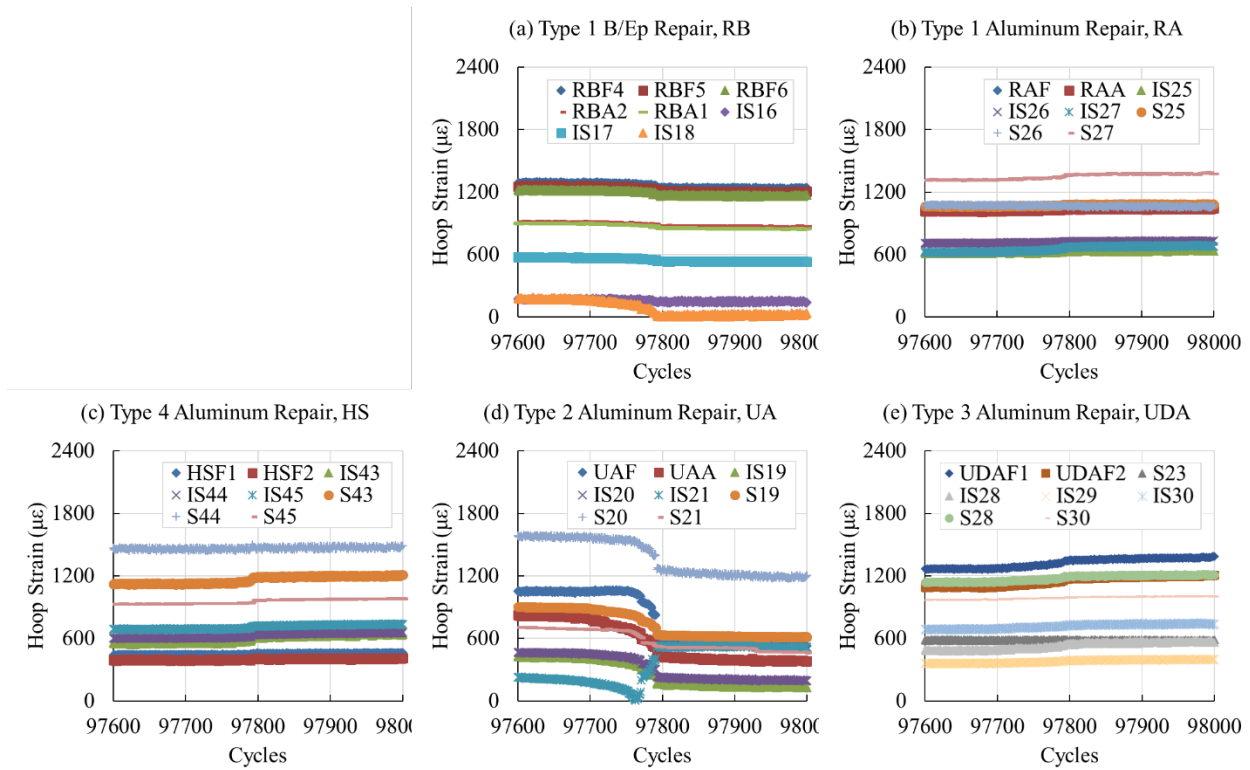


Figure 24. Hoop-strain monitoring during fatigue cycling. Hoop-strain redistribution observed at approximately 97,800 cycles: (a) RB, (b) RA, (c) HS, (d) UA, (e) UDA

4.2 THERMAL RESIDUAL STRAIN DURING CURING CYCLE

During the curing process of the repair installation, the strain near the crack tip and the temperature of the external surface were monitored. All measurements during the curing process are provided in appendix D. Representative results are provided in this section.

The typical strain gauge layout for each repair is shown in figure 25. The strain gauges installed 0.5 inch from the crack tip monitored the strain variations near the crack tip during the curing process. Back-to-back strain gauges installed 0.75 inch from the patch boundary monitored the occurrence of bending that happened during the curing process

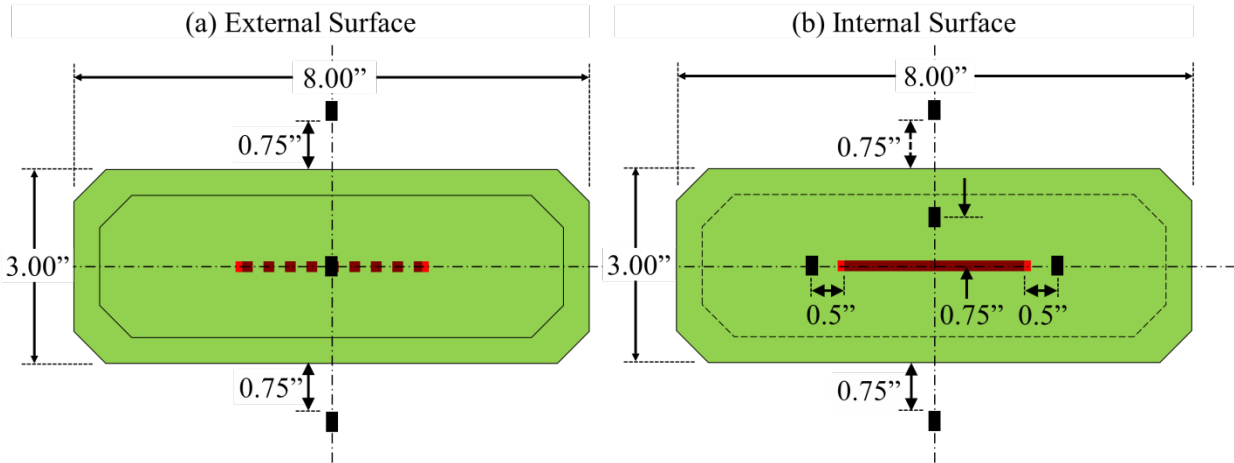


Figure 25. The typical strain gauge layout in the vicinity of each repair: (a) external surface and (b) internal surface

Representative results of the strain histories for reference B/Ep repairs are shown in figure 26. In the first 50 minutes of the curing process, the temperature was ramped up from room temperature to 250°F. The temperature was then held constant at 250°F for 90 minutes. In this stage, strain remained relative constant. After the temperature decreased to room temperature, thermal residual strains existed in all the repairs at the end of the cure cycle. The thermal residual strain in the vicinity or the crack-tip location for this repair was approximately 500 $\mu\epsilon$. All raw strain gauge data collected during the curing process are shown in appendix D.

Thermal residual strains, measured along the patch boundary of each repair at the end of the curing process, are shown in figure 27. In general, for both B/Ep and aluminum patches, the thermal residual strains on the internal skin surface along the patch boundary are in tension, whereas the corresponding strains on the external skin surface are in compression. The thermal residual strains at the boundary of the B/Ep patches were much higher than those in the aluminum patches because of the lower coefficient of thermal expansion of B/Ep.

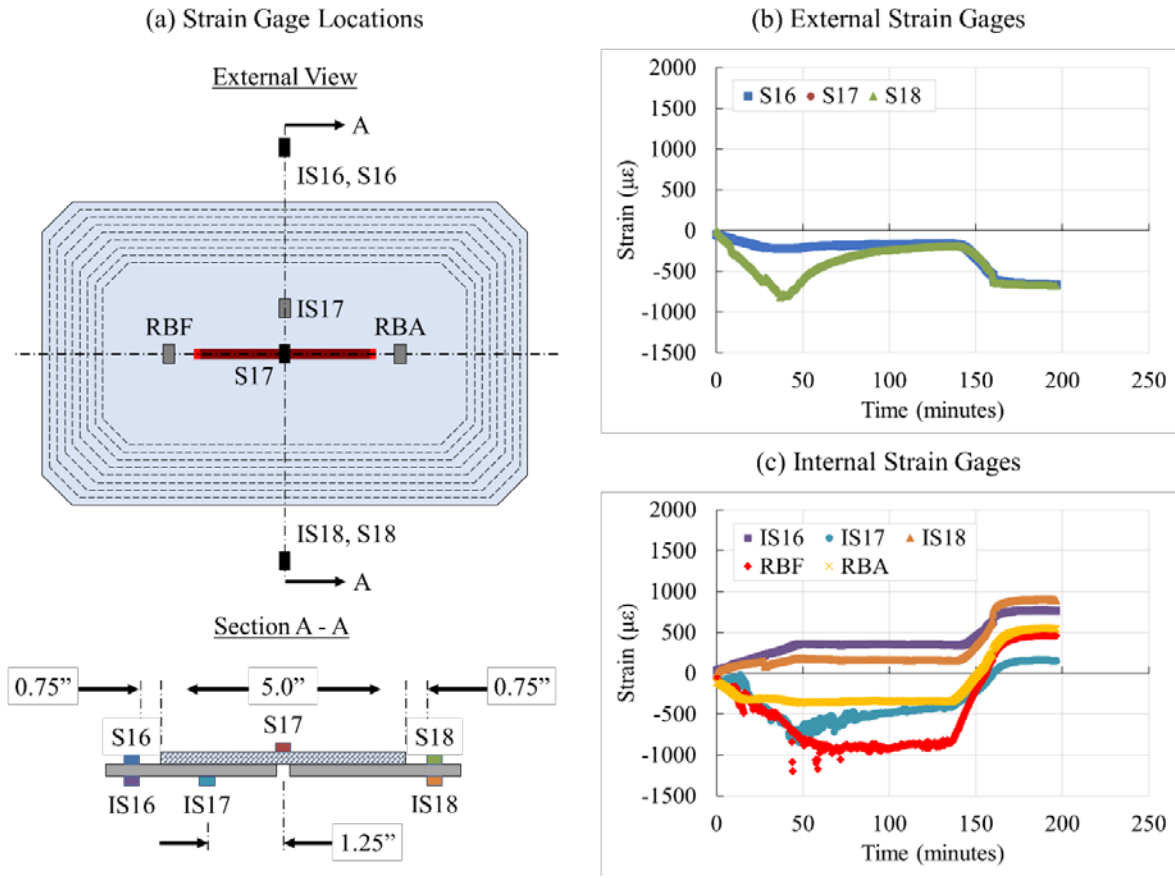


Figure 26. Strain history measurement during curing cycle of RB repair

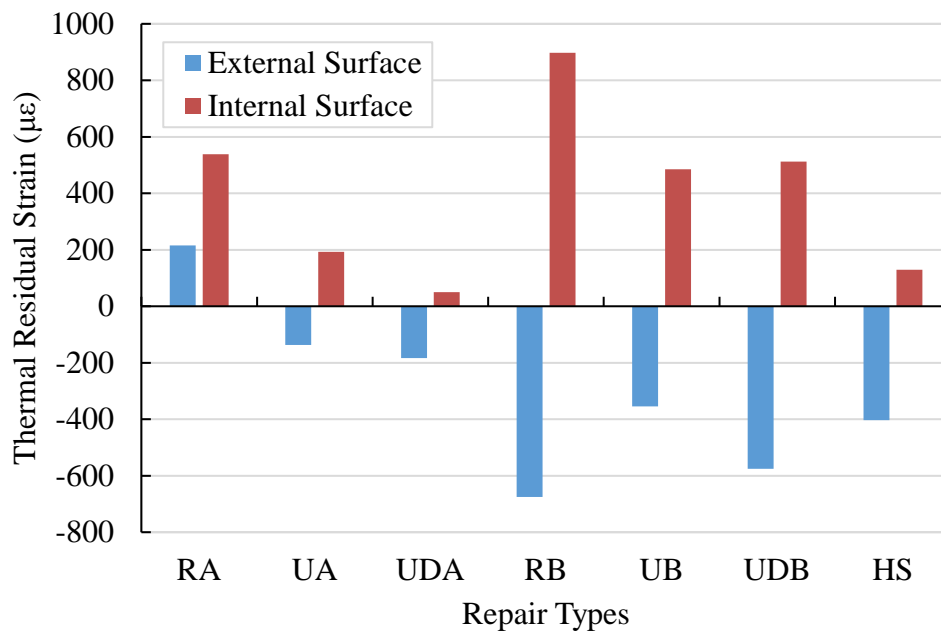


Figure 27. Thermal residual strain along the patch boundary of all repairs

4.3 STRAIN MONITORING

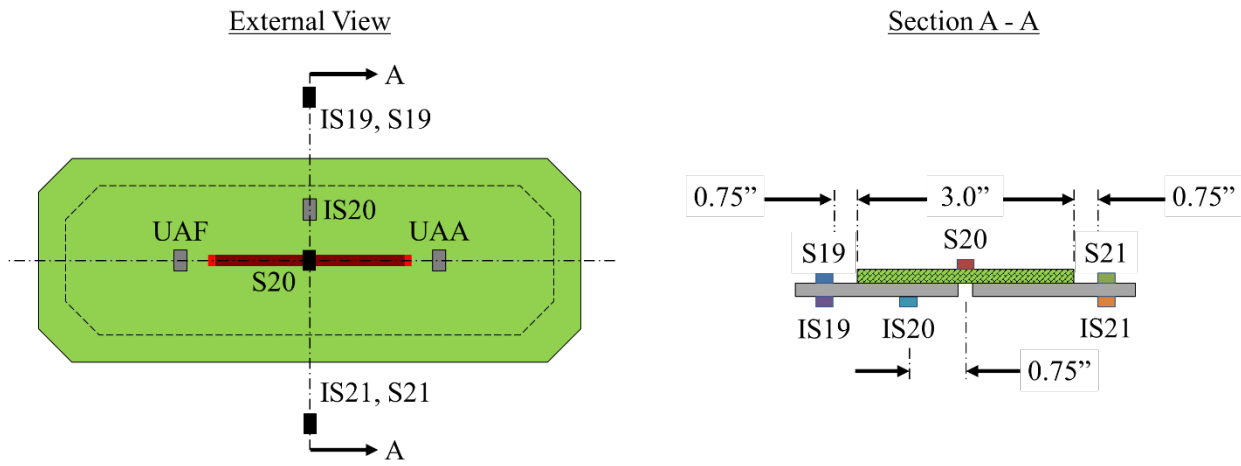
Strain surveys were taken at 75% of the simulated service load conditions under ambient conditions, at every 20,000 cycles, throughout the fatigue test. Representative results of the type-2 under-designed repairs are provided in the section. The strain history of all other repairs can be found in appendix E.

Type 2: Under-Designed Aluminum Repair

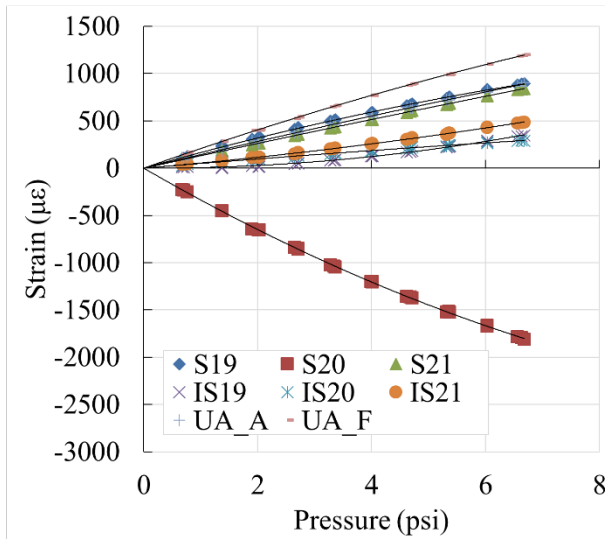
Figure 28a shows the typical strain gauge pattern and locations instrumenting each repair patch. For this example, a type-2 aluminum patch designated UA is considered. Along cross section A, gauges S19 and S21 were located on the outer surface of the skin, 0.75 inches away from the patch boundary. Gauges IS19 and IS21 were corresponding back-to-back gauges installed on the same location on the interior surface. Gauge S20 was located at the center of the patch on the outer surface.

Representative results for the UA patch are shown in figure 28b. The results indicate bending along the patch boundary where the outer skin surface is in higher tension than the inner skin surface. In addition, high compressive strains were measured in the center of the patch above the notch. The strain measurements history during fatigue is shown in figure 28c. The results of strain gauge S20 show that the compressive strain slightly decreased with fatigue cycles. However, these results are inconsistent because strain gauge S20 repeatedly disbonded because of compressive strains, and its replacement in a high-strain gradient region resulted in scatter. In general, strains remained relatively constant throughout the fatigue test.

(a) Strain Gage Locations



(b) Strain Response



(c) Strain History

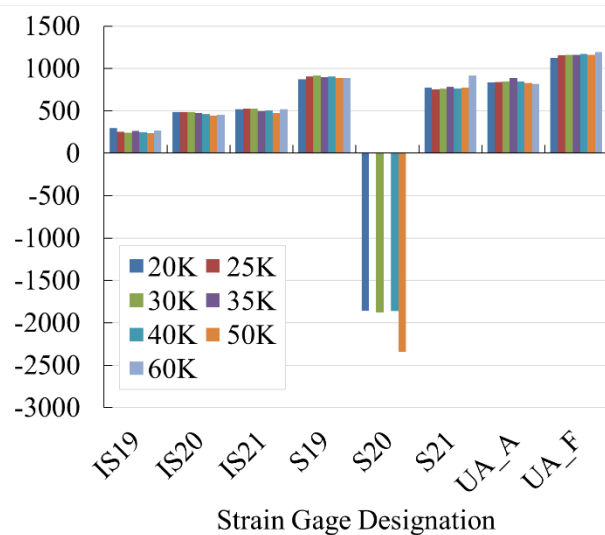


Figure 28. Strain-gauge measurements at strain survey loads in ambient environmental conditions during fatigue, type-2 aluminum repair, UA: (a) strain gage locations, (b) strain survey as function of pressure, and (c) strain history

Type 2: Under-Designed B/Ep Repair

Similar results for a type-2 B/Ep patch, designated UB, are shown in figure 29. The strain gauges instrumenting the patch are indicated in figure 29a. Along the cross section A, gauges S13 and S15 were located on the outer surface of the skin, 0.75 inch away from the patch boundary. Gauges IS13 and IS15 were corresponding back-to-back gauges installed on the same location on the interior surface. Gauge S14 was located at the center of the patch on the outer surface.

Figure 29b shows a large amount of bending along the patch boundary where the outer skin surface is in tension, whereas the inner skin surface is slightly in compression. High compressive strains were measured on the outer surface of the repair patch over the notch centerline. The variation of

strain during fatigue is shown in figure 29c indicating a slight reduction in strains in the early stages of fatigue, resulting from the relaxation of residual strains induced during the curing process of the initial patch installation. After 10,000 cycles, the results appeared to be relatively constant throughout the fatigue test up to 90,000 cycles. The detailed raw strain gauge data for all the repair patches are provided in appendix E, and the procedure of the data reduction is provided in appendix F.

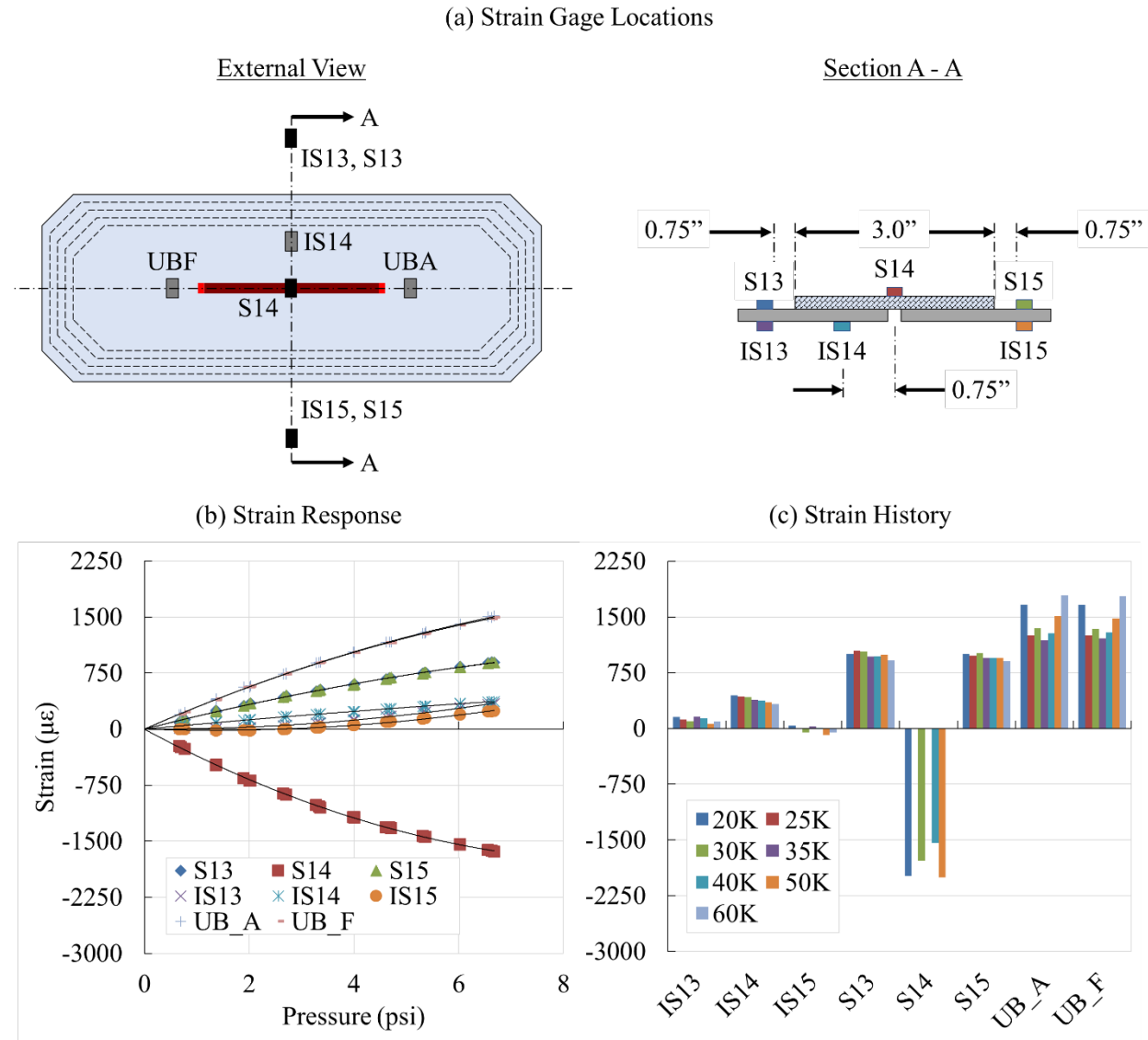


Figure 29. Strain-gauge measurements at strain survey loads in ambient environmental conditions during fatigue, type-2 B/Ep composite repair, UB: (a) strain gauge locations, (b) strain survey as function of pressure, and (c) strain history

Comparison of Type-2, Type-3, and Type-4 Aluminum Repairs

Representative results of type-2 (under designed), type-3 (under designed with disbonds), and type-4 (hand sanded) aluminum repairs are provided in this section. It should be noted that the

patch configurations (geometry and dimensions) of the type-4 repair were identical to that of the type-2 repair. Ideally, if the patches were perfectly bonded, strain field of all these patches should be similar. This is not the case, however, as surface preparation procedures and bonded surface areas were not the same for all of these repairs. In terms of surface preparation, the fuselage panel surface areas to which repair patches UA and UDA were installed were prepared using a grit blast deoxidization process, whereas the fuselage panel surface area to which repair patch HS was installed was prepared using a hand sanding process. In terms of bonded surface area, repair patches UA and HS featured identical patch geometry and dimensions and, therefore, identical bonded surface areas, whereas repair patch UDA included several areas of disbond that significantly reduced its bonded surface area.

Representative results are shown in figures 30 and 31 for strains measured along the patch boundary and in the center of the patch, respectively. In general, as shown in the figures, the measured strains of each repair remained relatively constant throughout the fatigue test. The back-to-back strain measurements along the patch boundary were compared between the type-2 aluminum (UA) repair, type-3 aluminum (UDA) repair, and the type-4 aluminum (HS) repair (see figure 30). In general, the bending hoop strains along the patch boundary were similar for the three types of aluminum repairs. The hoop strains at the center of the patch were compared between the UA, UDA, and HS repairs (see figure 31). Strains measured for UA and HS, repair patches with identical configurations, were approximately equal on the internal and external surfaces, whereas strains measured for UDA were significantly reduced. This difference in strain response can be attributed to the presence of disbonds that are prevalent in UDA and not the other two aluminum repairs.

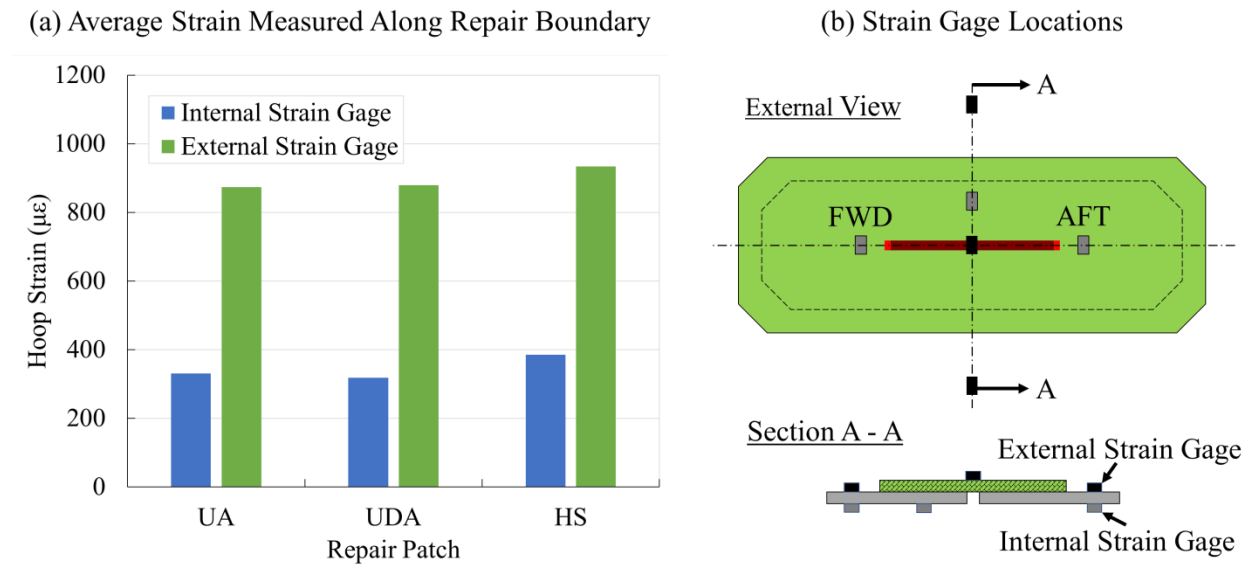
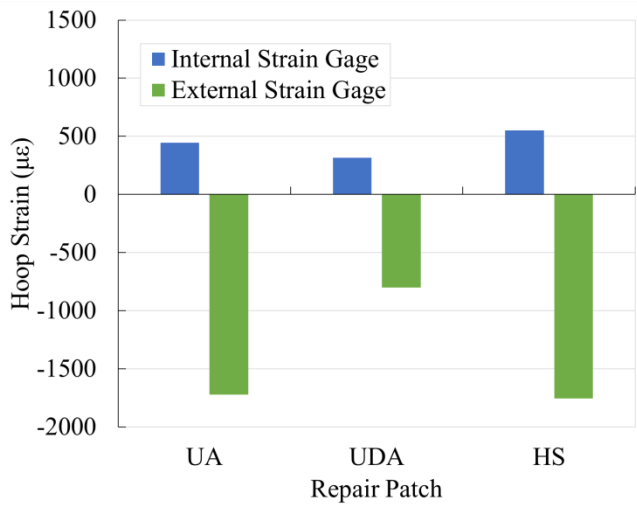


Figure 30. (a) Comparison of the average strain measured along the boundary of repair patches and (b) the locations of strain gauges with respect to the repair patches

(a) Average Strain Measured at the Center of the Repair



(b) Strain Gage Locations

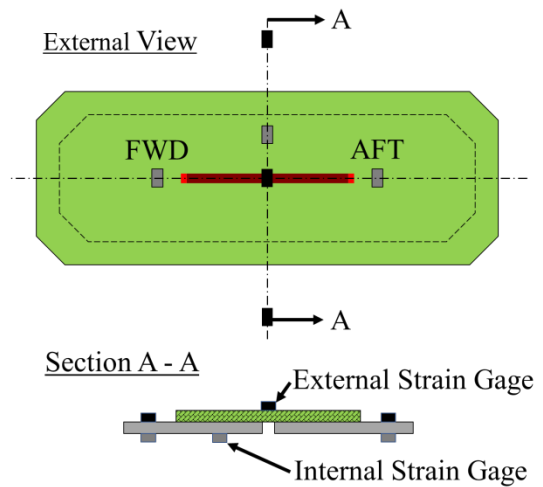


Figure 31. (a) Comparison of the average strain measured at the centers of repair patches and (b) the location of strain gauges with respect to the repair patches

Strain Surveys at Different Environmental Conditions

During the test, strain surveys were conducted at every 10,000 cycles. This strain survey data were collected at ambient and hot-wet (165°F and 85% RH) environmental conditions during 20,000 to 80,000 fatigue cycles and at ambient, hot-wet (165°F and 85% RH) and cold-dry (-25°F) environmental conditions during 80,000–90,000 fatigue cycles. All results are provided in appendix G.

Representative strain survey results for B/Ep repairs are shown in figure 33 for three environmental conditions at 80,000 cycles. The location of these gauges with respect to the repair patch are shown in figure 32. Shown in figures 33a, 33b, and 33c are the strain measurements as a function of increasing pressure at cold-dry environmental conditions, ambient environmental conditions, and hot-wet environmental conditions, respectively, for the external and internal gauges in the vicinity of the patch. The comparison of the strains at maximum strain survey loads is shown in figure 33d. Shown in figure 34 are strain measurements at three environmental conditions at maximum strain survey loads for the crack-tip strain gauges.

Assessing the results, strain values measured at cold-dry environmental conditions were higher than those measured at ambient environmental conditions, and strains measured at ambient environmental conditions were higher than those measured at hot-wet environmental conditions. Similarly, both forward and aft side crack-tip gauges showed that the strains at cold-dry conditions were highest, and the strains at hot-wet conditions were lowest. Furthermore, as the gauge distance from the crack tip increases, the magnitude of strains reduced.

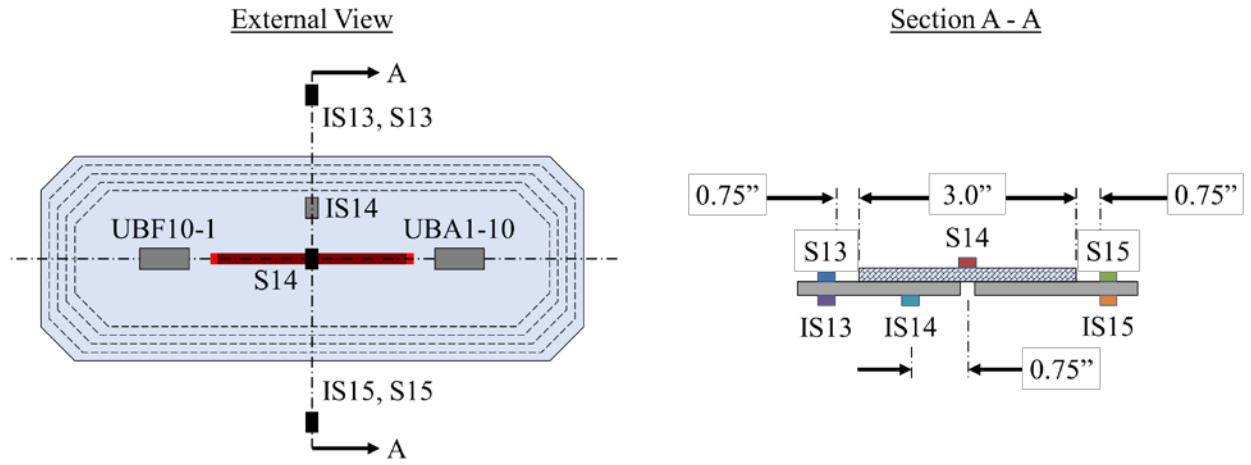


Figure 32. Location of strain gauges in the vicinity of the type-2 B/Ep repair patch, UB

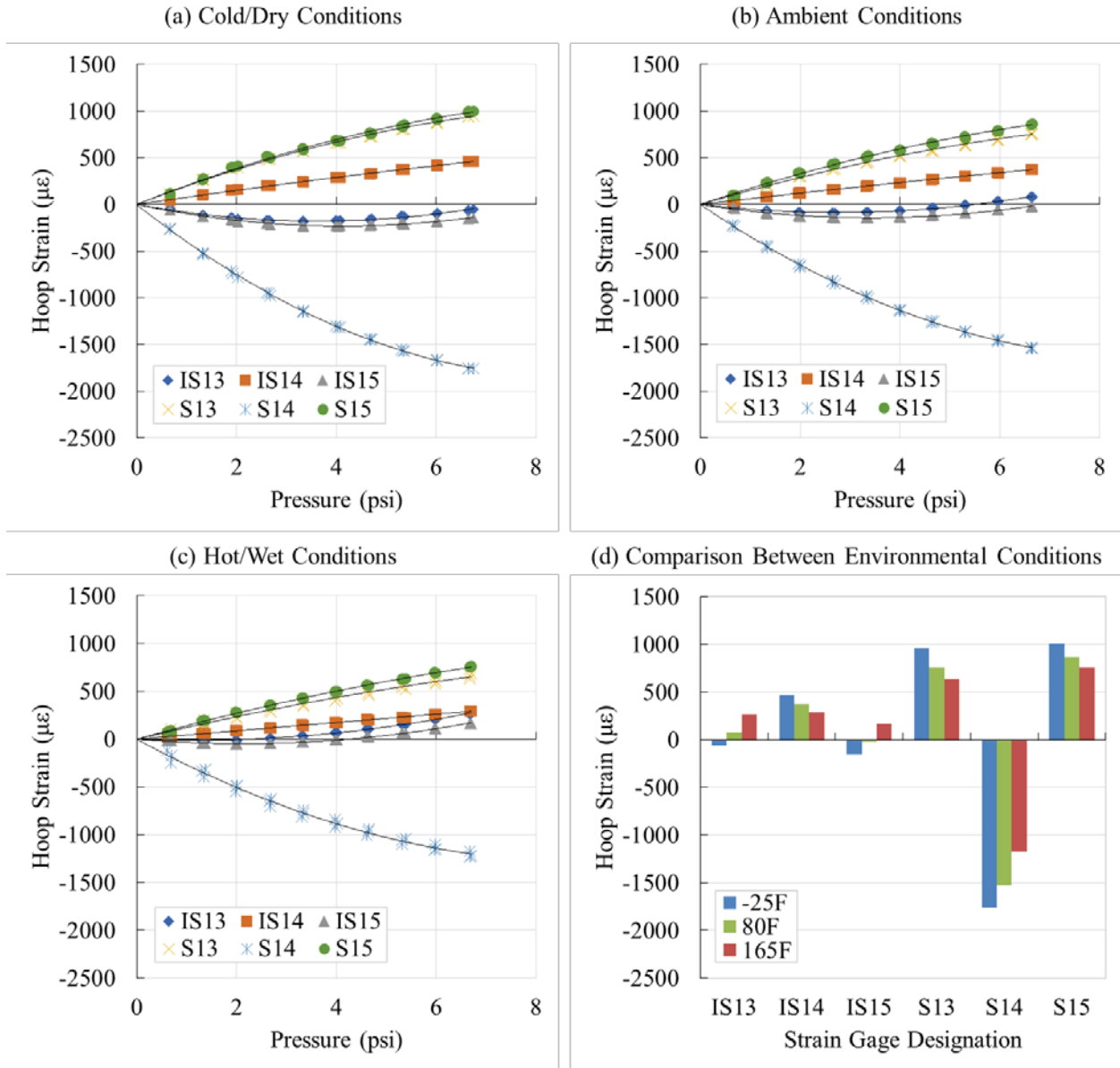


Figure 33. Results of strain survey conducted at 80,000 cycles at three environmental conditions for the type-2 B/Ep repair, UB: (a) cold-dry conditions, (b) ambient conditions, (c) hot-wet conditions, and (d) a comparison between environmental conditions

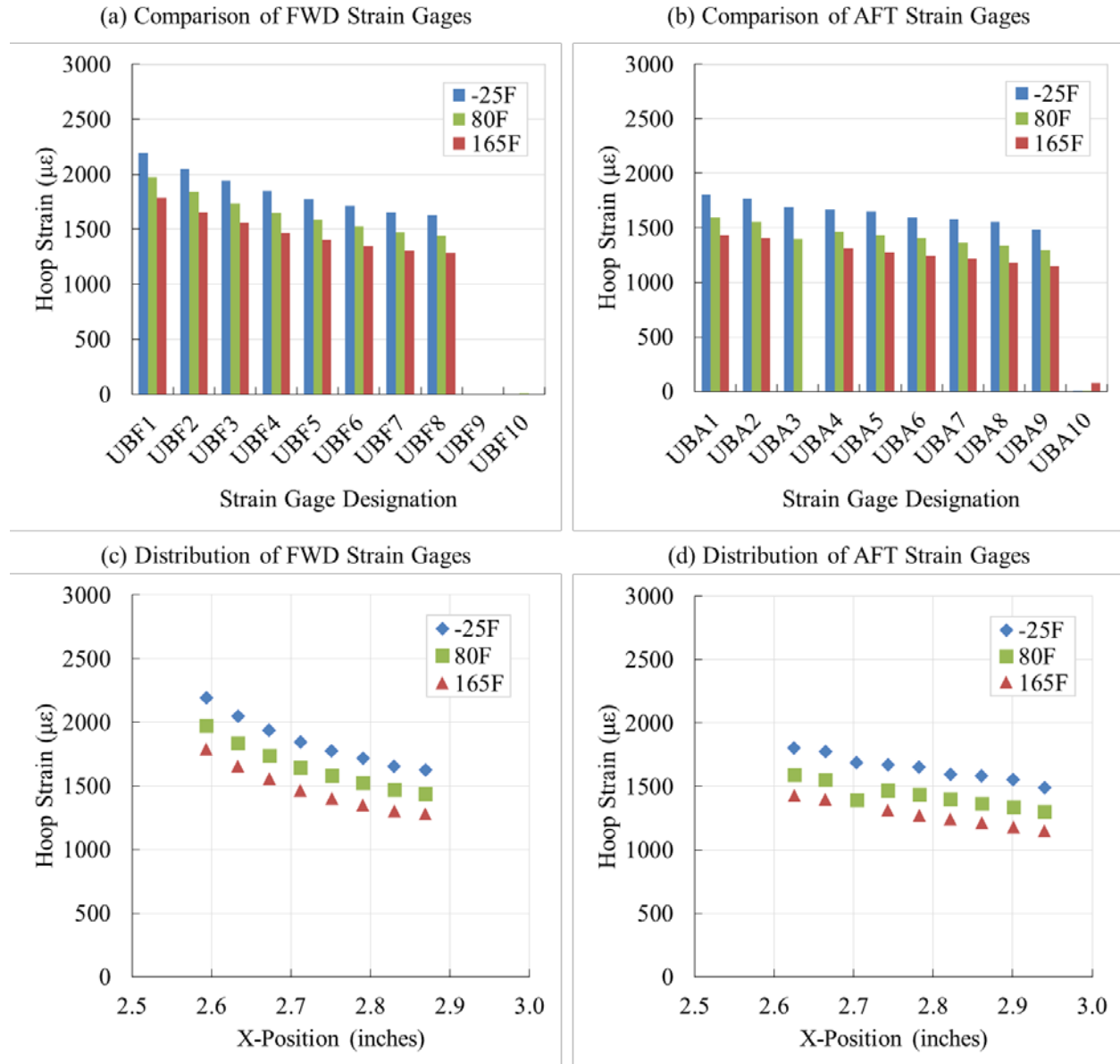


Figure 34. Notch-tip strain comparisons at maximum strain survey loading conditions under three different environmental conditions: (a) forward strain gauge chain and (b) aft strain gauge chain and strain distribution ahead of the (c) forward crack tip and (d) aft crack tip

Representative strain survey results for aluminum repairs are shown in figure 36 for three environmental conditions at 80,000 cycles. The location of these strain gauges with respect to the repair patch are shown in figure 35. Shown in figures 36a, 36b, and 36c are the strain measurements as a function of increasing pressure at cold-dry environmental conditions, ambient environmental conditions, and hot-wet environmental conditions, respectively, for the external surface, internal surface, and crack-tip gauges. The comparison of the strains at maximum strain survey loads is shown in figure 36d.

Assessing the results, strain survey measurements for the aluminum repairs showed that environmental conditions have a negligible effect on the strain at all locations within the vicinity of the repair. This difference in behavior can be attributed to the material properties of the fuselage panel and the repair patches. For the B/Ep repair, the difference between the coefficient of thermal expansion of the panel and the repair patch facilitated the development of thermal residual strain during the patch-curing process. The aluminum repair, however, exhibited the same material properties as the fuselage panel; therefore, the coefficients of thermal expansion were equal, and negligible thermal residual strain was developed during the patch-curing process.

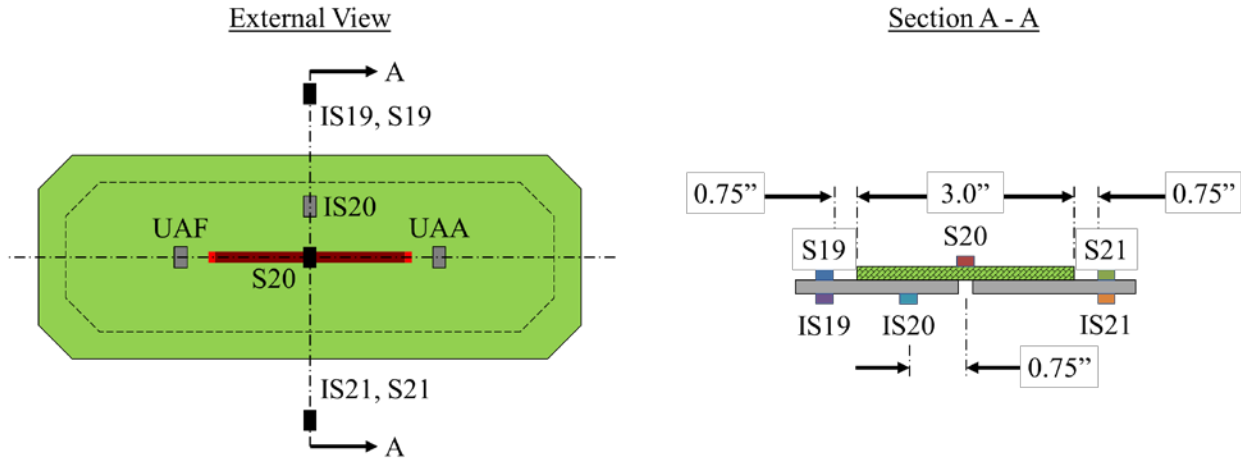


Figure 35. Location of strain gauges in the vicinity of the type-2 aluminum repair patch, UA

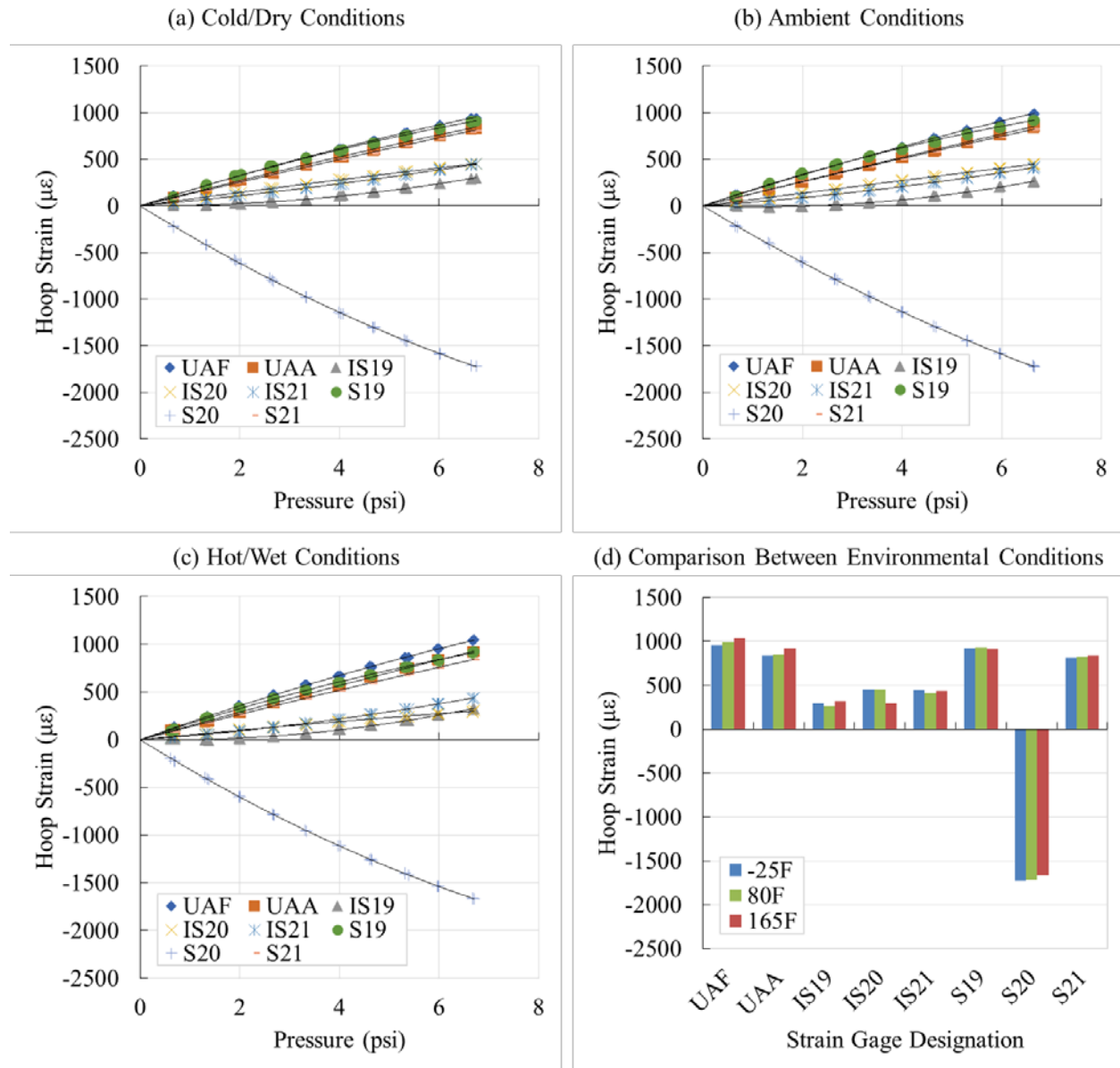


Figure 36. Results of strain survey conducted at 80,000 cycles at three environmental conditions for the type-2 aluminum repair, UA: (a) cold-dry conditions, (b) ambient conditions, (c) hot-wet conditions, and (d) a comparison between environmental conditions

Full-Field Strain Distributions

Wide-field-of-view (WFOV) images of the repair patch and surrounding area were taken using the DIC method to monitor for strain redistribution and load transfer. Full-field images of strain were taken periodically under laboratory ambient conditions at 75% service load conditions. Representative results of the full-field hoop strain are shown in figure 37 for type-2 aluminum repair, UA, at several fatigue cycles. As shown, tensile strains were measured in the vicinity of the patch boundary in the skin, whereas compressive strains were measured in the center region of the patch along the notch centerline. Similar trends in the results were observed from strain gauge

measurements shown in figure 36. In general, the global strains on the external surface remained relatively constant throughout the fatigue test up to 90,000 cycles.

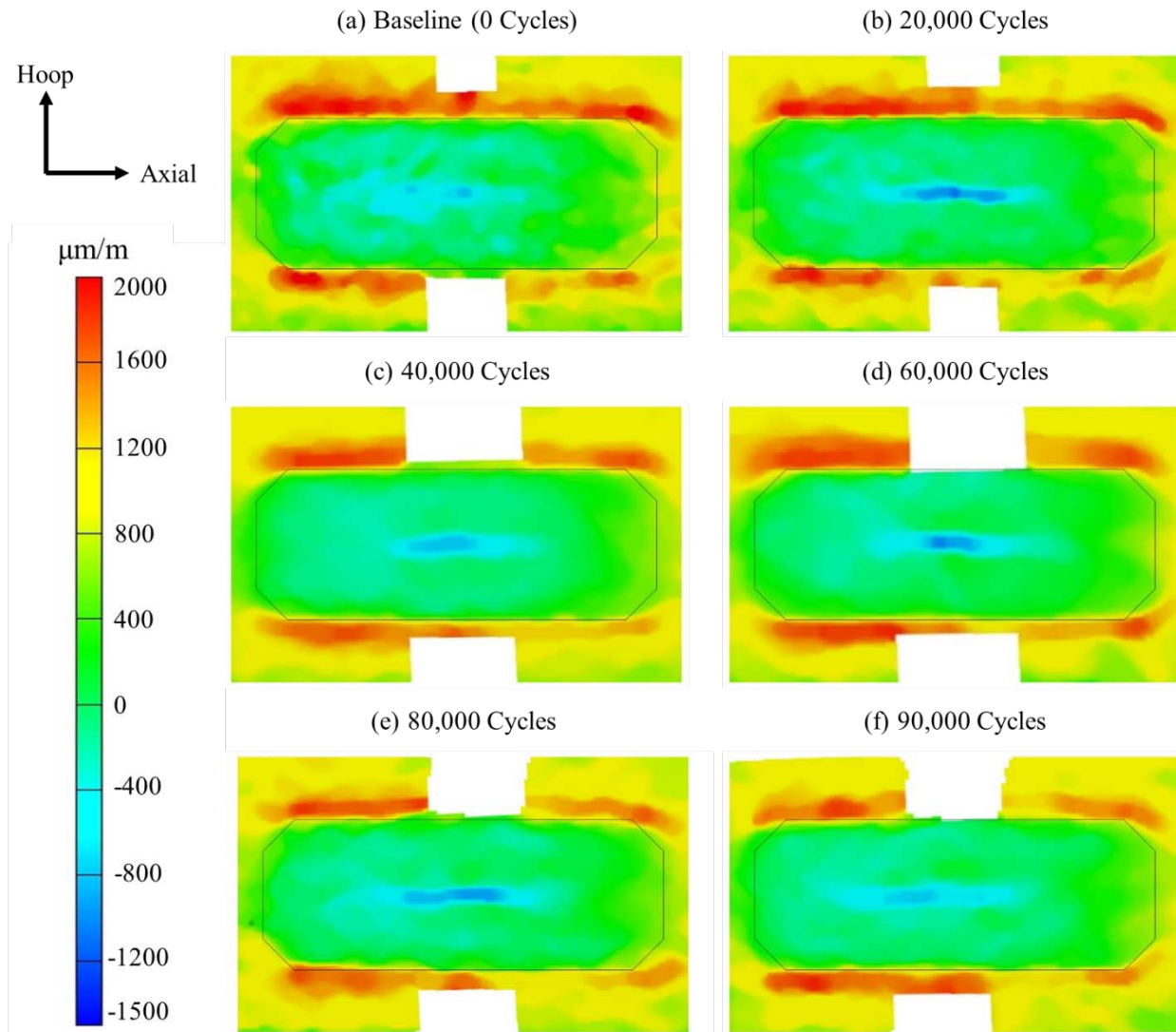


Figure 37. WFOV full-field hoop strain for UA repair at strain survey loads in ambient environmental conditions during hot-wet phases: (a) baseline, (b) 20,000 cycles, (c) 40,000 cycles, (d) 60,000 cycles; and during cold-dry phases: (e) 80,000 cycles and (f) 90,000 cycles

Further details from higher resolution, full-field strain measurements near the notch region are provided in the narrow-field-of-view (NFOV) images using the DIC method, which is shown in figure 38. The figure shows strain measurements made at three stages of the fatigue test: baseline (zero cycles), the middle of the fatigue test at 40,000 cycles, and the end of the fatigue test at 80,000 cycles. Local strain redistribution is evident by the expansion of the compression zone at the center of the repair patch, which is a result of crack extension.

In addition, the hoop-strain variation across the patch, shown in figure 38, is provided along three vertical sections equally spaced at 1.5 inches apart: section 1, located along the centerline of the

patch; section 2, located within the original crack-tip region; and section 3, located in the intact region ahead of the original crack tip. Overlaid in the section plots are strains measured using strain gauges. In general, the hoop strain varied most along the patch boundaries and toward the center of the patch where the notches were located. Strain redistribution occurred with crack extension, as seen by the growth of the compressive region in the center of the patch. In addition, there was good correlation between strain measured by strain gauges and that which was measured using DIC.

Along section 1, the hoop-strain values ranged from approximately $2000 \mu\epsilon$ in the skin outside the patch to approximately $-2500 \mu\epsilon$ in the center of the patch for the baseline measurement (see figure 38a). High-strain gradients were evident over short distances at the patch boundary and the notch region. Across the patch boundary, the strain was reduced from $2000 \mu\epsilon$ to zero over a distance of approximately 0.2 inch. The strain gradient was also quite high in a narrow band of approximately ± 0.5 inch around the notch. Over this short distance, the strain ranged from 0 to $-2500 \mu\epsilon$. The magnitude of the compressive strain in the center of the patch was reduced to approximately $-2000 \mu\epsilon$ as the number of cycles increased, as shown in figures 38b and 38c for 40,000 and 80,000 cycles, respectively. As shown in the strain-variation plots, data from the DIC were in good agreement with data measured using strain gauges that were also located along section 1.

Similar trends in strain distributions were displayed along section 2, where high-strain gradients occurred over short distances at the patch boundary and the notch region. The values ranged from approximately $2000 \mu\epsilon$ in the skin outside the patch to approximately $-1500 \mu\epsilon$ in the center throughout the fatigue test.

Along section 3, high-strain gradients were initially measured over short distances only at the patch boundary. Hoop-strain values ranged from approximately $2,000 \mu\epsilon$ in the skin outside the patch to approximately $-500 \mu\epsilon$ in the center, as shown in figures 38a and 38b, at the baseline (zero cycles) and 40,000 cycles, respectively. As shown in figure 38c, the compressive region crosses section 3, resulting in an increase in the compressive hoop strain to $-1500 \mu\epsilon$ in the center of the patch. Similar results obtained from all other repair patches are shown in appendix H (DIC data).

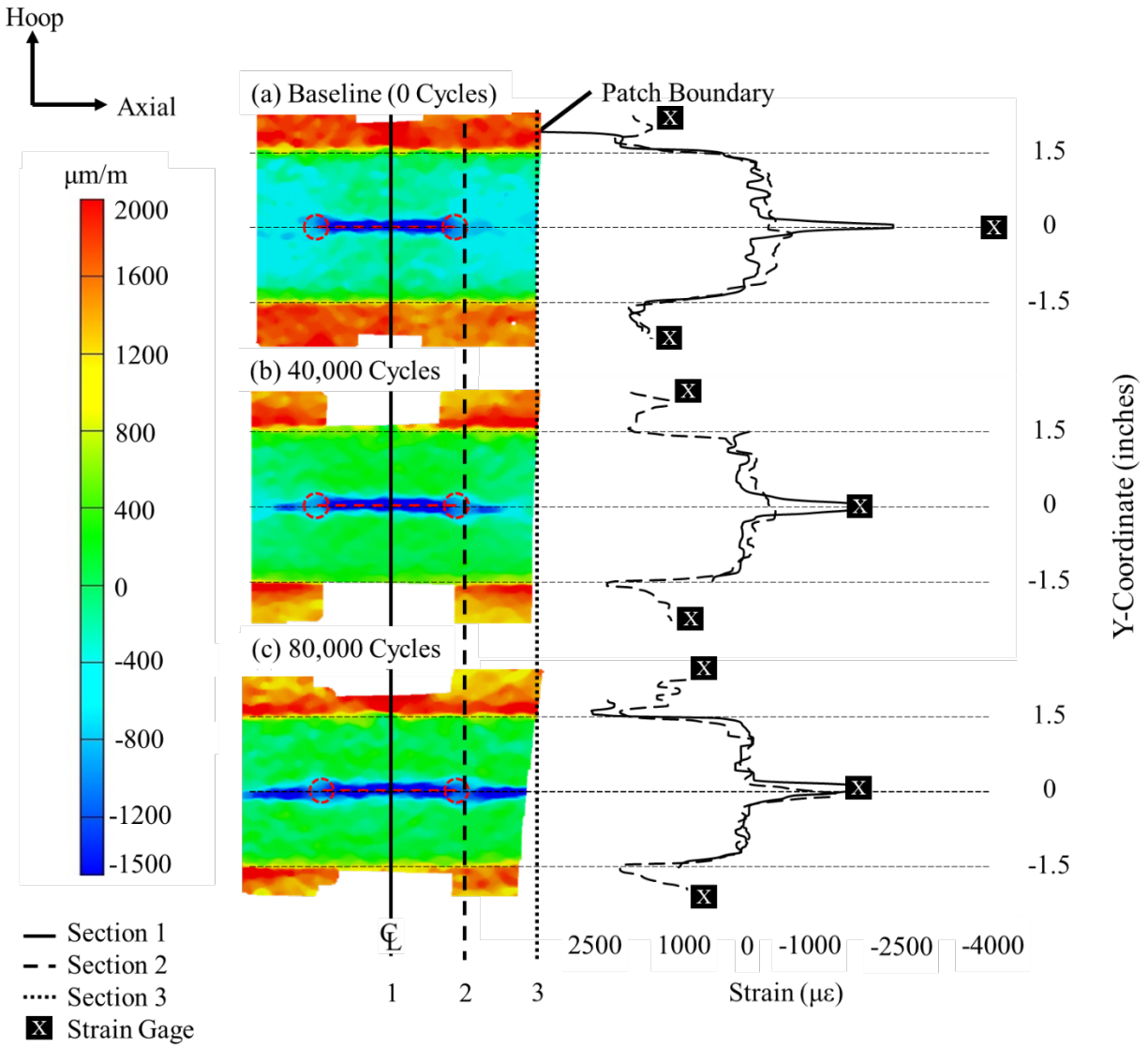


Figure 38. NFOV hoop-strain variation in the type-3 B/Ep repair, UDB; and comparison between DIC and strain gauge measurements at different cycles: (a) baseline (0 cycles), (b) 40,000 cycles, and (c) 80,000 cycles

4.4 FATIGUE CRACK GROWTH

Fatigue crack growth in the fuselage skin under each repair was continuously monitored visually using high-magnification cameras. Both low- and high-frequency EC inspections were made in 10,000 cycle intervals. In general, limited crack growth was observed in the type-2 aluminum repair, UA, as shown in figure 39. Apparently, the underdesigned configuration was conservative for this aluminum patch repair.

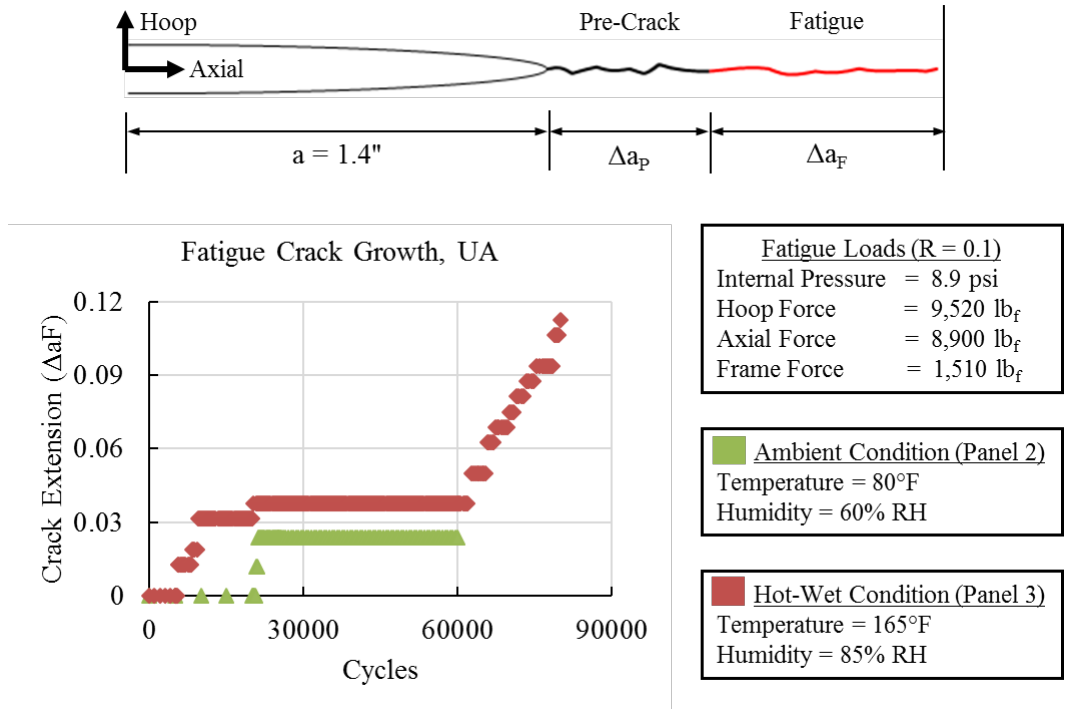


Figure 39. Fatigue crack-growth measurements of the underdesigned aluminum repair, UA

For the remaining repairs, namely the type-2 B/Ep repair (UB) and type-3 repairs (UDB and UDA), considerable fatigue crack growth was observed. Representative results are shown in figure 40 for the UDB and UDA repairs. As shown, slow and stable crack growth was observed in both repair patches. In addition, the crack growth was symmetric and co-linear, and the measured rate was nearly constant after the initial 5000 fatigue cycles. Results from visual and HFEC inspections were in good agreement. The complete crack-growth data in tabular form are provided in appendix I (Crack Growth Data).

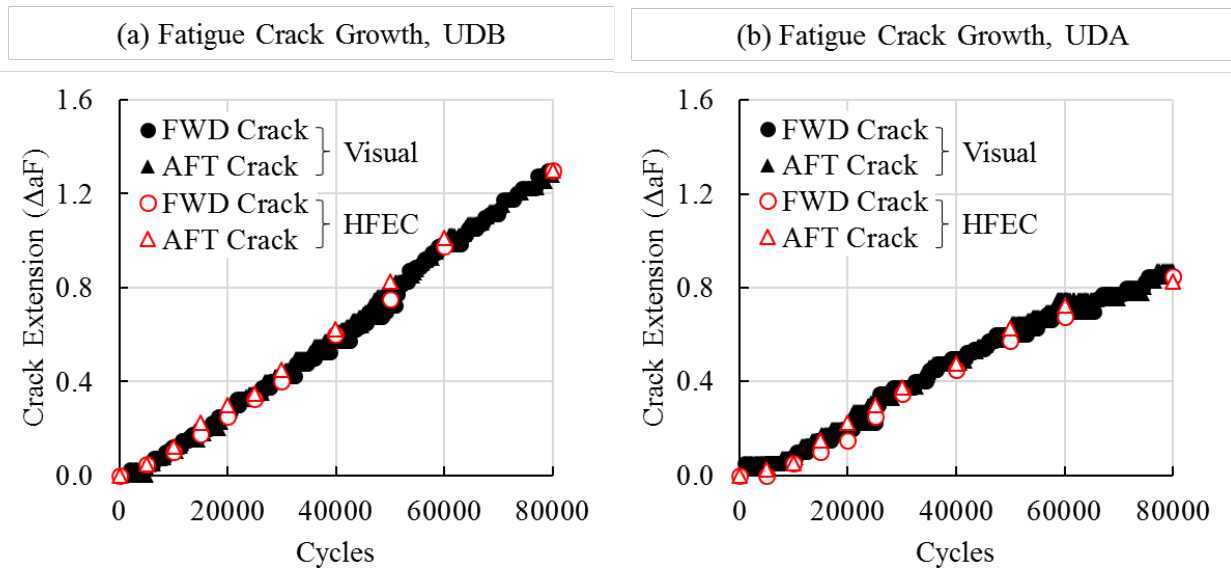
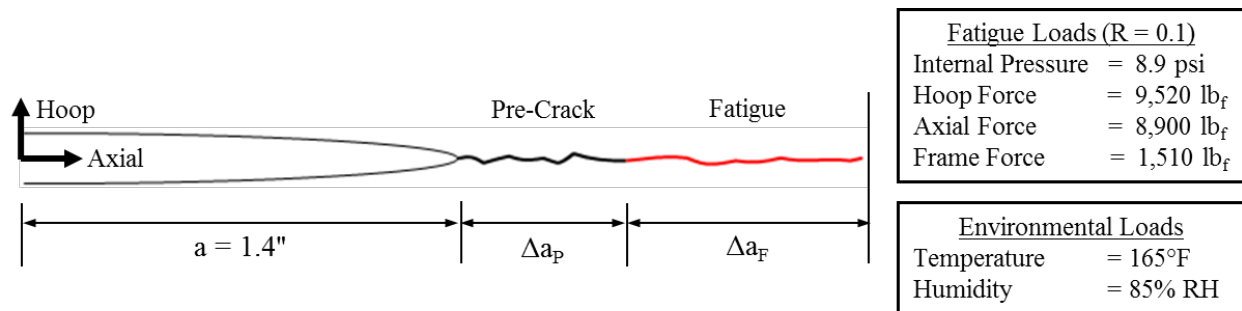


Figure 40. Fatigue crack-growth measurements: (a) B/EP repair, UDB; and (b) aluminum repair, UDA

A comparison of the results from panel 2 tested under ambient conditions [5, 7] with those from the current panel-3 results, tested under hot-wet (165°F and 85% humidity) conditions, reveal differences in which the environment may be a contributing factor on fatigue performance (see figure 41). Although the difference in results from the two panel tests was certainly a result of other factors, including inherent scatter from applied loads and the location, geometry, and installation of the repairs, temperature and humidity also played a role. Results for the B/Ep composite repairs shown in figure 41a reveal slower crack growth under hot-wet conditions compared to those under ambient lab conditions for which the average measured rates were 1.71×10^{-5} in./cycles and 1.99×10^{-5} in./cycles, respectively. In addition, stable crack growth did not occur until after 5000 cycles under hot-wet conditions. Mismatches in the coefficient of thermal expansion of the composite patch and aluminum fuselage skin resulted in the residual thermal stresses ahead of the notch due to the initial patch installation curing process. At elevated temperatures, these residual stresses were relaxed, as shown in figure 42a. As shown, the hoop strains measured from two notch gauges located the same distance from the crack tip were approximately 10% lower under hot-wet conditions as compared to ambient conditions after 20,000 fatigue cycles.

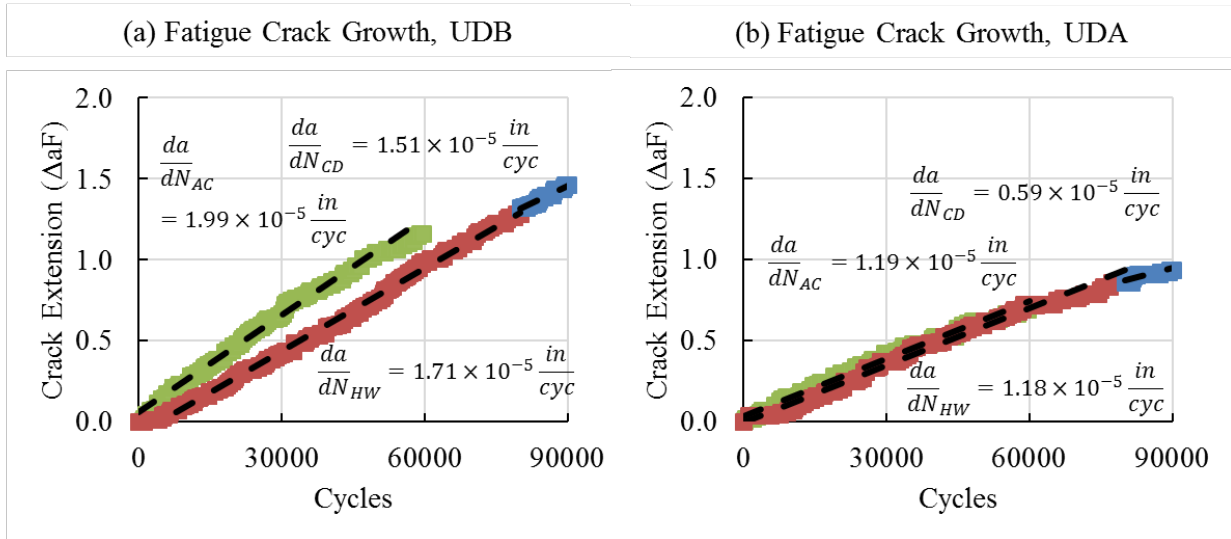
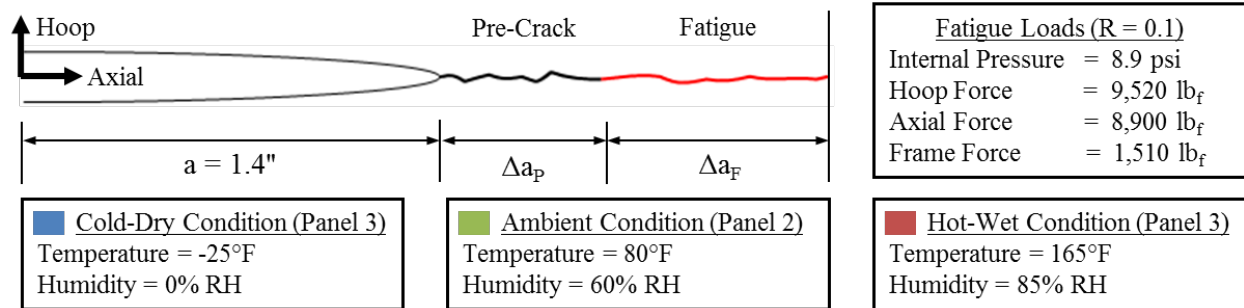


Figure 41. Effect of repair quality on fatigue crack growth in B/Ep and aluminum-bonded repairs

Results for the aluminum repair indicated limited effect of environment on the fatigue crack growth, as shown in figure 41b. As shown, the fatigue crack-growth behavior was similar for hot-wet and ambient conditions for which the average measured rates were 1.18×10^{-5} in./cycle and 1.19×10^{-5} in./cycle, respectively. Because both the repair and the fuselage skin were made of aluminum, the coefficients of thermal expansion were comparable, resulting in limited thermal residual stresses after the initial patch installation curing process. As shown in figure 42b, the hoop strains measured from two notch gauges ahead of the crack tip were similar for both conditions.

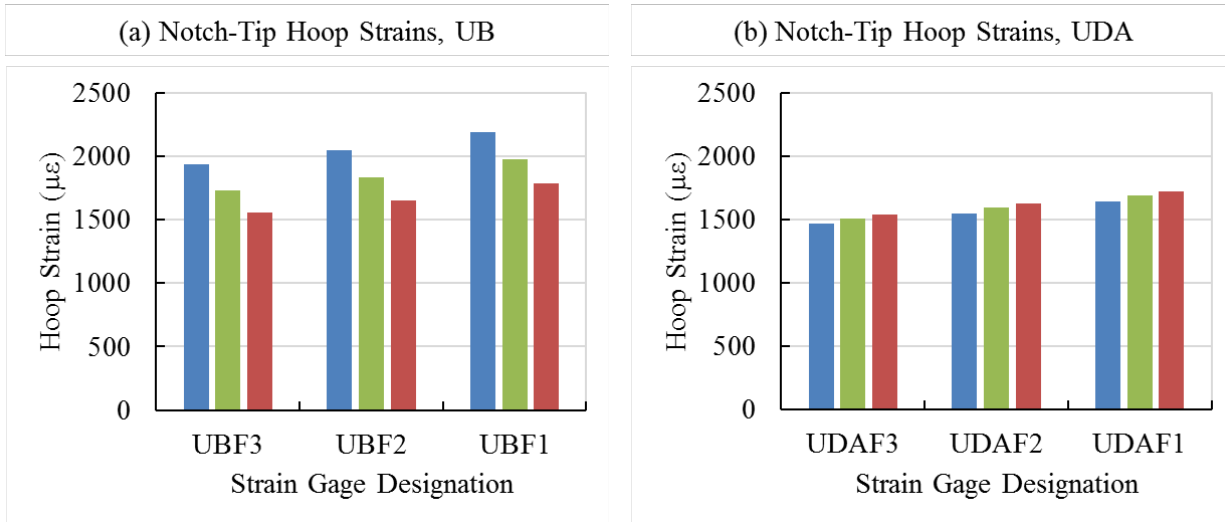
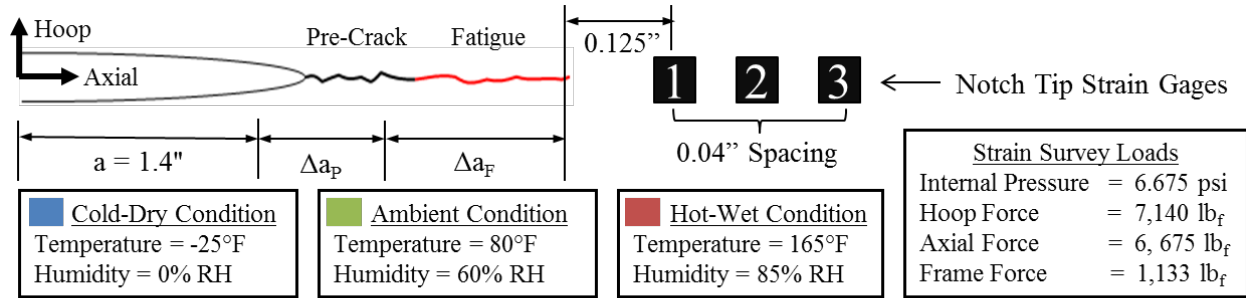


Figure 42. Effect of environment on the notch-tip region strains after 80,000 cycles: (a) B/Ep repair, UB; and (b) aluminum repair, UDA

On the contrary, under cold-dry conditions, the hoop strains were approximately 10% higher than those under the ambient conditions. However, the crack-growth rate under cold-dry conditions was slower than that under ambient and hot-wet conditions. The summary of the crack-growth rate under various environmental conditions for type-3 repairs is shown in table 8. It is noted that an MSD formed on the lower skin of the lap joint was discovered at approximately 97,000 cycles, which may cause this slow crack-growth behavior. Therefore, the crack-growth rate under cold-dry conditions was inconclusive.

Table 8. Crack-growth rate for the type-3 B/Ep repair and aluminum repair

	UDB da/dN (10^{-5} in/cycles)	UDA da/dN (10^{-5} in/cycles)
Ambient Conditions	1.99	1.19
Hot-Wet Conditions (0 – 80,000 cycles)	1.71	1.18
Cold-Dry Conditions (80,000 – 90,000 cycles)	1.51	0.59

Finally, a comparison of the effectiveness of various repair patches, in terms of both pre-cracking and fatigue crack-growth rates, is shown in figure 43. The results indicate that repair patches were effective in reducing crack-growth rate. The highest crack-growth rate was 1.99×10^{-5} in./cycle for the underdesigned B/Ep repair with intentionally inserted disbond, as compared to 5.45×10^{-5} in./cycle for the average pre-cracking growth rate. The results also show that the effectiveness decreased as the repair quality degraded. A very limited crack growth was observed from the properly designed repairs and reference repairs, and a higher crack-growth rate was observed from the underdesigned repairs. As expected, the underdesigned repairs with intentionally inserted disbond showed the highest crack-growth rate.

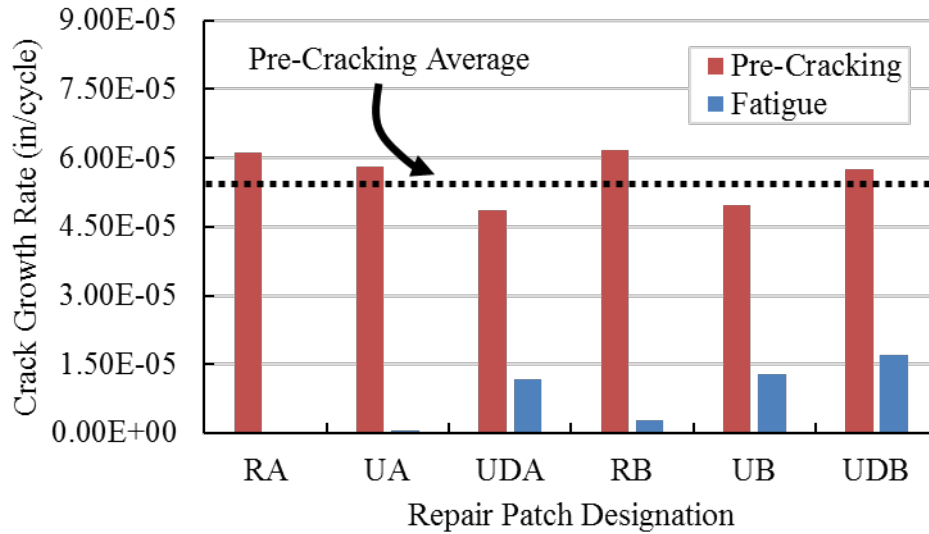


Figure 43. Comparison of the crack-growth rate before and after six repair patches

4.5 DISBOND INSPECTIONS USING NDI

Flash thermography and resonance ultrasonic were used to monitor for disbonds in the repair patches in 10,000 cycle intervals. Correlations of disbond detection were made with full-field strains measured using the DIC. Representative results are discussed in the following sections.

Flash Thermography

The flash thermography system worked effectively on all B/Ep composite repairs. Figure 44 shows the representative results from type-2 and type-3 B/Ep repair with 20,000 cycle intervals. Note that for the type-3 B/Ep repair, UDB includes intentional disbond inserts at the patch boundary and at the notch-tip regions. Photographs in the figure show the results after an exposure time of 2.5 sec. The flash thermography clearly indicated the disbond inserts, the notch location, and crack growth from the notch tips. In general, there was no indication of disbond growth in all B/Ep composite repairs using the flash thermography.

Resonance Ultrasonic

The resonance ultrasonic system was used for all repairs. Calibration standards with known disbond defects were designed and built for both B/Ep and aluminum repairs to adjust the settings of the resonance ultrasonic system for flaw detection. Figure 45 shows representative results for type-3 aluminum repair, UDA, in which the central disbond region outlined in red was readily detected. In general, there were no indications of disbond growth for all four types of repairs using the resonance ultrasonic.

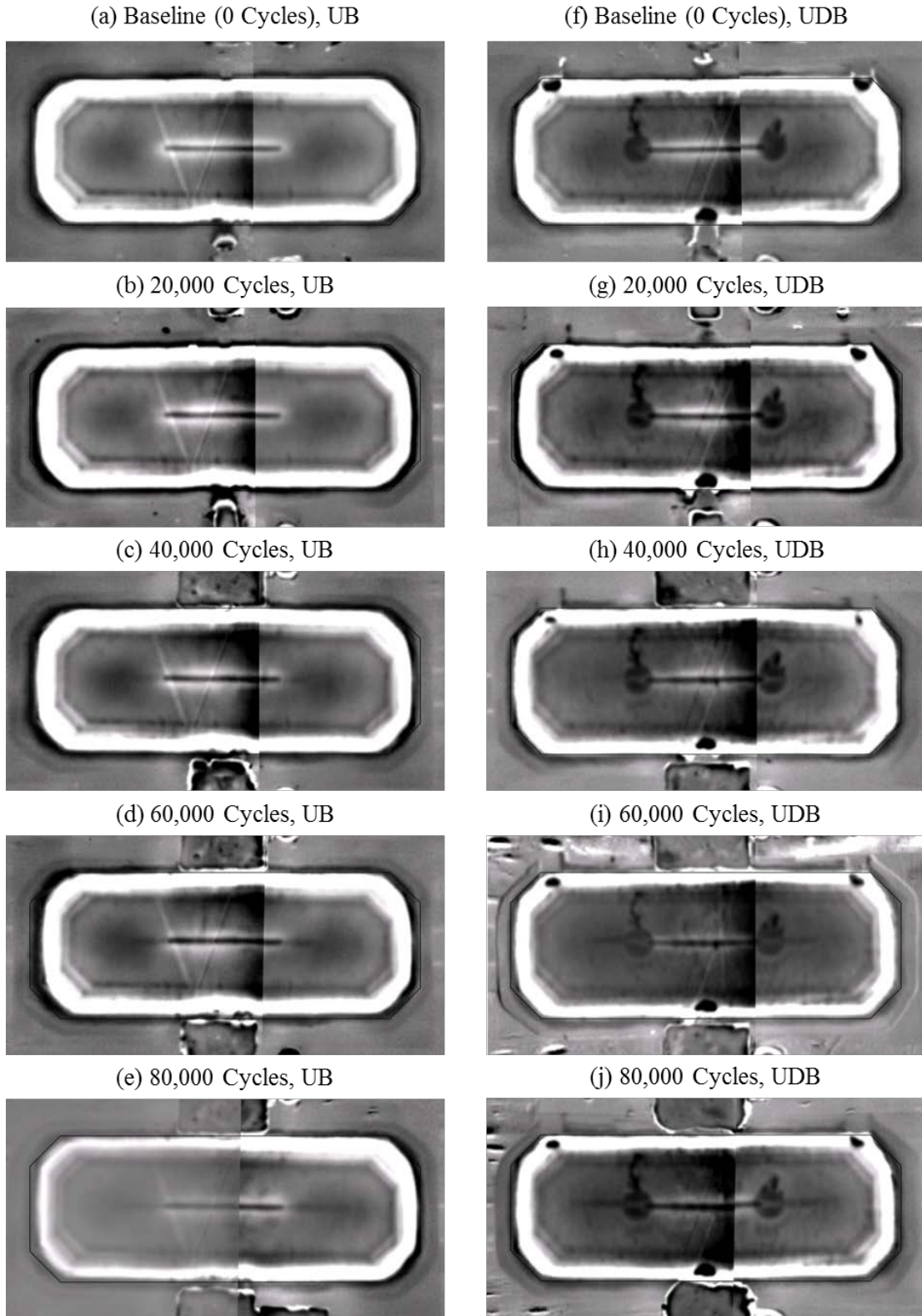


Figure 44. Flash thermography illustrating disbond inserts and crack growth up to 80,000 cycles of repair patches UB, (a) to (e); and UDB, (f) to (j)

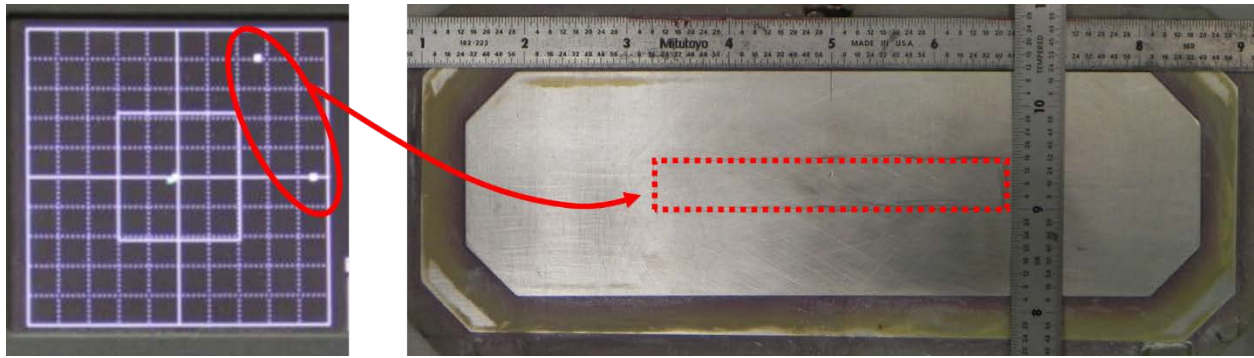


Figure 45. Detection of disbond insert using resonance ultrasonic for type-3 aluminum repair, UDA

NDI-DIC Correlations

Correlations between disbond detection and the full-field strains measured using the DIC is shown in figure 46 for the type-3 B/Ep repair, UDB. The full-field strains and strain variation across the repair measured using DIC revealed a dispersed compression region outlining the width of the disbond area at the notch region. The width of the compression region measured was 0.5 inch, which was the same as the intentional disbond insert.

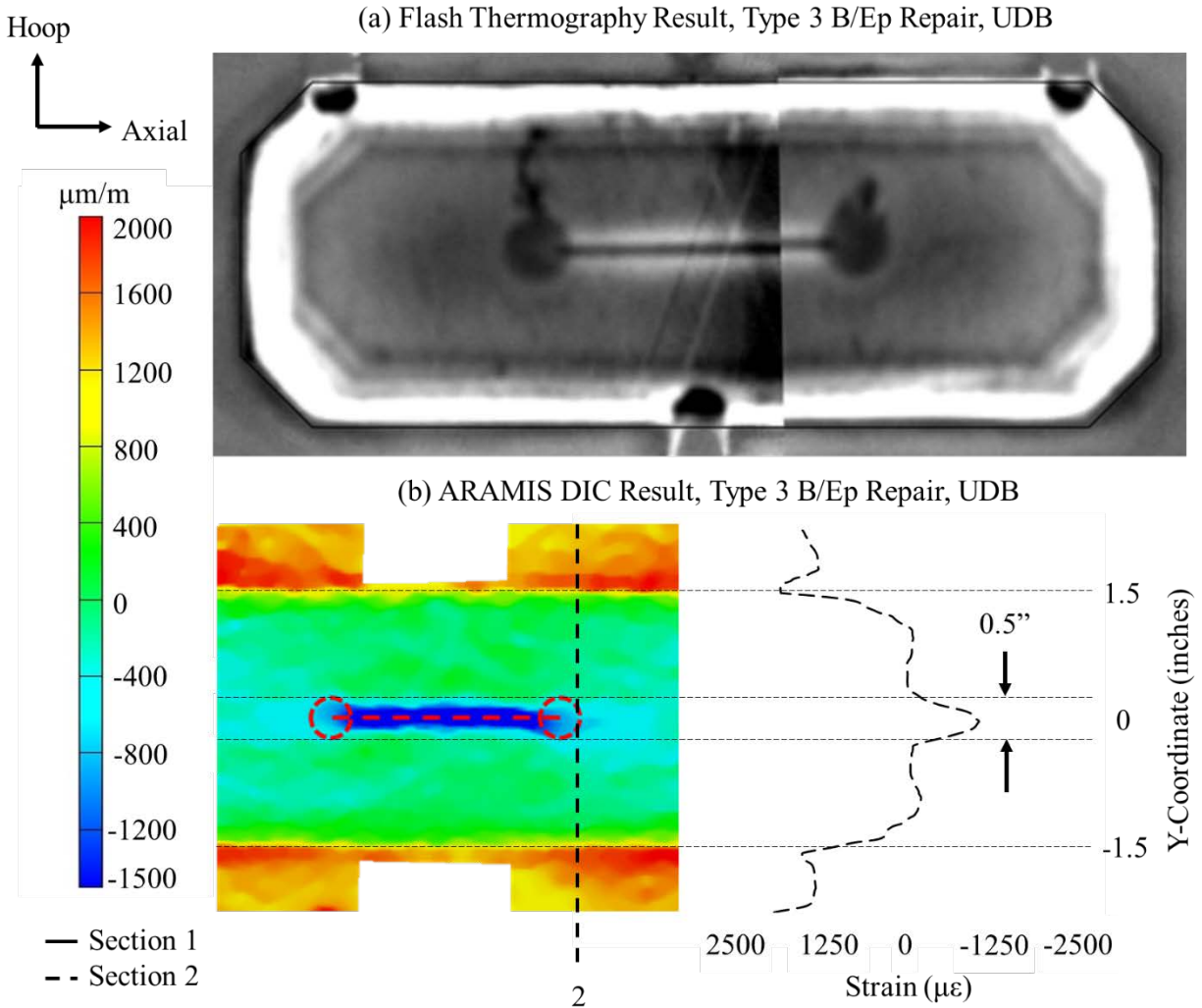


Figure 46. NDI-DIC correlation, type-3 B/Ep repair with known disbond inserts: (a) flash thermography, and (b) ARAMIS DIC

Correlations between disbond detection and the full-field strains measured using the DIC is shown in figure 47 for the type-3 aluminum repair, UDA. For this repair, a 3.5 by 0.5 inch FEP tab was inserted over the notch location to create disbond between the repair patch and the fuselage panel skin. The outline of the disbond is indicated from the resonance ultrasonic (see figure 45). The corresponding full-field strains and strain variation across the repair measured using DIC revealed a dispersed compression region outlining the width of the disbond area. The width of the compression region measured was 0.5 inch, which was the same as the intentional disbond insert. Therefore, a good correlation was found between the strain distribution and disbond indication for this repair.

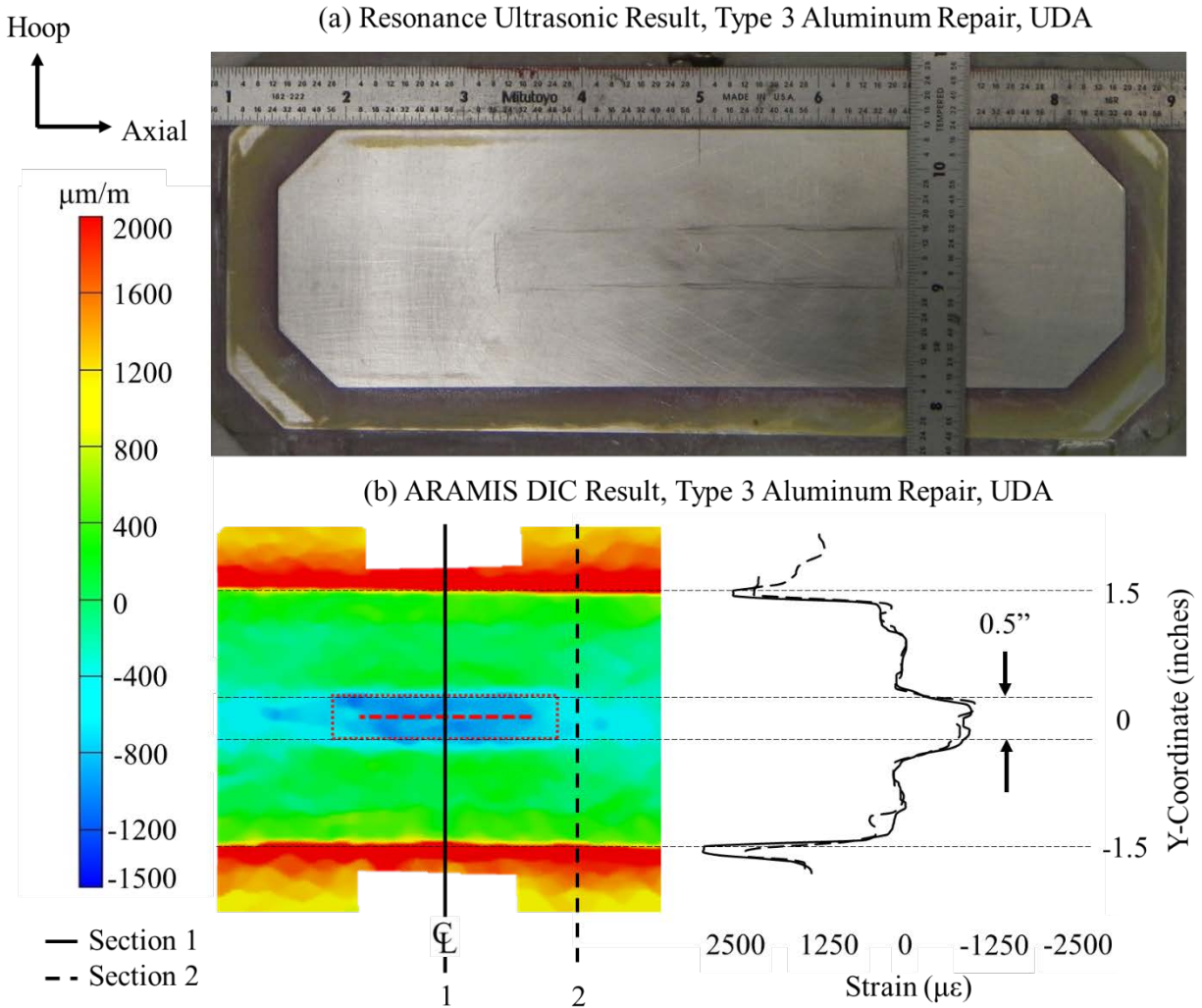


Figure 47. NDI-DIC correlation, type-3 aluminum repair with known disbond inserts: (a) resonance ultrasonic, and (b) ARAMIS DIC

4.6 DAMAGE MONITORING USING SHM

Eleven SHM data packages were collected during the 80,000 cycles of fatigue testing. The crack correlation model developed during panel 2 testing was improved and successfully applied to the panel 3 patches. Figure 48 shows the crack-growth measurements at each data interval performed by the SHM system for both the UB and UDB patch.

As shown in figure 48, crack growth was accurately predicted by the SHM system within the tolerance of conventional crack-length measuring techniques such as HFEC. Further, the correlation of SHM signals to physical damage in the host structure was shown to be accurate and reliable even when the host structure and repair patch system have undergone extreme hot/wet conditions.

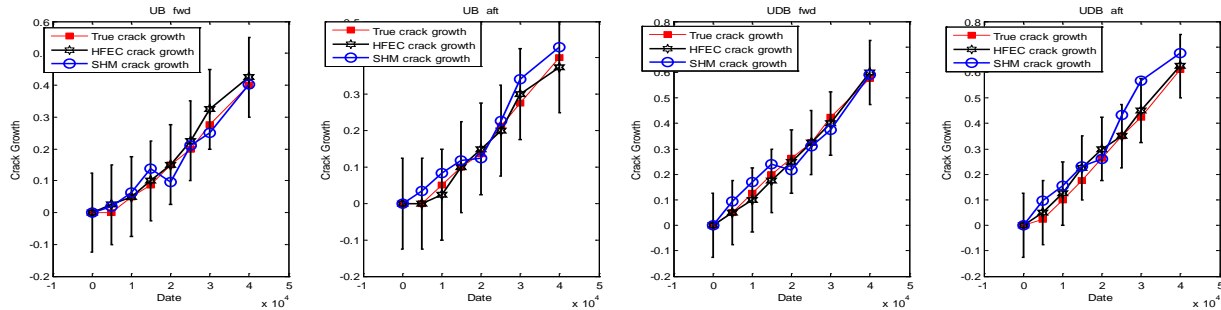


Figure 48. SHM crack-growth measurements for UB and UDB repairs

Additionally, Boeing, the FAA WJHTC, and North Carolina State University collaborated on the SHM data processing. The motivations for working together include:

1. Boeing provided data collected during the full-scale panel testing and provided engineering consultation to the FAA WJHTC to build a technical partnership in this area. Both Boeing and the FAA WJHTC benefit from this partnership for future testing efforts.
2. Survey state-of-the-art methods and techniques developed by Fuh-Gwo Yuan (NC State), a leading expert in NDI and SHM.
3. Satisfy Master's degree requirements for David Westlund (FAA WJHTC), with Fuh-Gwo Yuan acting as project advisor.

Damage indices were processed by the FAA WJHTC, including the energy damage index, the scatter energy damage index, and the correlation damage index. This computed information from raw SHM data was compared to the independent results obtained by Boeing and showed good correlation.

5. TEST AND ANALYSIS CORRELATION

The previous test-analysis correlations [6] revealed that there was a need to improve the prediction capability of the CRAS closed-form method for the thermal residual stresses in a boron patch repair because of the thermal expansion coefficient mismatch between the aluminum skin and a boron patch. For simplicity, the effect of thermal stresses was previously always estimated by using the CRAS method, whereas the effect of the mechanical loads was predicted by both CRAS and FE analysis. Therefore, a full finite element analysis of a curved panel with under-design and reference boron (UB and RB) patches under both thermal and mechanical loads was conducted in this study, and the results were compared with strain gauge data. The objectives here were: (1) to assess the prediction capabilities of the FE analyses using commercial codes, such as Nastran or ABAQUS, to accurately determine the thermal stresses in a boron patch repair and (2) to seek a remedy for CRAS closed-form method.

The under-designed and reference boron (UB and RB) patches were modeled ply by ply with solid elements. The skin underneath the patch and the rest of the curved panel were modeled by shell elements, whereas the adhesive layer was by solid elements. A 3-inch crack was introduced into the skin and the adhesive. The detailed FE model with the UB and RB patches, skin crack, and adhesive crack are shown in figures 49–51.

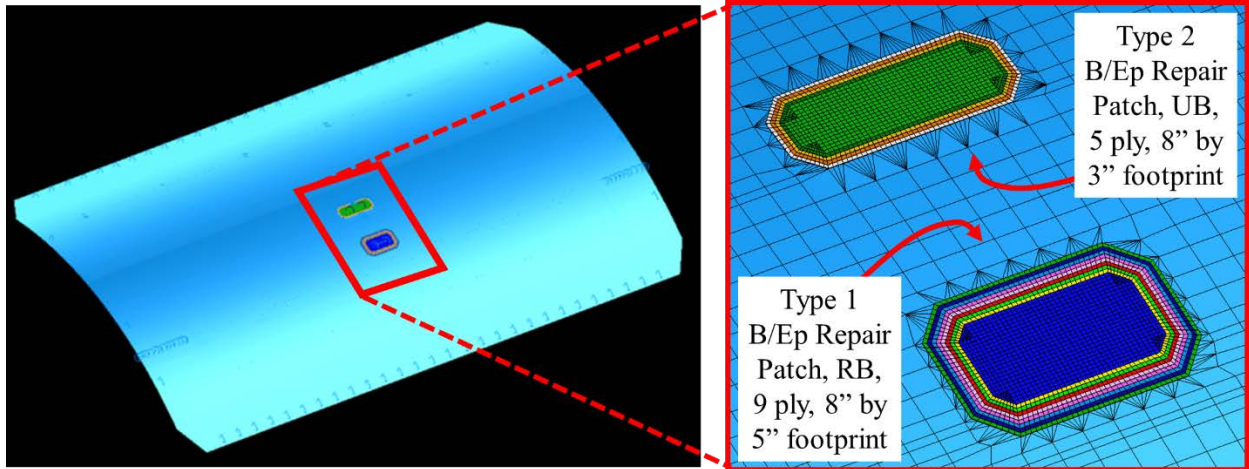


Figure 49. FE meshes for under-designed (UB) and reference B/Ep (RB) patches

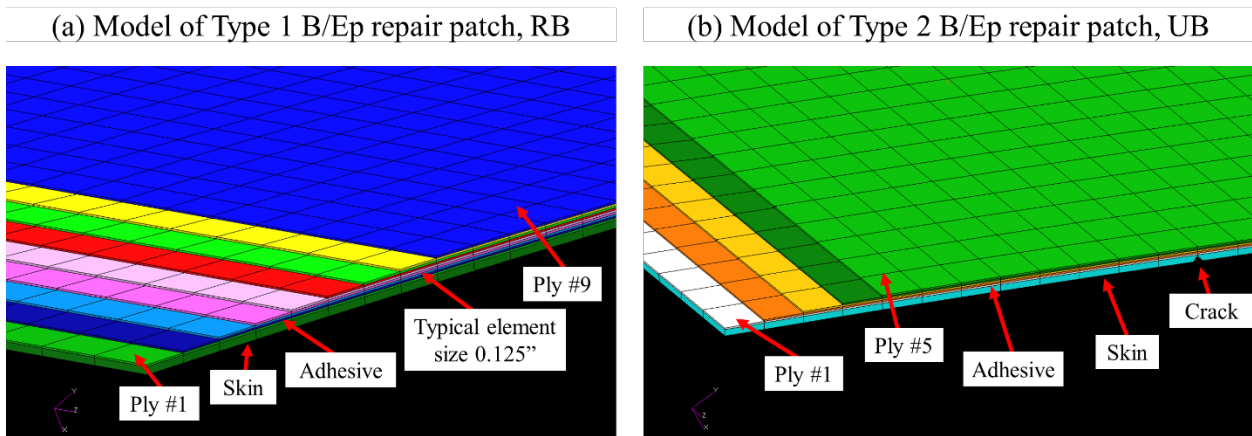


Figure 50. Detailed ply-by-ply models of B/Ep patches: (a) UB patch and (b) RB patch

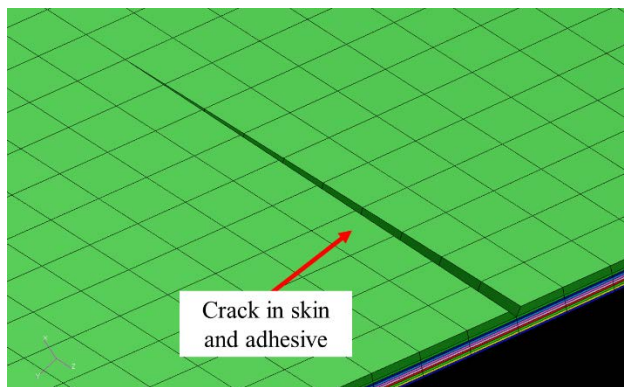


Figure 51. A view of crack in skin and adhesive

The FE analyses were geometrically nonlinear and performed using Nastran SOL 106 for three operating temperatures (e.g., room temperature, -25°F , and 165°F), each under a simultaneous applied static load at 75% of the maximum fatigue loads corresponding to a 6.75 psi pressure

loading, as conducted in the strain surveys. Figures 52–54 show the comparison between analytical predictions and test data from the strain surveys at gauges IS14, IS15, S13, S14, and S15 for the UB patch at three operating temperatures. Locations of these gauges are shown in figure 55. Good correlation was found for a room temperature case, except for gauge S14 located directly over the crack center. The discrepancy at gauge S14 might be attributed to the fact that the finite width of the crack was modeled as a line in an FE analysis. However, the correlation was fair for only a low -25°F case. Again, the comparison was worst for gauge S14. In contrast, strain predictions by the analytical method at gauges S13, S14, S15, IS14, and IS15 under a 165°F operating temperature seemed to shift uniformly upward when compared with the test results. Therefore, it appears that thermo-elastic FE analyses of a full curved panel may still not be adequate to capture the effect of thermal stresses in boron patches. Further study is needed.

Conversely, for simplicity, the effect of thermal stresses on crack growth between a thin and thick boron patch (UB versus RB) was measured qualitatively in terms of crack-opening displacements. A larger crack opening displacement would result in a larger crack growth. The ratio of the crack-opening displacements of the RB patch to the UB patch at three operating temperatures (room temperature, -25°F, and 165°F) was found to be 0.57, 0.54, and 0.6, respectively. Because the ratios for the cases of -25°F and 165°F were roughly the same as those for a room-temperature case, the FE analysis may also fail to predict the greater effect of thermal stresses in a thick boron patch on crack growth as observed from the test.

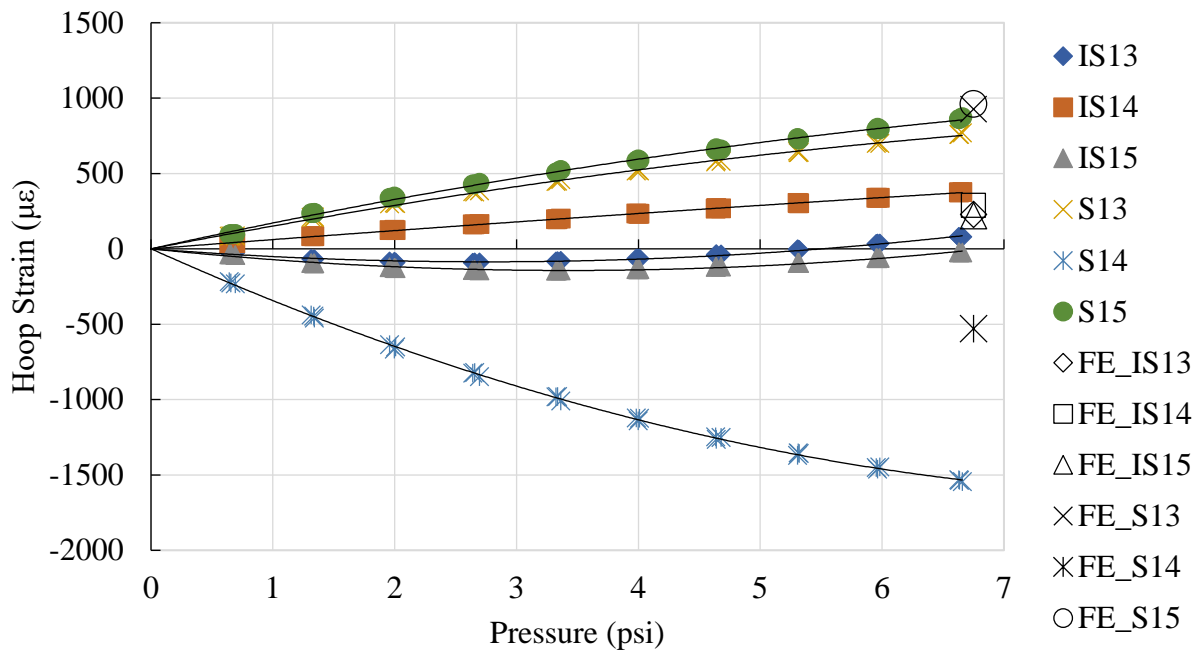


Figure 52. Comparison between FE prediction and strain gauge results for a UB patch at room temperature

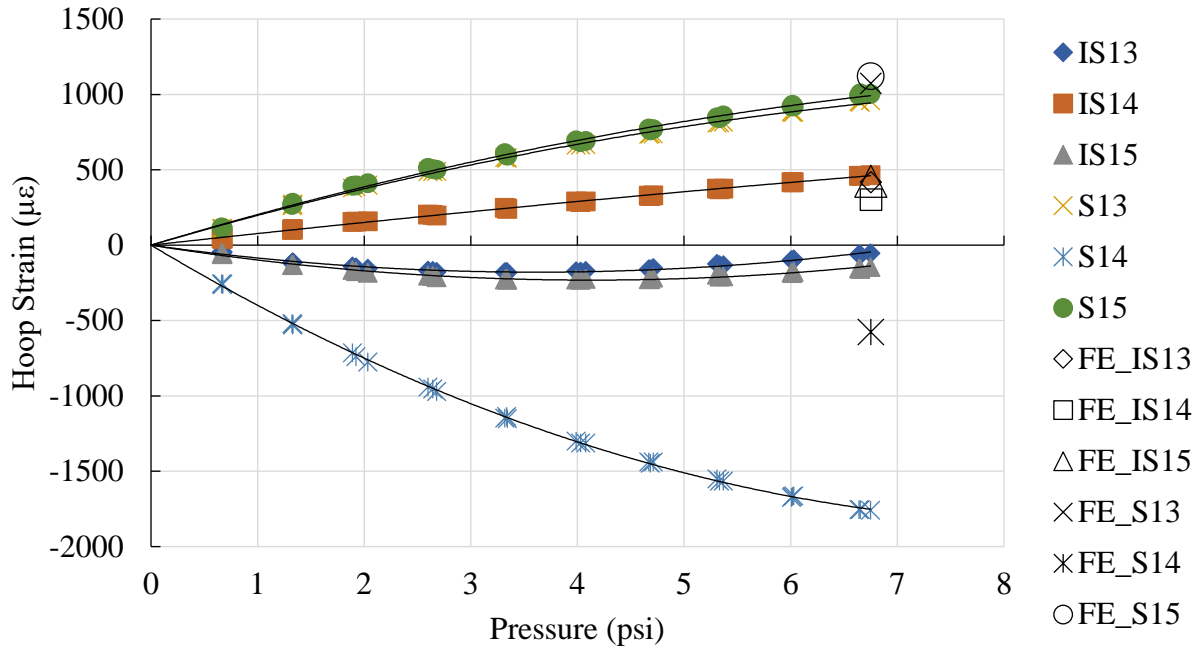


Figure 53. Comparison between FE prediction and strain gauge results for a UB patch at cold temperature of -25°F

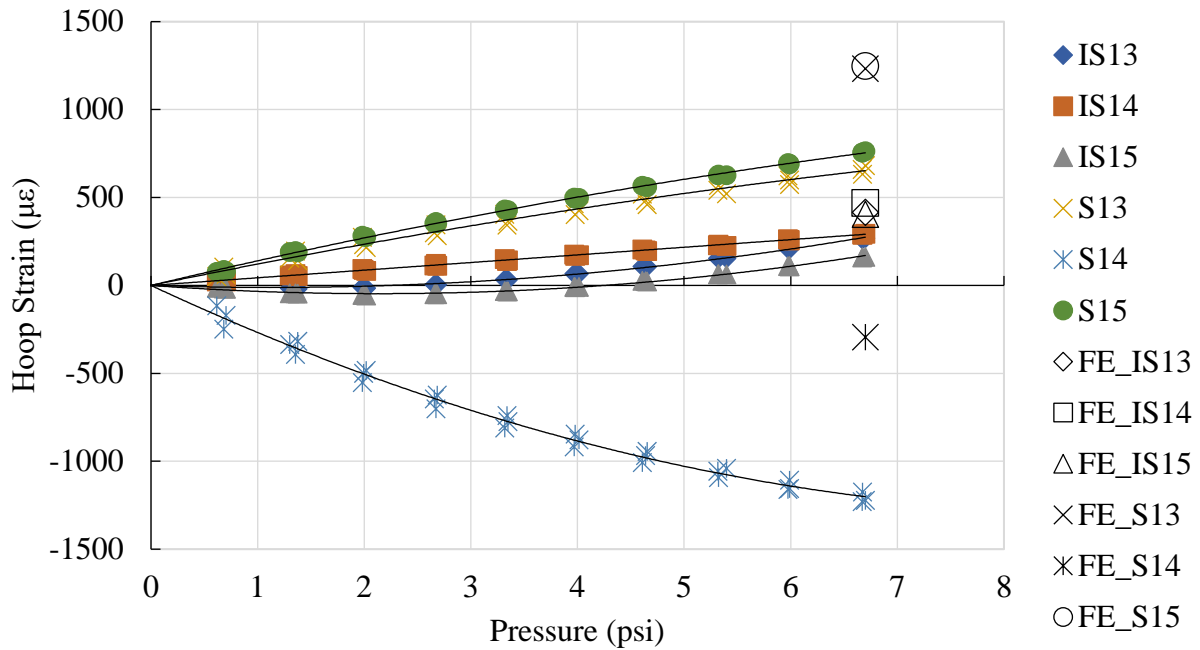


Figure 54. Comparison between FE prediction and strain gauge results for a UB patch at hot temperature of $+165^{\circ}\text{F}$

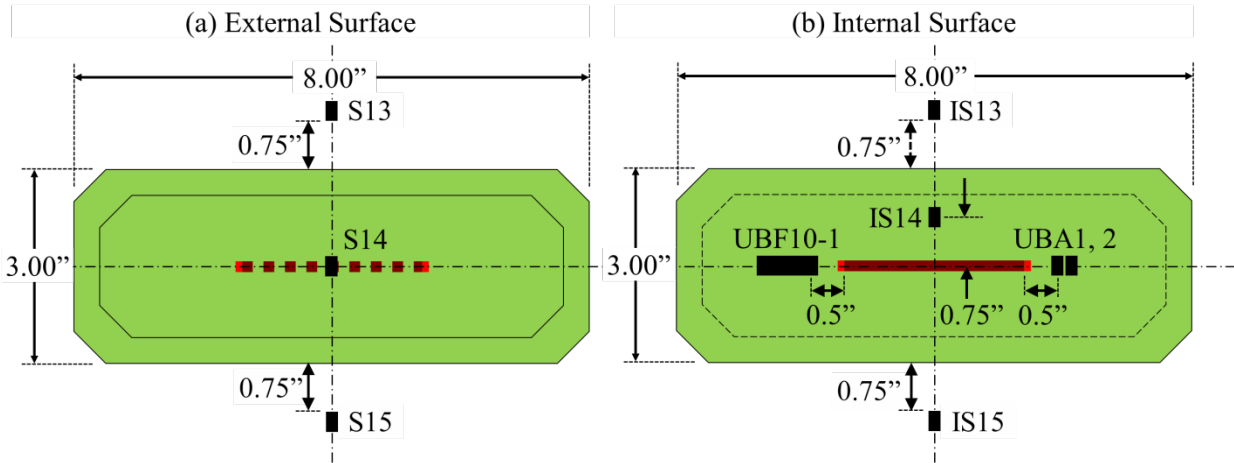


Figure 55. Locations of strain gauges used for comparison with FE predictions: (a) external surface and (b) internal surface

6. SUMMARY

In this study, the environmental effects on the fatigue performance of bonded repairs to the mid-bay cracks of the metallic fuselage panel were investigated. The goal was to collect experimental data using the various types of repairs to verify the ability of analytical tools to predict the behavior of bonded patches. Both boron-epoxy (B/EP) and aluminum patch repairs were intentionally made deficient to allow damage growth in the form of crack propagation and disbonding during fatigue cycling. Full-scale fatigue tests were performed using a Boeing 727 fuselage panel. For all phases, a digital image correlation method was used to obtain full-field displacement and strain measurements in the patch and surrounding regions. Several nondestructive inspection methods were used to monitor crack and disbond growth, including flash thermography, resonance ultrasonic, and eddy current.

In general, the representative results revealed that hot-wet environmental conditions (165°F and 85% humidity) had a limited impact on fatigue performance. Fatigue performance was reduced for the defective repairs as compared to the reference. Globally, strains remained relatively the same throughout the testing up to 80,000 cycles. Local strain redistribution occurred with crack growth. In the B/Ep composite repair patches, crack growth was slower under hot-wet conditions than in the ambient conditions. Mismatches in the coefficient of thermal expansion of the composite patch and aluminum fuselage panel skin resulted in the development of tensile residual stresses ahead of the notch during the initial patch-installation curing process. At elevated temperatures, these tensile residual stresses were relaxed, resulting in slower crack growth. On the contrary, tensile residual stress increased under cold-dry conditions, resulting in faster crack growth. Results for the aluminum repairs indicated that environment had a limited effect on the fatigue crack growth under hot-wet or cold conditions. With both the repair and the fuselage skin being aluminum, residual strains due to thermal mismatch do not occur. Data from this program will be used to assess tools and methods for evaluating and monitoring the repair integrity over the life of the part.

7. REFERENCES

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2. Bakuckas, J. G., McIver, K., and Hsu, C. (2009). *Durability and Damage Tolerance of Bonded Repairs to Metallic Fuselage Structure*. Proceedings from the 25th ICAF Symposium, Rotterdam, Netherlands.
3. Chadha, R., Bakuckas, J.G., Won, I., Westerman, E.A, Keller, R., McIver, K., Hsu, C., Awerbuch, J., and Tan, T. (2010). *Characterization of Adhesive-Bonded Repairs to Fuselage Structure*. Proceedings from the 2010 Aircraft Airworthiness & Sustainment Conference, Austin, TX.
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6. FAA Report. (2015). Adhesively Bonded Repairs to Metallic Fuselage Structure: Test 2 Monitoring Damage Growth. (DOT/FAA/TC-15/3).
7. FAA Report. (2013). Adhesively Bonded Repairs to Metallic Fuselage Structure: Test 1, Fatigue and Residual Strength Performance. (DOT/FAA/AR-11/4).

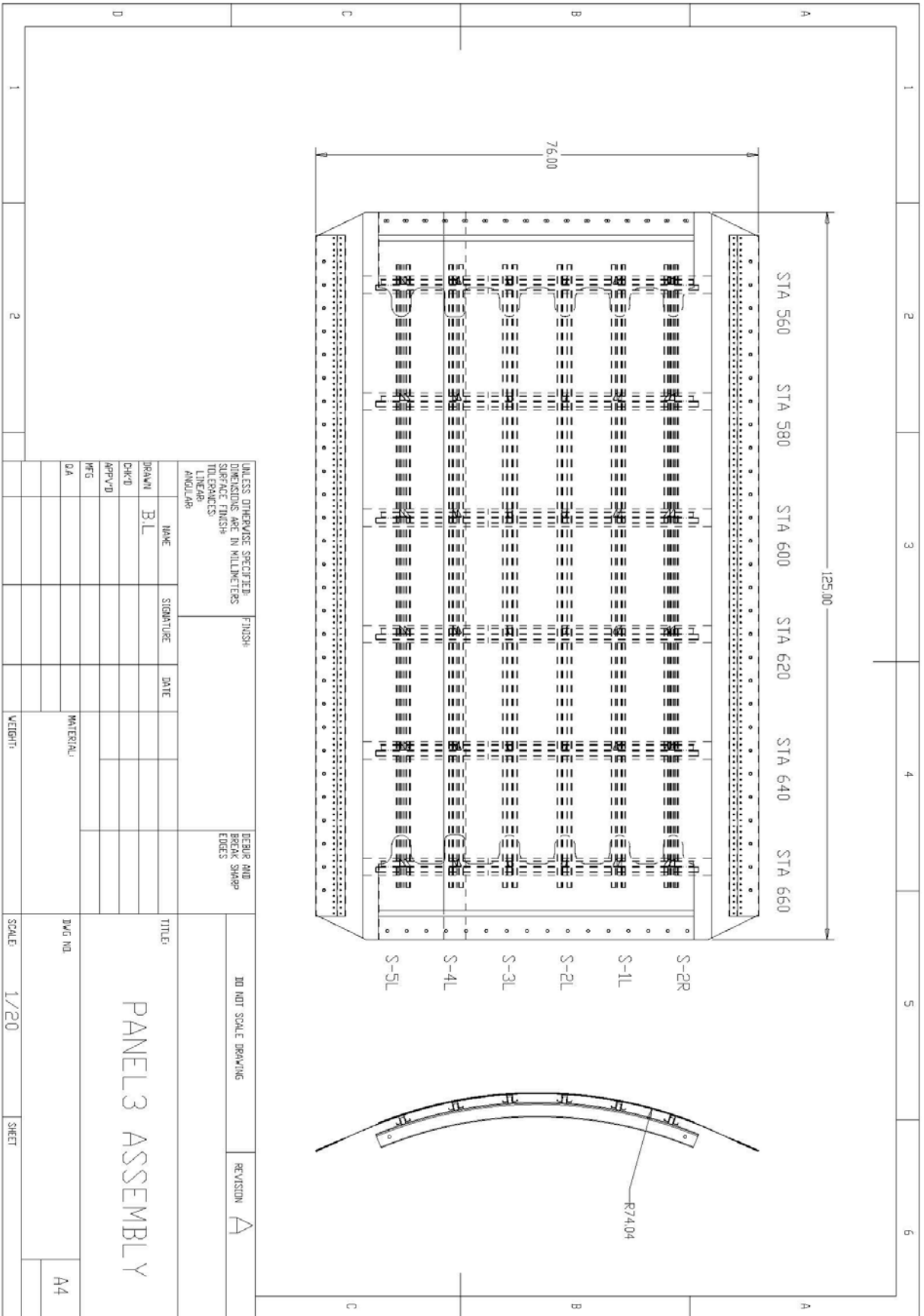
APPENDIX A—PANEL ENGINEERING DRAWINGS

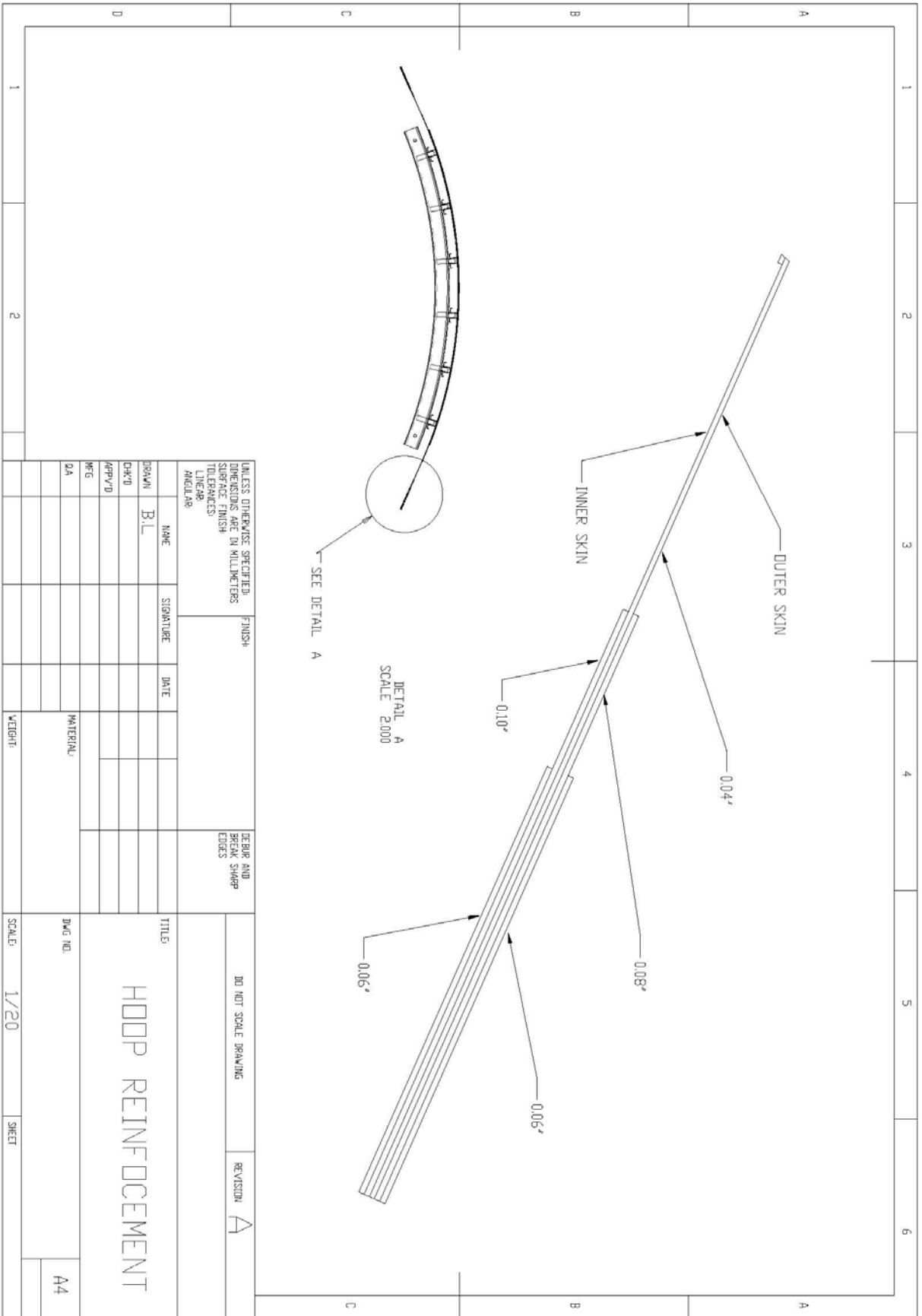
Detailed engineering drawings for the panel tested are included in the appendix. The selected panel configurations represent a generic fuselage structure from a retired passenger service airplane, specifically a Boeing 727-225 with serial number 22553, and registration tail number N675MG. While the airplane was in service, it accumulated 29,821 flight cycles and 48,579 flight hours. The airplane was owned and operated by Champion Air Lines, was well-maintained and stored, and had a well-documented and accessible service history.

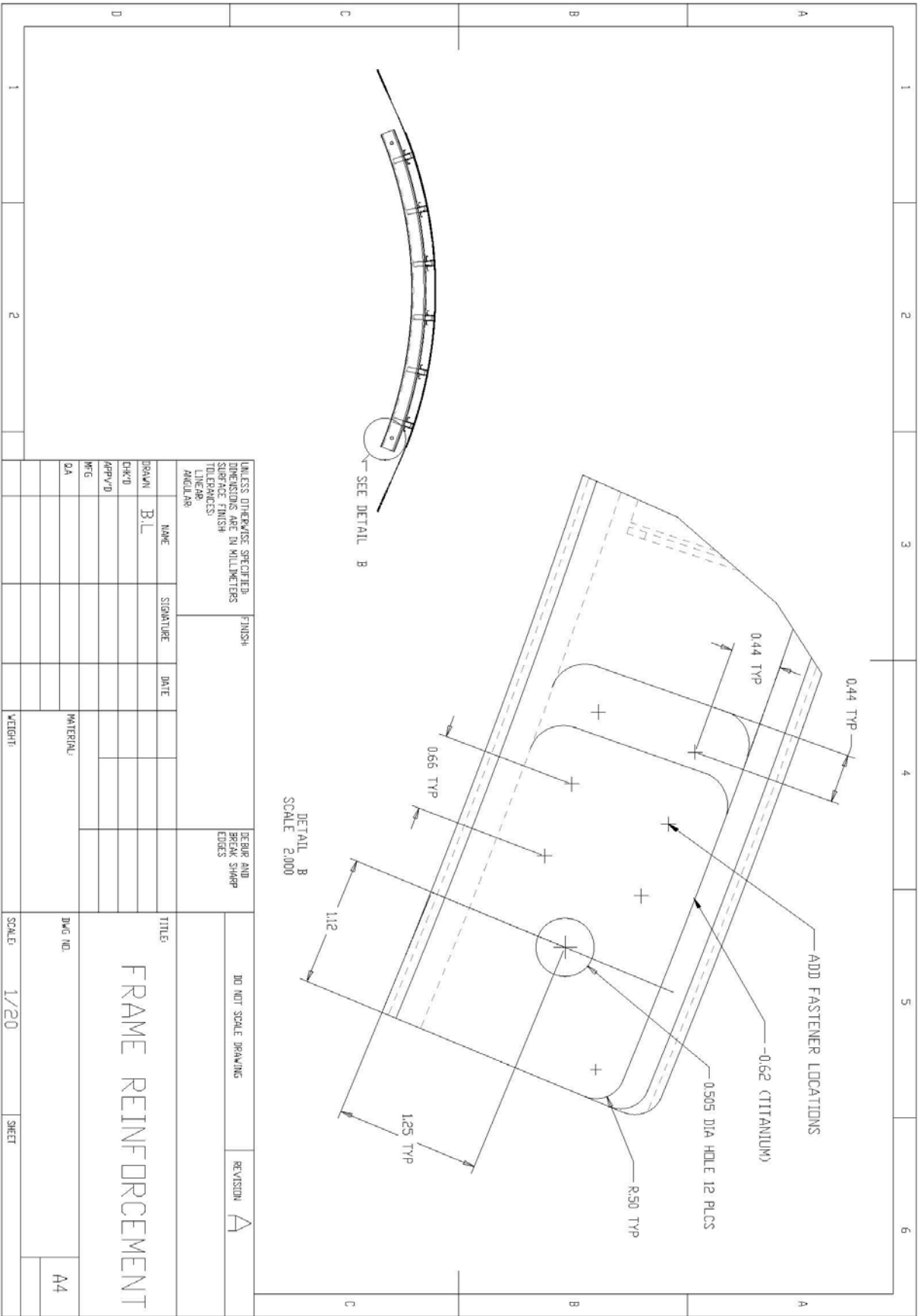
The panel was removed from the crown of the airplane having dimensions of 125 by 73 inches and a radius of 74 inches. The substructure included six stringers (S), S-2R to S-5L, in the longitudinal direction with 9.5-inch spacing; and six frame stations (FS), STA560 to STA660, in the hoop direction with 20-inch spacing. The Z-shaped frames, stringer clips, and hat-shaped stringers are made from 7075-T6 aluminum.

The panel skin was 2024-T3 aluminum with a thickness 0.04 inch at all bays. A longitudinal lap joint was located along stringer S-4L, which were connected together by three rows of rivets. The doubler was bonded to the outer skin, and there was a sealant between the doubler and the inner skin of the lap joint.

The panel was reinforced along the four edges with aluminum doublers. In both longitudinal doublers, 28 0.5-inch-diameter holes were inserted, spaced 4 inches apart. In both hoop doublers, 16 0.5-inch-diameter holes were inserted, spaced 3.5 inches apart. These holes were used to attach the edges of the panel to the loading mechanisms of the Full-Scale Aircraft Structural Test, Evaluation and Research (FASTER) fixture, which has seven hoop loaders on each side and four longitudinal loaders on both ends. Each actuator is attached to the panel at four holes using a whiffle tree assembly. The two ends of each frame, where the frame load is applied, were also reinforced with aluminum doublers. An elastomeric seal was bonded along the perimeter of the inner surface of the curved panel to attach to the pressure box of the FASTER fixture.



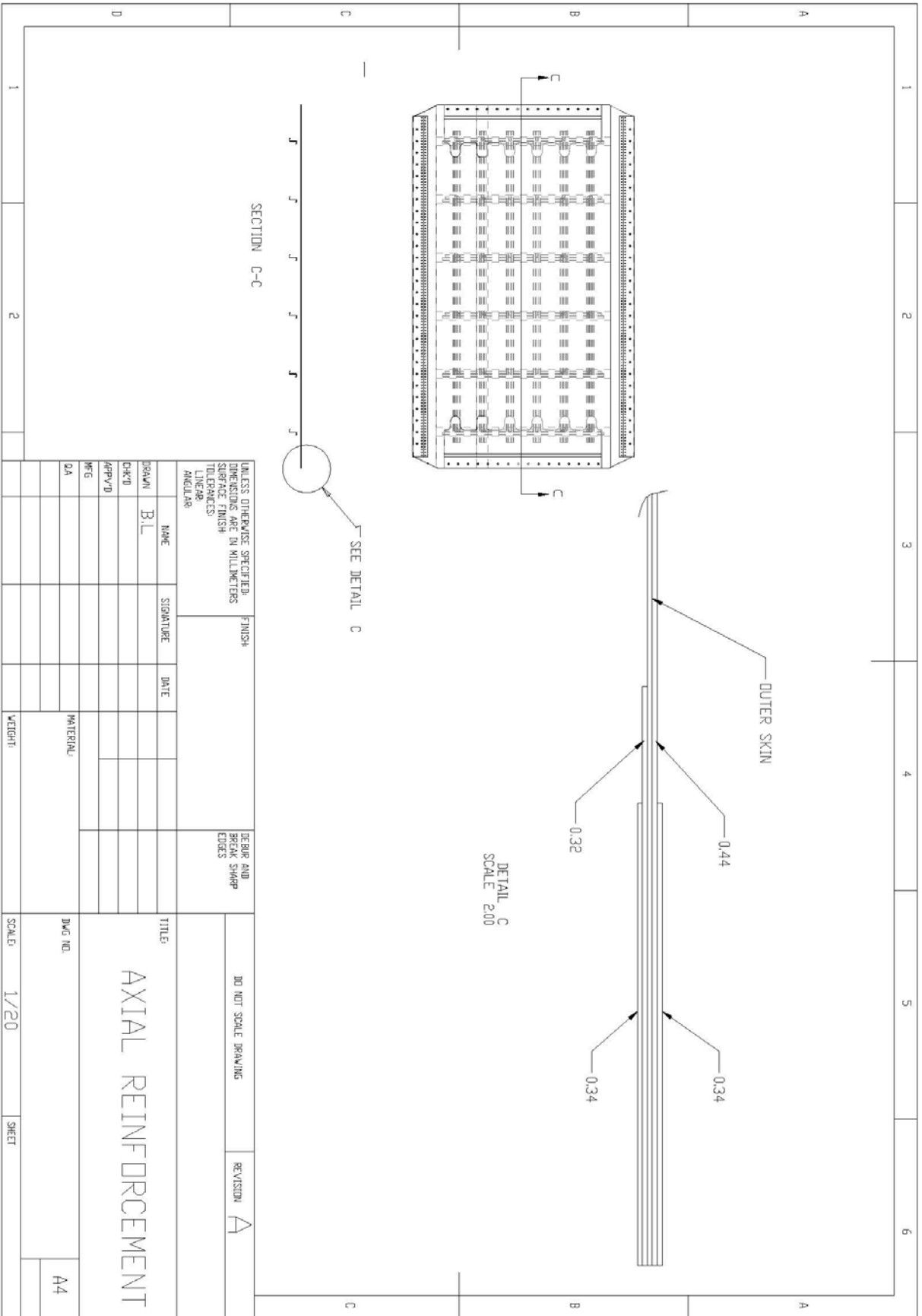


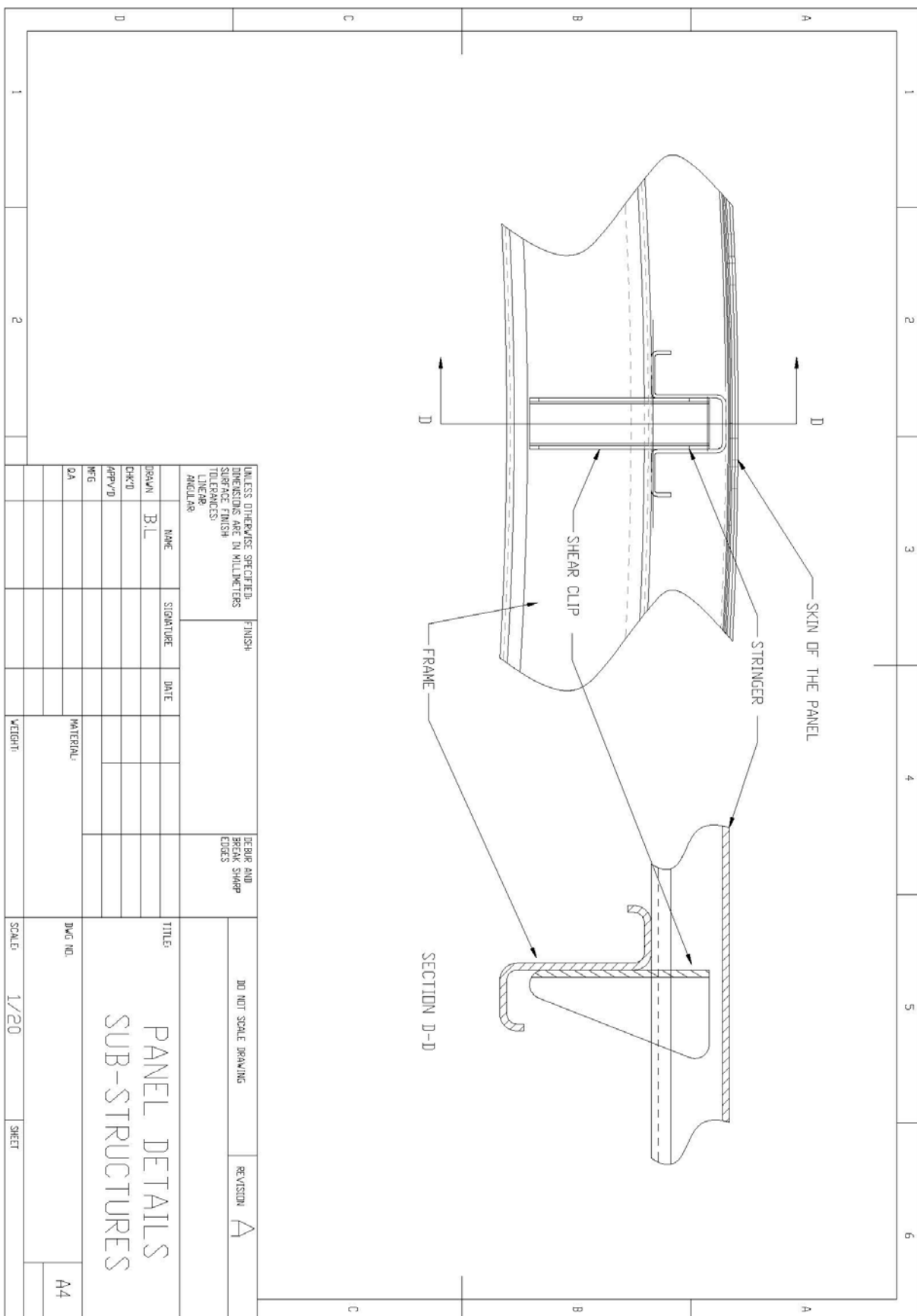


DETAIL B
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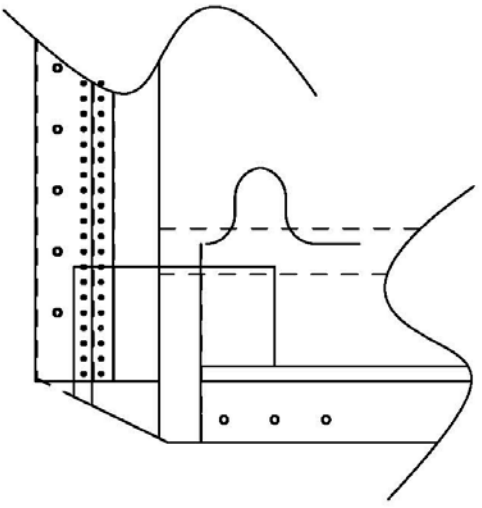
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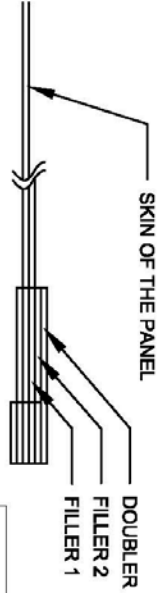




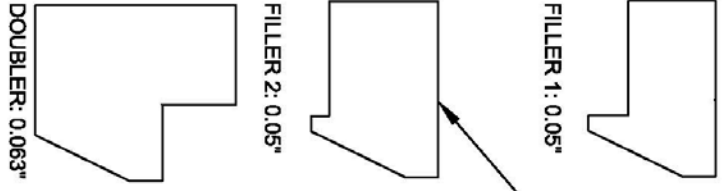
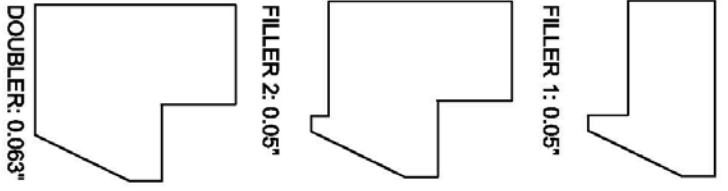
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TOP VIEW



FRONT VIEW



SMALLER DUE TO LAP JOINT

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APPENDIX B—RATIONALE BEHIND REPAIR TYPES

Several types of boron/epoxy (B/Ep) composite and aluminum-bonded repairs were considered in this study and are categorized as type 1 (reference repairs), type 2 (under-designed), type 3 (under-designed and partial disbond), and type 4 (hand sanded), as summarized in table B-1. Note that type 1–3 repairs are identical to those used in the previous second panel test [5, 7]. These repair configurations were retained in this study for comparison purposes to assess the effects of hot-wet environmental conditions (165°F and 85% humidity) on repair performance. For the four types of patches, the rationale behind repair types is described below.

Type-2, Under-Designed Repairs

A good design B/Ep patch was considered as the basis for under-designing the repairs. To achieve the under-designed B/Ep repair configuration, the following procedure was followed:

1. Determine stresses at the prospective crack location using global finite element analysis.
2. The stresses at the prospective crack location were used in the Composite Repair of Aircraft Structure (CRAS) software developed by The Boeing Company under U.S. Air Force funding to develop the reference patch sizing.
3. The under-designed patch was designed by reducing the number of plies from nine to five and the maximum width of the B/Ep patch from 5 inches to 3 inches (hoop direction), and reducing the number of doublers of the aluminum patch from three to two layers. Details of repair patch configurations and dimensions are shown in table B-1.

Type-3, Partial Disbond Repairs

The type-3 repairs had the same configuration as the type-1 B/Ep patch and aluminum patch. To further reduce the effectiveness of the repair patches, intentional partial disbonds were introduced on the repairs at the patch edges and crack tips. The disbonds were located between the patches and the aluminum skin. The disbonds were typically of two types—one at the crack tip and one at the patch boundary. Details of repair patch configurations and dimensions are shown in table B-1.

1. Crack-tip disbonds: The rationale behind the crack disbonds was based on a literature survey and CRAS predictions. According to the literature, disbonds at the crack tips have a negligible effect on crack growth. However, in these studies, the crack tip was stop-drilled and the disbond does not fully cover the crack length. Furthermore, CRAS predictions showed that, for the case in which the disbond surrounds the whole crack length, the stress intensity factor at the crack tips can increase by 10–20% compared to the repair patch without any disbond surrounding the crack. For the aluminum patch, the disbond was 3.5 by 0.5 inch surrounding the crack; however, circular disbonds of 0.5 inch in diameter were located only at the two tips of the crack for the B/Ep patch. This was to avoid any unpredictable results due to the under-estimation of residual thermal stresses in the case of the B/EP repair patch.
2. Patch edge disbonds: Patch edge disbond locations were decided based on the literature survey, which showed that the edge disbonds can cause a total delamination of the substrate because of the high load transfer between the skin and the patch. The disbonds were

introduced at the patch corner as the load transfer is highest at this region. The disbond in the middle of the patch was introduced because, when the disbond grows it may link up with the disbond around the crack.

Type-4, Hand-Sanded Repair

The type 1–3 repairs were prepared using a grit blast surface preparation procedure, which provide a uniform surface roughness. Hand sanding is the preferred surface-preparation method in the field. The purpose of adding the hand-sanded repair was to extend the test perimeter and observe if the hand-sanded repairs showed any degradation in repair durability performance. Using CRAS, the configuration of repair patches designed for a 3-inch-long through-thickness crack on a 0.04-inch skin is summarized in table B-1.

Table B-1. Repair patches configurations

Types	Name	Ply layup	Dimensions and fiber directions (L x W, θ)	Thickness	Stiffness ratio
1	RB	9 plies [20°/-20°/20°/- 20°/0°/-20°/20°/- 20°/20°]	Ply 1: 8.00 x 5.00 in., 20° Ply 2: 7.75 x 4.75 in., -20° Ply 3: 7.50 x 4.50 in., 20° Ply 4: 7.25 x 4.25 in., -20° Ply 5: 7.00 x 4.00 in., 0° Ply 6: 6.75 x 3.75 in., -20° Ply 7: 6.50 x 3.50 in., 20° Ply 8: 6.25 x 3.25 in., -20° Ply 9: 6.00 x 3.00 in., 20°	0.051 in.	1.9
2	UB	5 plies [20°/-20°/0°/- 20°/20°]	Ply 1: 8.00 x 3.00 in., 20° Ply 2: 7.75 x 2.75 in., -20° Ply 3: 7.50 x 2.50 in., 0° Ply 4: 7.25 x 2.25 in., -20° Ply 5: 7.00 x 2.00 in., 20°	0.029 in.	1.16
3	UDB	5 plies [20°/-20°/0°/- 20°/20°]	Ply 1: 8.00 x 3.00 in., 20° Ply 2: 7.75 x 2.75 in., -20° Ply 3: 7.50 x 2.50 in., 0° Ply 4: 7.25 x 2.25 in., -20° Ply 5: 7.00 x 2.00 in., 20°	0.029 in.	1.16
1	RA	3 layers of doublers	Sheet 1: 8.00 x 3.00 in. Sheet 2: 7.40 x 2.40 in. Sheet 3: 6.80 x 1.80 in.	0.06 in.	1.5
2	UA	2 layers of doublers	Sheet 1: 8.00 x 3.00 in. Sheet 2: 7.20 x 2.20 in.	0.04 in.	1
3	UDA	2 layers of doublers	Sheet 1: 8.00 x 3.00 in. Sheet 2: 7.20 x 2.20 in.	0.04 in.	1
4	HS	2 layers of doublers	Sheet 1: 8.00 x 3.00 in. Sheet 2: 7.20 x 2.20 in.	0.04 in.	1

APPENDIX C—STRAIN GAUGE LOCATIONS

The panel was instrumented with approximately 200 strain gauges to monitor strains throughout the test. Strains were monitored at various locations. Strain gauges were placed on the fuselage panel skin, repair patches, and the substructures of the panel to monitor the strain distribution and ensure proper load introduction. The details of the strain gauges used are provided in the tables and figures within this appendix.

Strain gauges used throughout the test were 350 ohms with a Constantan[®] foil alloy (see figure C-1). A three-conductor, Teflon[®]-coated twisted cable was used for the connection to the strain gauges. The strain gauge, coating, cable, and adhesive types for each panel are listed in table C-1. The strain gauges installed on the outer surface of the panel were exposed to controlled temperature and humidity profiles. To avoid ingress of humidity in the gauges, these gauges were covered using Teflon tapes and were sealed with B-1/2 sealant.

To ensure loads were transferred properly within the panel, strain gauges for the substructures were installed in the beginning of the testing, irrespective of the test phases. A total of seven strain gauges were installed at the flange of the stringers, and 8 strain gauges were installed at the outer and inner flange of the frames. The locations of these strain gauges are shown in figures C-2 and C-3. These strain gauges were removed at the later stage of the test because of the limitation of channels.

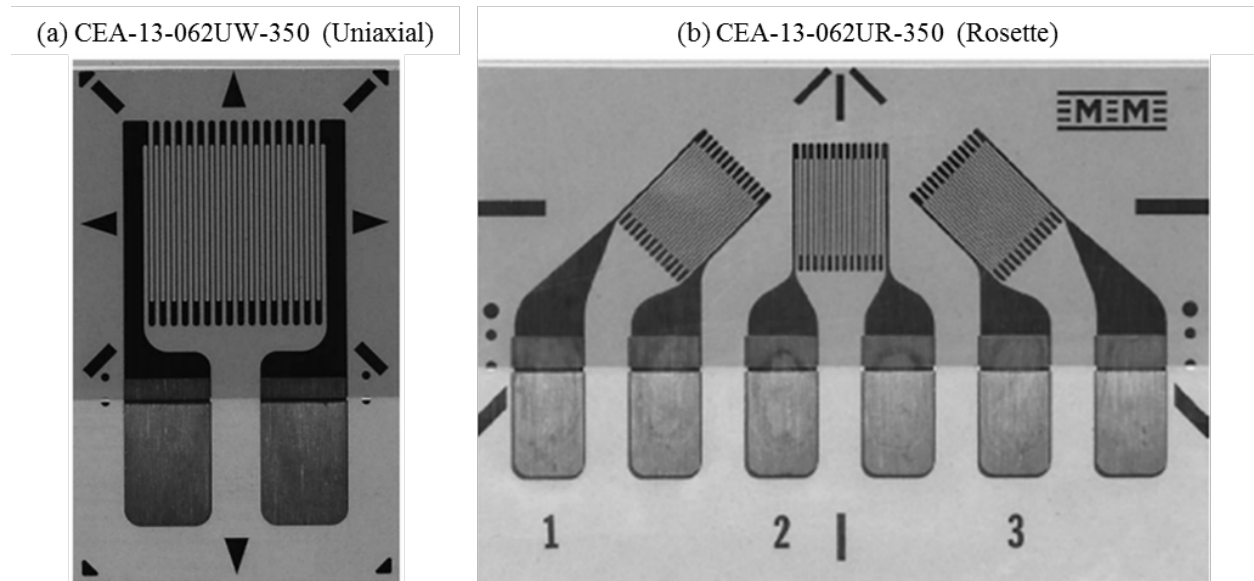


Figure C-1. Strain gauge used throughout the test (a) uniaxial, (b) rosette

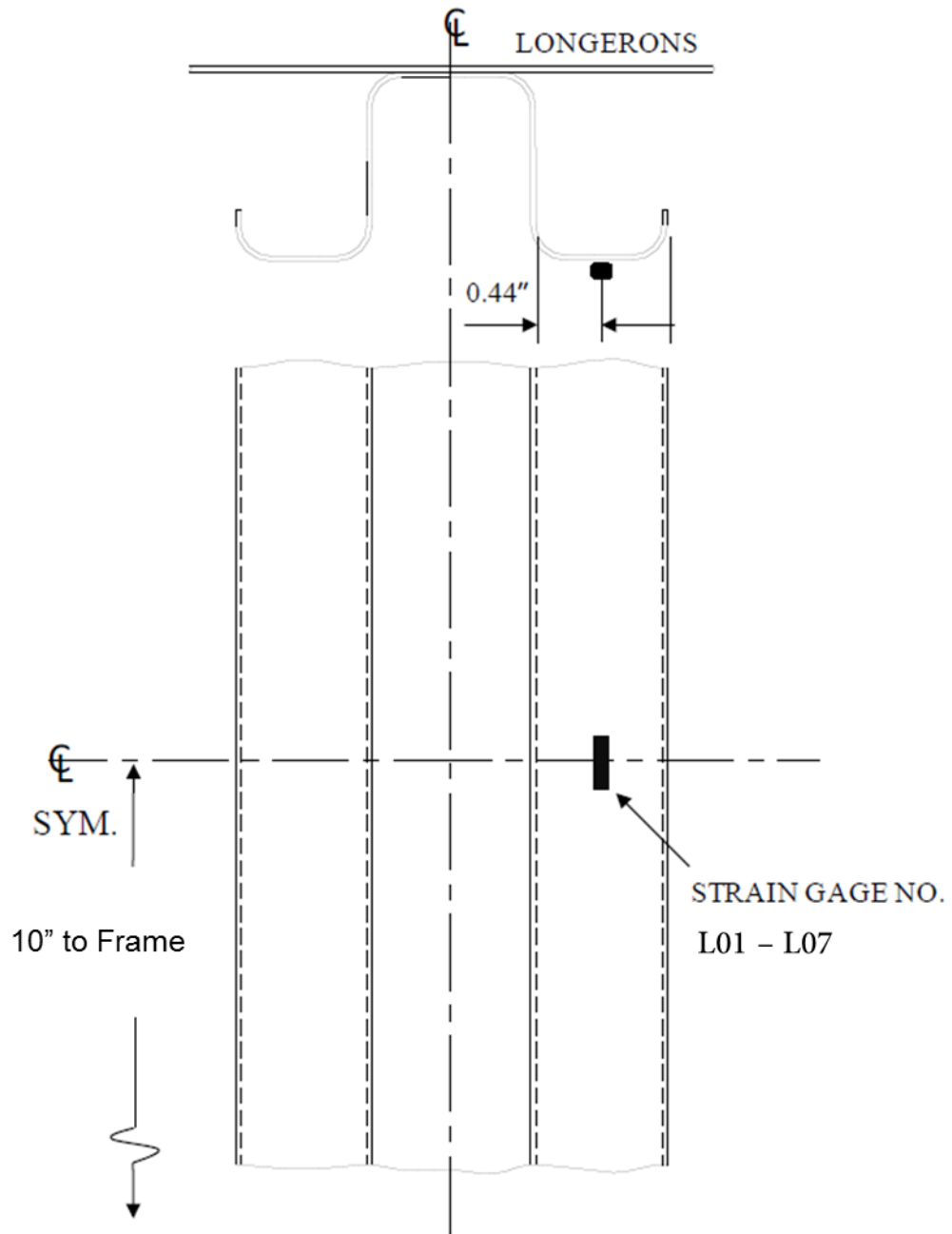


Figure C-2. Schematic of axial strain gauges at the lower cap of the stringers

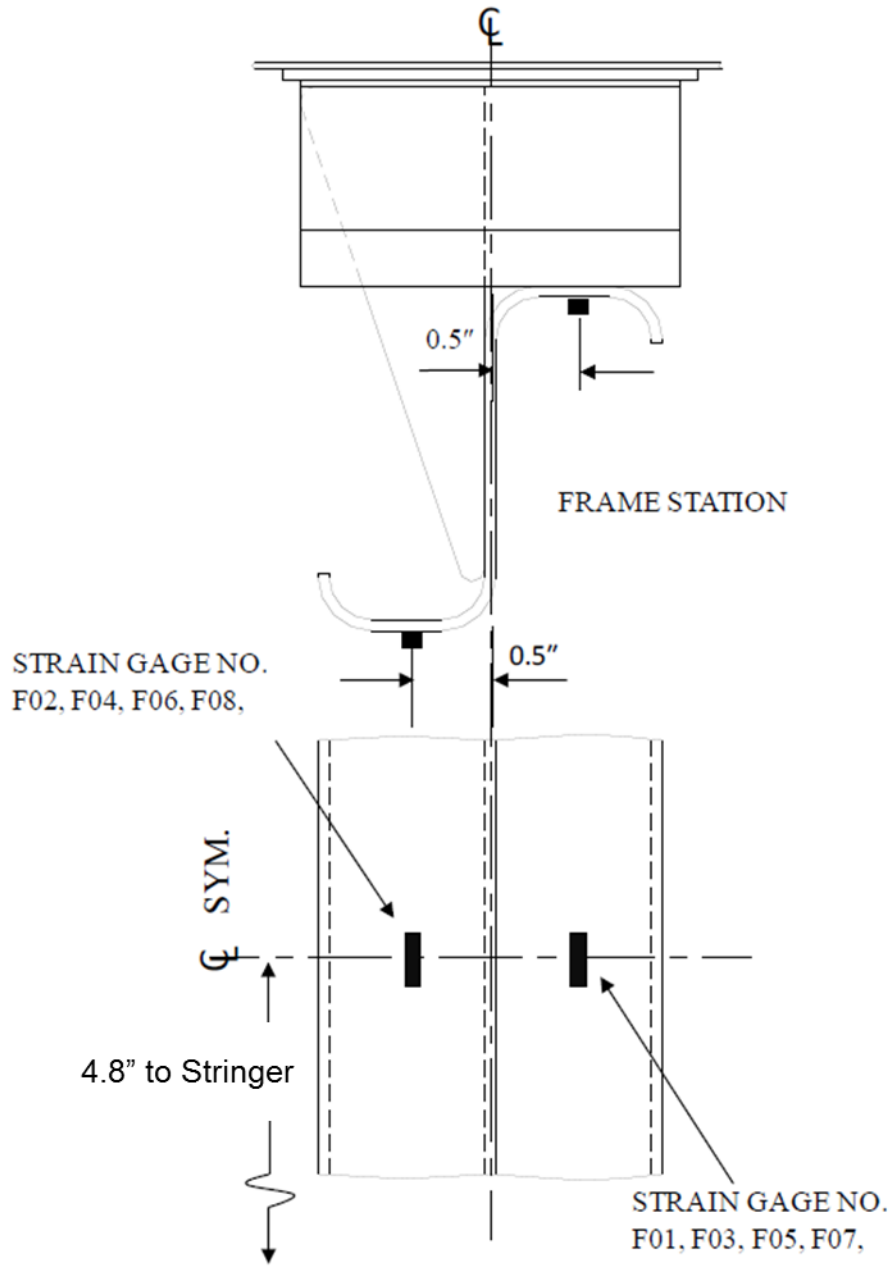


Figure C-3. Schematic of the axial strain gauges at the inner and outer cap of frames

Table C-1. General strain gauge information

	Pristine Panel	Phase I Hot-Wet	Phase II Cold-Dry
Vishay Micro-Measurement Part No., Axial	CEA-13-062UW-350		
Vishay Micro-Measurement Part No., Rosette	CEA-13-062UR-350		
Vishay Micro-Measurement Part No., Coatings	M-Coat A		
Vishay Micro-Measurement Part No., Cable	330-FTE		
Vishay Micro-Measurement Part No., Adhesive	M-Bond 200/AE-10		

To collect the baseline strain data, the strain gauges were also installed on the fuselage skin before any damage to the panel was introduced. The locations of strain gauges on the pristine panel and substructures are shown in figures C-4 and C-5, respectively.

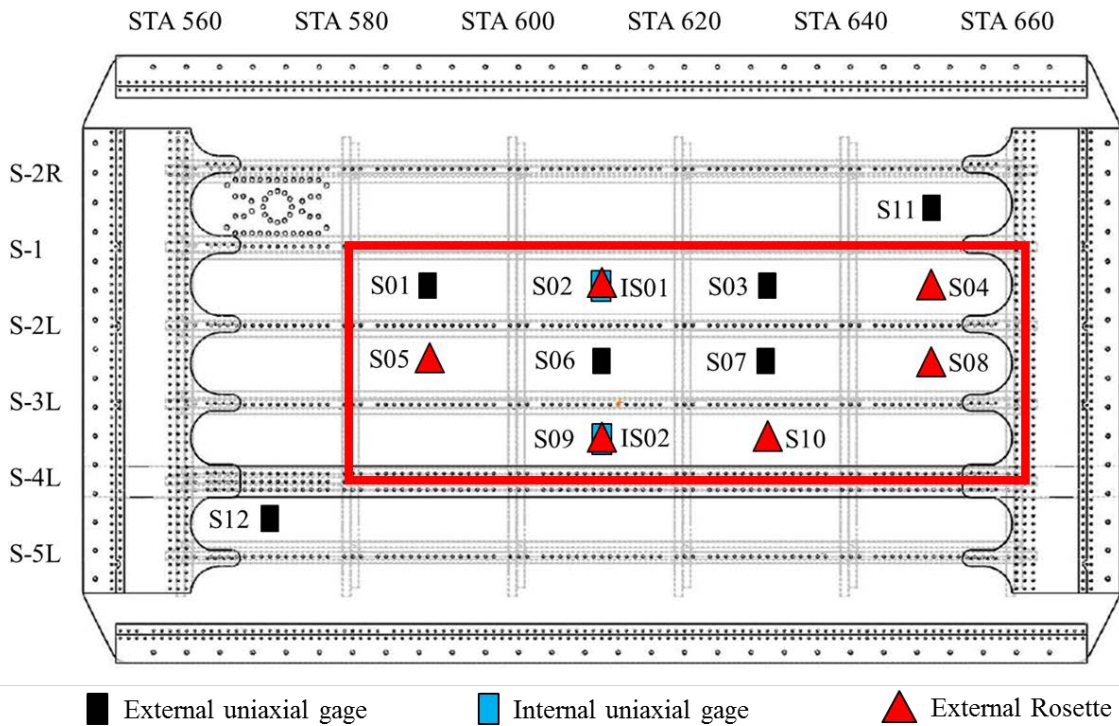


Figure C-4. Strain gauge locations for pristine panel

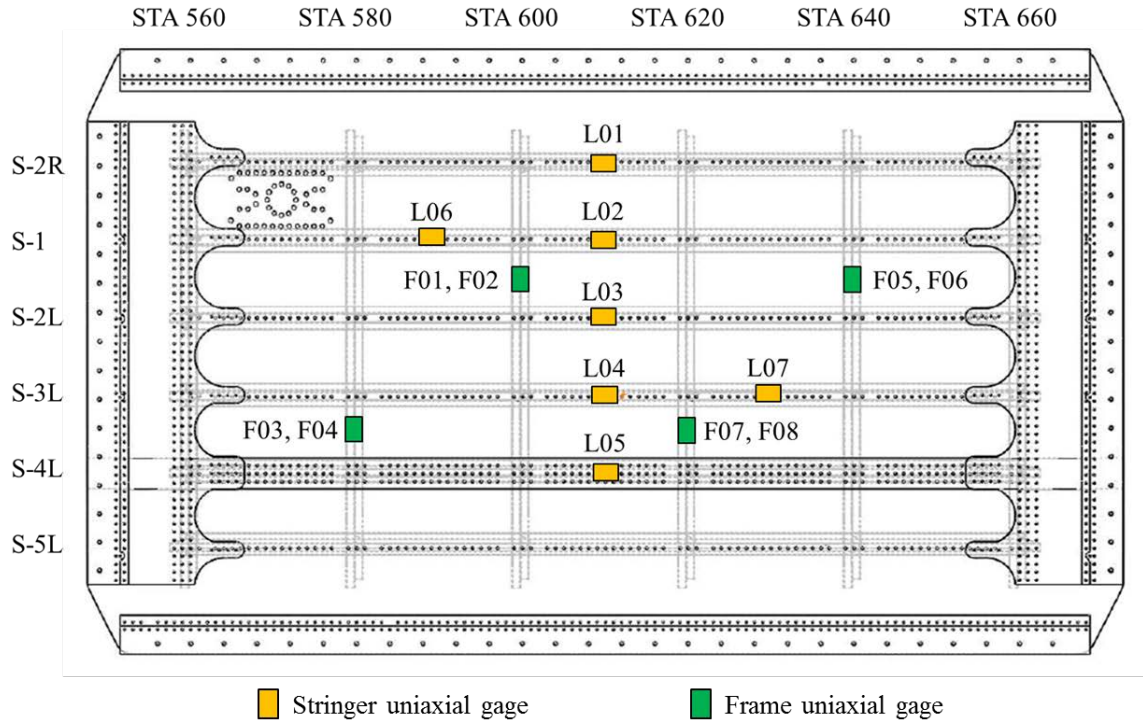


Figure C-5. Strain gauge locations for substructures

Twelve repair patches were installed throughout the test. For each repair patch, strain gauges were installed along the patch boundaries on the inner and outer skin surfaces, at the patch outer surface, and along the notch tip. Typically, each repair patch includes eight strain gauges, as shown in figure C-6. Locations of repair patches and their strain gauges are provided in figures C-7 and C-8.

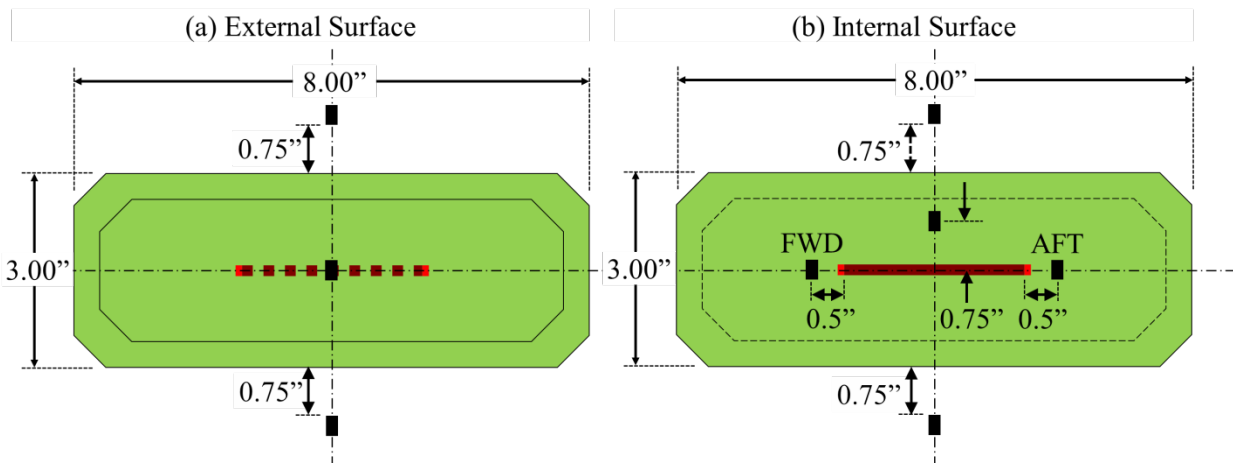


Figure C-6. Typical strain gauge layout in the vicinity of each repair patch: (a) external panel surface, and (b) internal panel surface

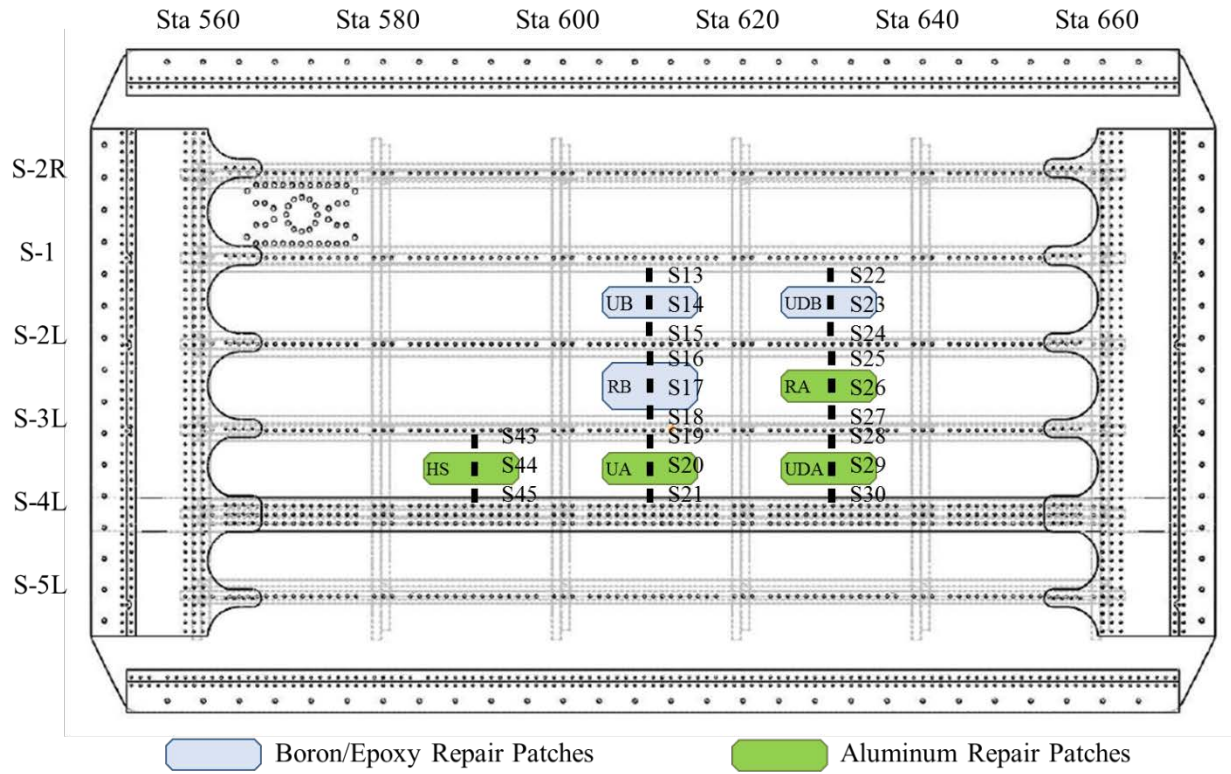


Figure C-7. External strain gauge locations for type-1, -2, -3, and -4 repairs

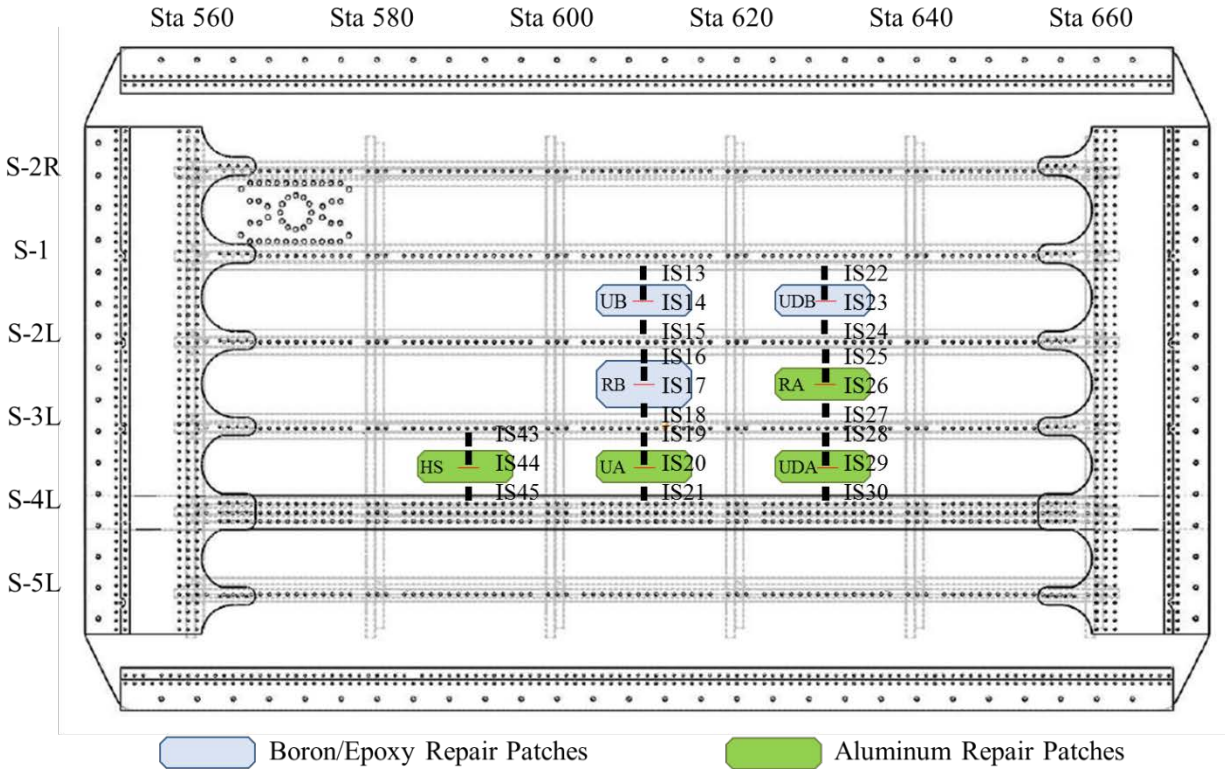


Figure C-8. Internal strain gauge locations for type-1, -2, -3, and -4 repairs

Strain Gauge Chains

After 80,000 cycles, a supplementary study using strain gauge chains was conducted. The objective of using strain gauge chains was to examine whether a single gauge was sufficient to accurately determine the SIF for a curved panel with bonded repairs. The strain gauge chain was installed at four selected repair patch locations (RB, UB, UDB, and UDA), right in front of the crack tip. A linear elastic fracture mechanics approach has been widely used to study the SIF. For the isotropic materials, a single gauge technique to determine SIF was proposed by Dally and Sanford [1]. The technique is widely employed for determination of mode I SIF from one or more strain gauges on a flat plate. Sarangi et al. conducted experiments on the verification of optimal strain gauge locations and their importance in accurately determining mode I SIF [2].

In this study, the objective was to examine whether a single gauge was sufficient to accurately determine the SIF for a curved panel with bonded repairs. The closed-form solution described the strain distribution for a flat panel. To verify whether the closed-form solution was suitable for the curved panel with bonded repairs, a higher resolution of the strain distribution was essential. The conventional strain gauge could not provide such resolution. For this purpose, a strain gauge chain (SGC) was introduced to the testing program as an independent study.

SGC was manufactured by HBM™. A single chain consists of 10 micro-strain gauges evenly distributed at a 0.36-inch (9 mm) distance. Compared to the conventional strain gauge, as shown in figure C-9, the SGC is capable of measuring approximately a three times higher resolution of the strain gradient than the conventional strain gauges.

SG model #	Gage Length, a (in)	Gage Width, b (in)	Pitch, t (in)
CEA-062UW-350	0.062	0.12	N/A
1-KY-23-1/120	0.032	0.032	0.04

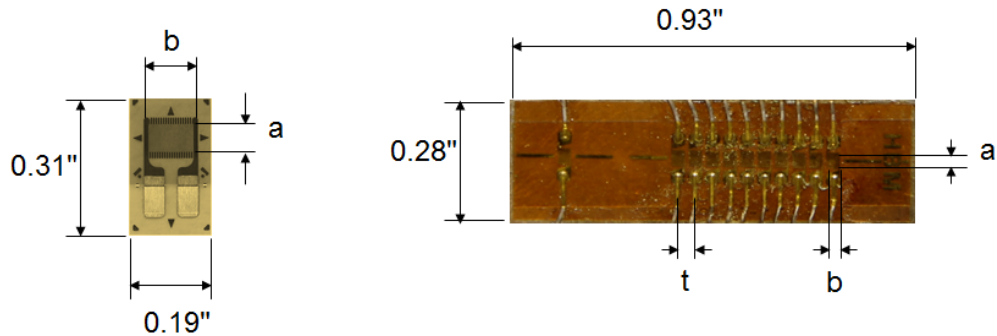


Figure C-9. Strain gauge dimensions and details: (left) conventional strain gauge and (right) strain gauge chain

Strain gauge chains were installed on the RB, UB, UDB, and UDA patch locations, and strain surveys with the SGCs were conducted after the 80,000-cycle and 90,000-cycle inspections. Additionally, variation in local strains due to thermal conditioning (under zero load) was measured in all locations. The typical setups for the strain gauge chains are shown in figure C-10. Finally, strain surveys were conducted under combined mechanical and environmental loading conditions. The local strains were measured during fatigue loading between 80,000 and 90,000 cycles.

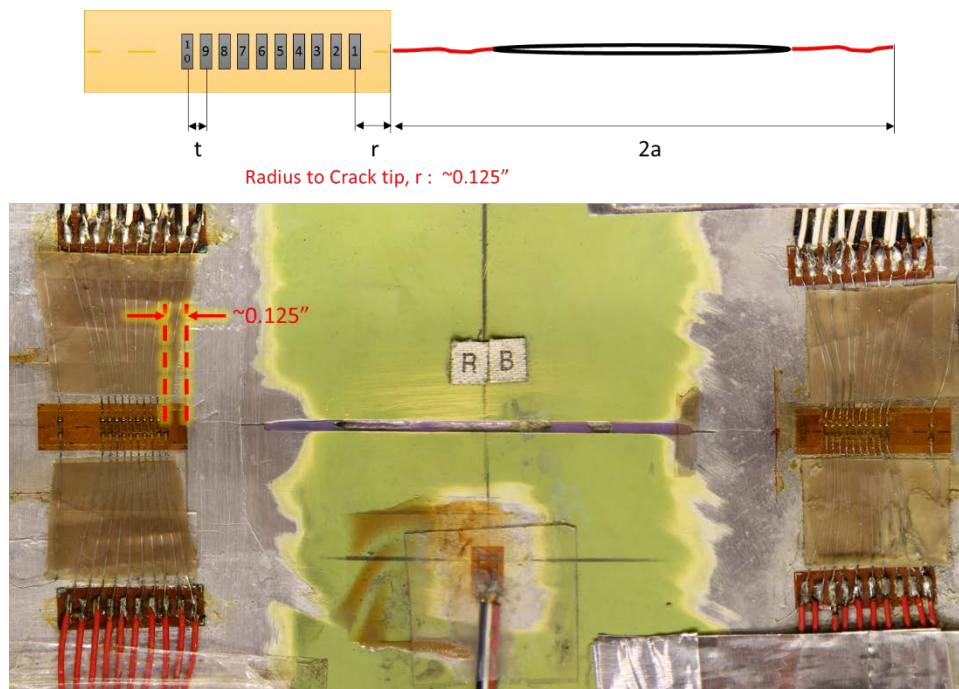


Figure C-10. Typical setup for SGC and the SGC installation on RB patch

References:

- C-1. J. W. Dally, R. J. Sanford, "Strain gage methods for measuring the opening mode stress intensity factor K_I ", *Experimental Mechanics*, Vol. 27, pp. 381-388, 1987
- C-2. Sarangi, H., K.S.R.K. Murthy, and D. Chakraborty, Experimental verification of optimal strain gage locations for the accurate determination of mode I stress intensity factors. *Engineering Fracture Mechanics*, 2013. 110: p. 189-200.

APPENDIX D—PATCH INSTALLATION AND STRAIN MONITORED DURING CURING PROCESS

The patch-installation procedures and the strain monitored during the curing process are provided in this section. The patch-installation procedure involves five major steps, and detailed procedures are provided in section D.1 and its subsections. Strain data recorded as function of time are provided in section D.2.

D.1. PATCH INSTALLATION

D.1.1. CLEANING AND PREPARATION OF SURFACE

- 1) The part's surface areas and adjacent surfaces were solvent-cleaned, and all contaminants were removed.
- 2) All the surface coatings and residual adhesive residues were removed down to bare metal.
- 3) The bare metal surface was solvent-cleaned, and all contaminants were removed.

D.1.2. DEOXIDIZATION

There are two deoxidization methods used in the test. For most of the repairs, the skin of the panel was deoxidized using grit blasting. Other repairs were designated “hand sand,” in which the surface of the skin was deoxidized using wheel grinding.

1. Grit Blasting
 - a. A region slightly larger than the bond area was grit-blasted. Figure D-1 shows the grit-blast procedure.
 - b. Loose grit residue was removed with clean, dry compressed air or nitrogen.



Figure D-1. Grit blasting

2. Hand Sanding

- a. A region slightly larger than the bond area was grit-blasted. Figure D-2 shows the wheel-grinding procedure.



Figure D-2. Wheel grinding

D.1.3. APPLICATION OF SOL-GEL COATING

1. Sol-gel solution was applied by brushing with a natural bristle brush. The surface was kept wet during application, as shown in figure D-3.
2. Sol-gel parts were left to dry under ambient conditions for a minimum of 60 minutes.

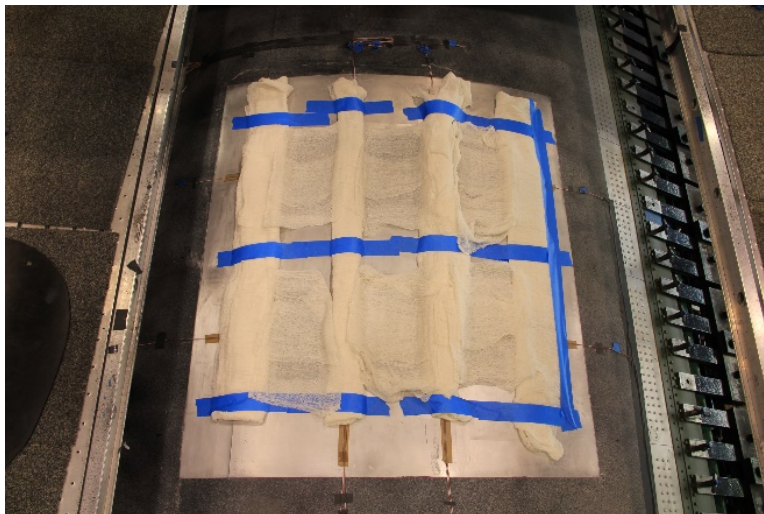


Figure D-3. Applying sol-gel solution

D.1.4. APPLICATION OF BOND PRIMER

1. Cytec Fiberite, Inc. adhesive primer was thoroughly mixed by agitation in the original container.
2. The primer was transferred to a reservoir with continued agitation during application.
3. The adhesive primer was applied to the bond surface to obtain a cured film thickness of 0.00015–0.00040 inch (0.15–0.40 mil).
4. Primed parts were allowed to dry at 135°F using a heat gun for 60 minutes before curing.

D.1.5. CO-CURING

1. The Henkel EA9696 OST (one tacky side) mat carrier, grade 10 film adhesive and patch were applied to the sol-gel-treated and primed surface using standard bond procedures.
2. Both the adhesive and primer were co-cured for 90 minutes at 250° ±10°F using standard heat blanket and vacuum bag processes, as shown in figure D-4.

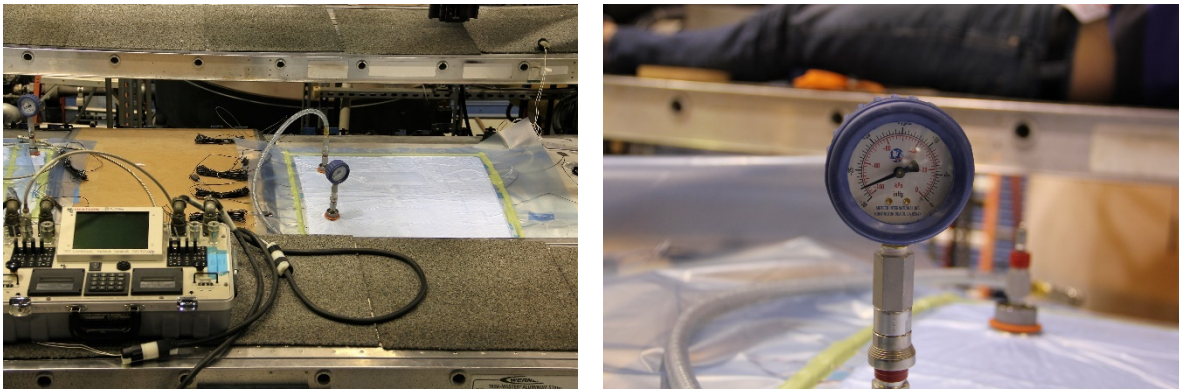


Figure D-4. Co-curing process

D.2. STRAIN MONITORING

Strains were monitored during the curing process on both exterior and interior surfaces of the panel. The strain and the temperature of each repair patch, plotted as a function of time, are provided in the figures below.

Repairs installed at 0 cycles (Type-1, -2, and -3 repairs)

Figures D5 through D-10 show the strains during the curing process for RA, RB, UA, UB, UDA, and UDB repairs, respectively. The figure also shows the location of the strain gauges during the curing process, on both the exterior and interior surfaces of the fuselage panel.

Repairs installed at 60,000 cycles (Type-4 repairs)

Figure D-11 shows the strains during the curing process for the HS repair. The figure also shows the location of the strain gauges during the curing process, both on the exterior and interior surfaces of the fuselage panel.

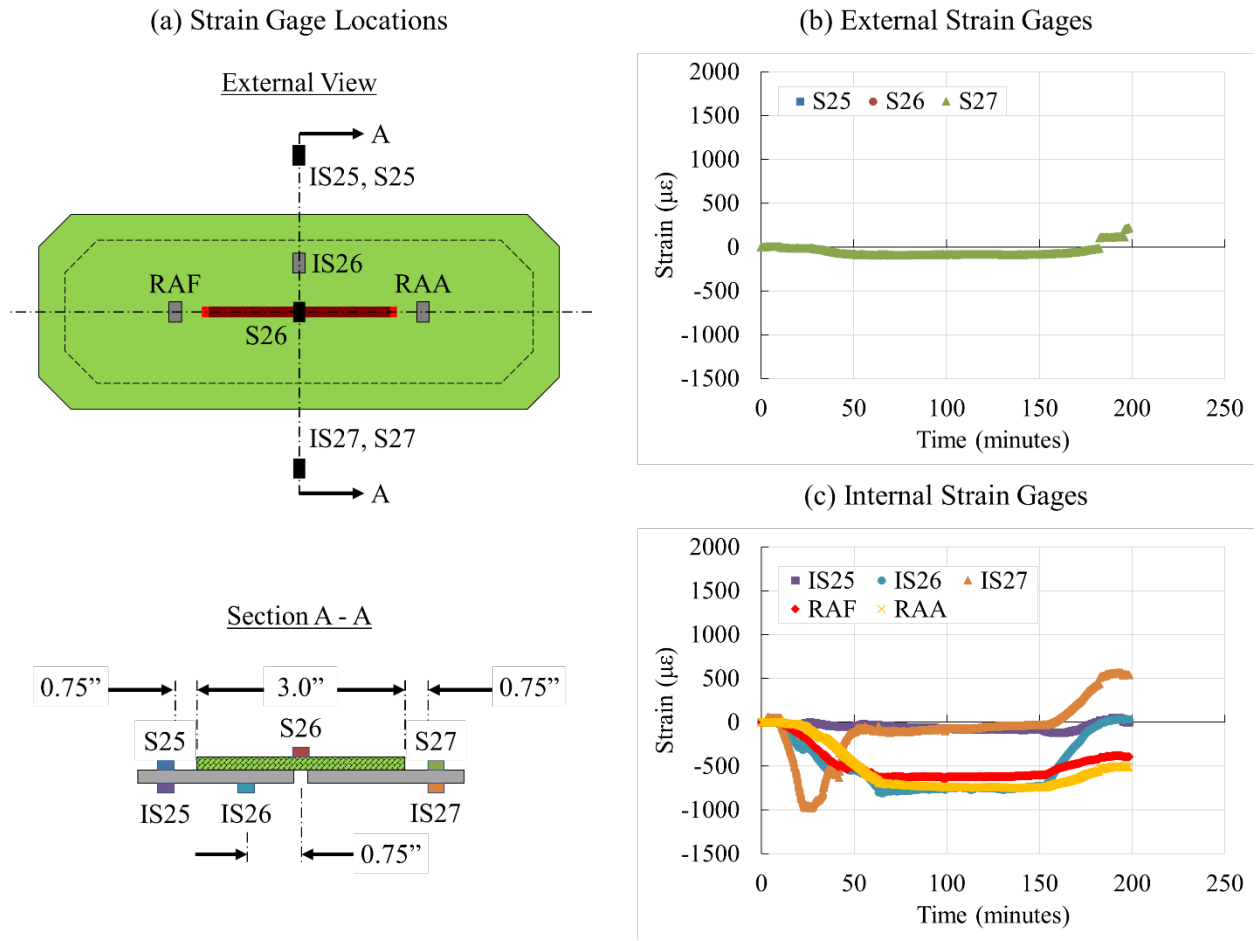


Figure D-5. Strain monitored during the RA repair curing

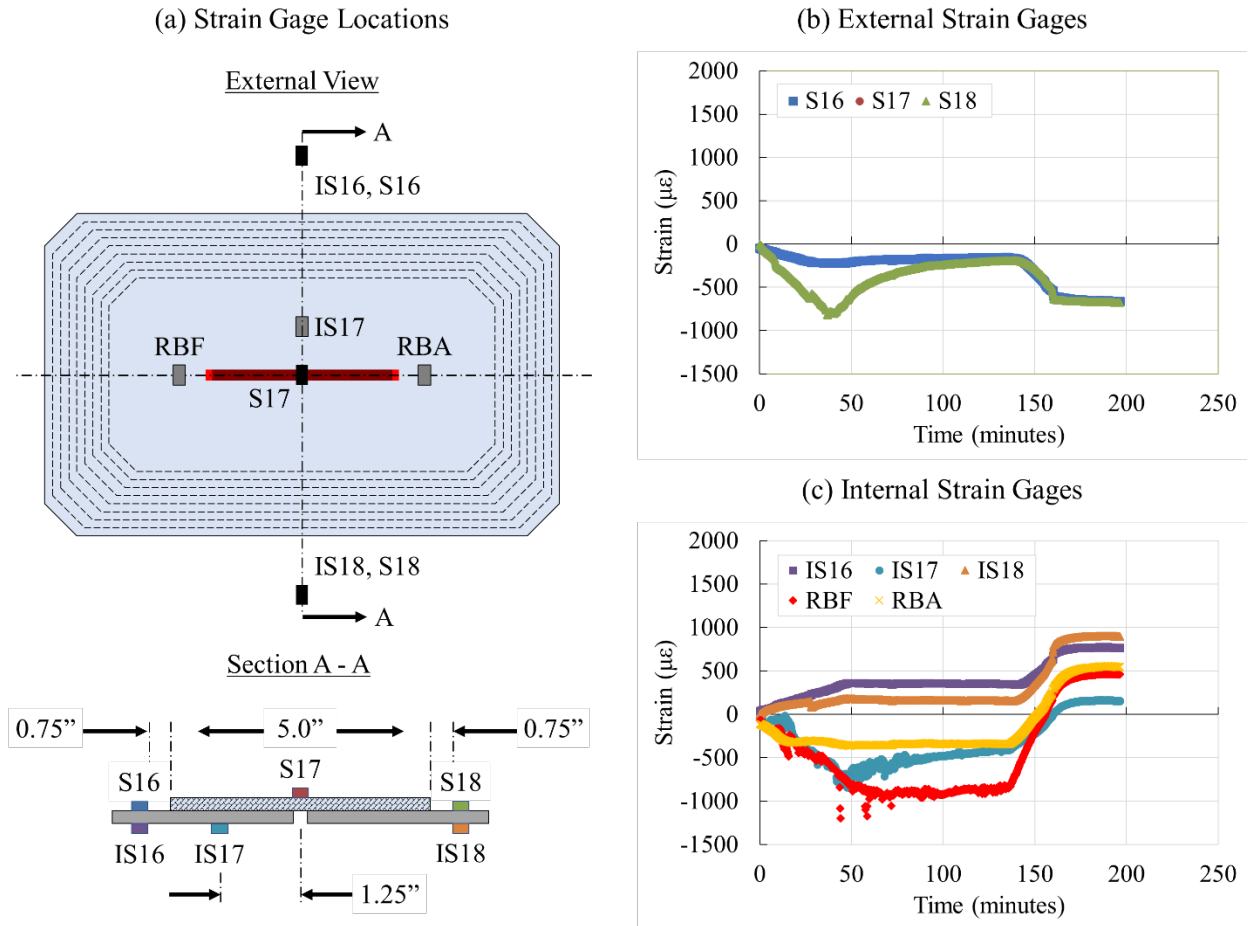


Figure D-6. Strain monitored during the RB repair curing

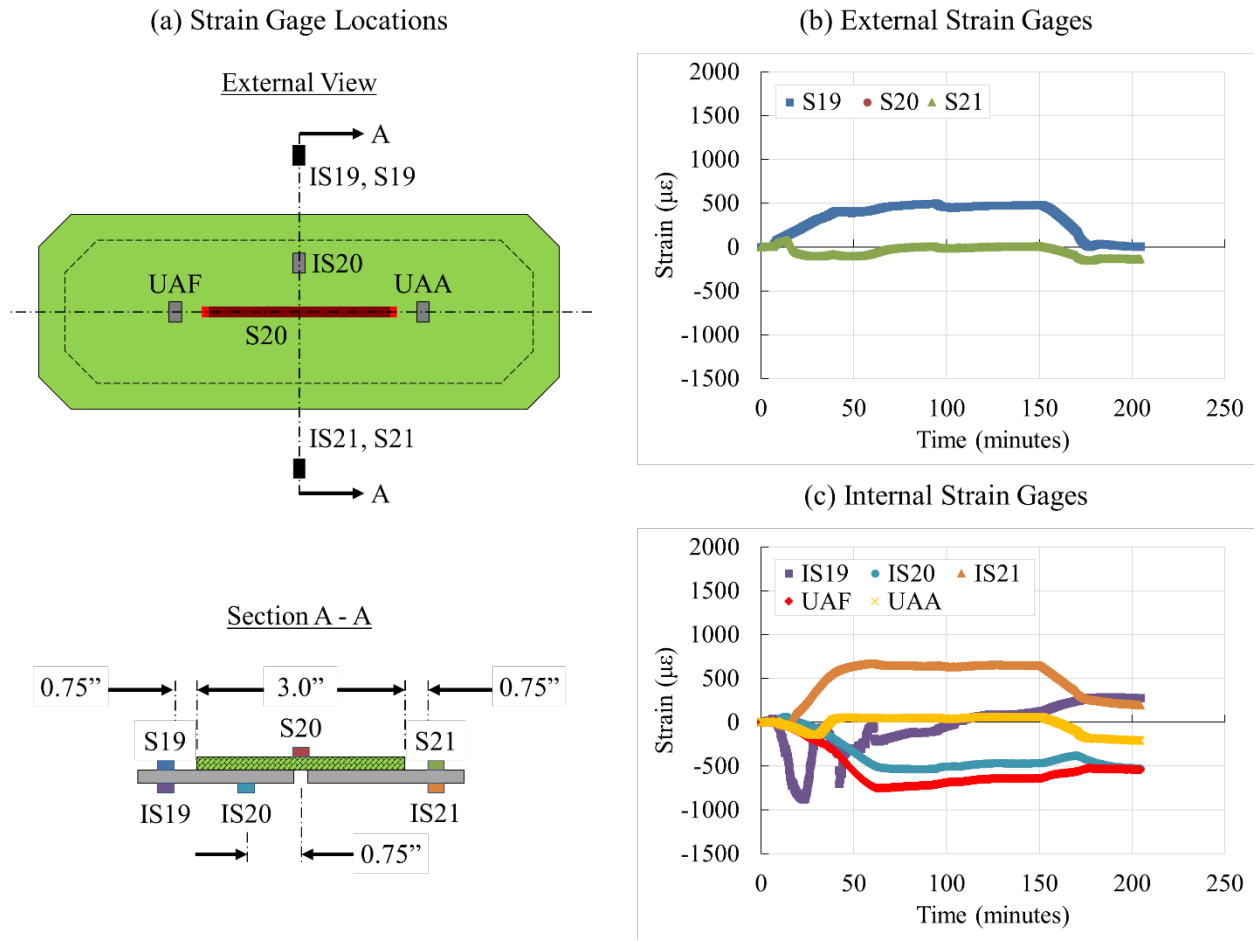


Figure D-7. Strain monitored during the UA repair curing

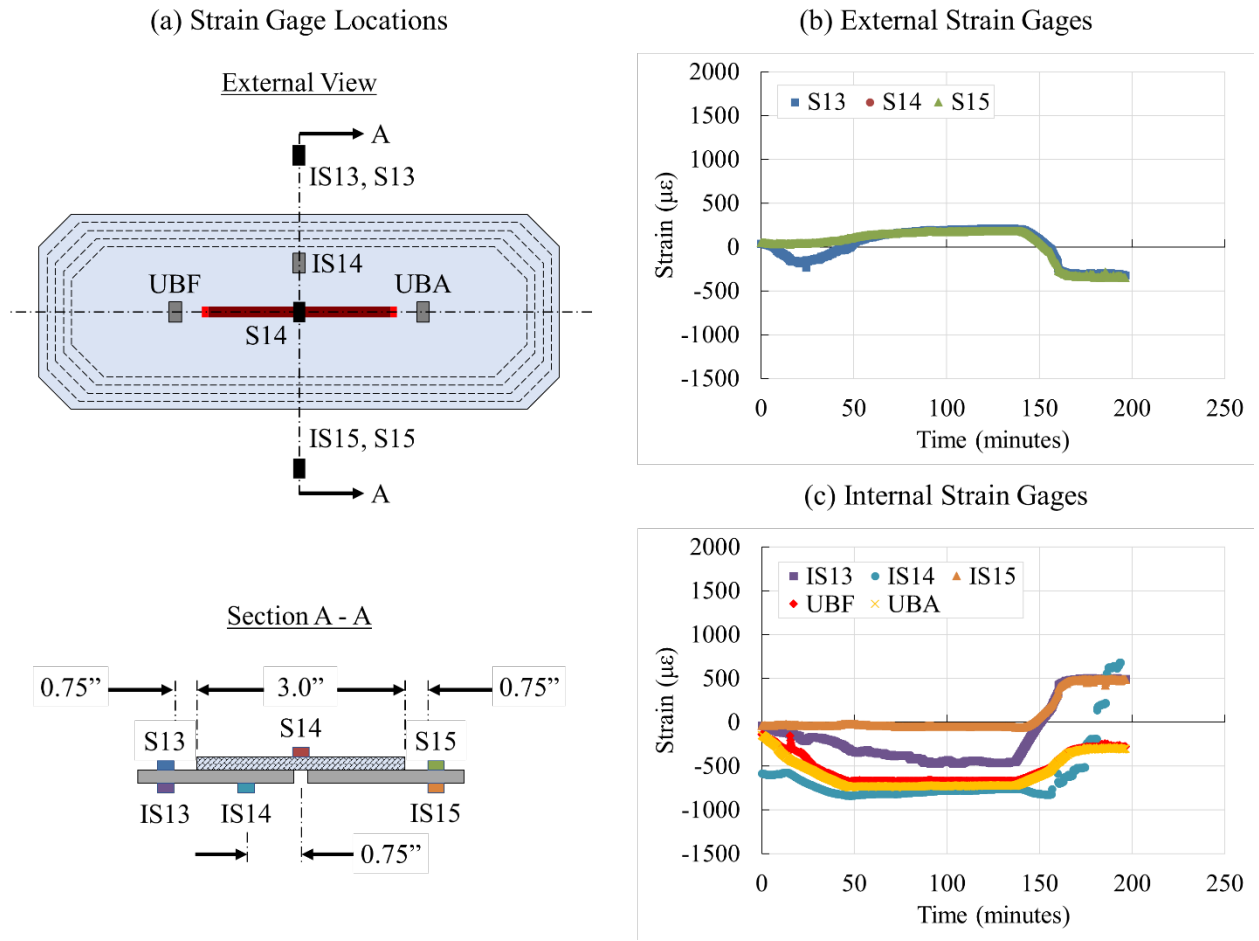


Figure D-8. Strain monitored during the UB repair curing

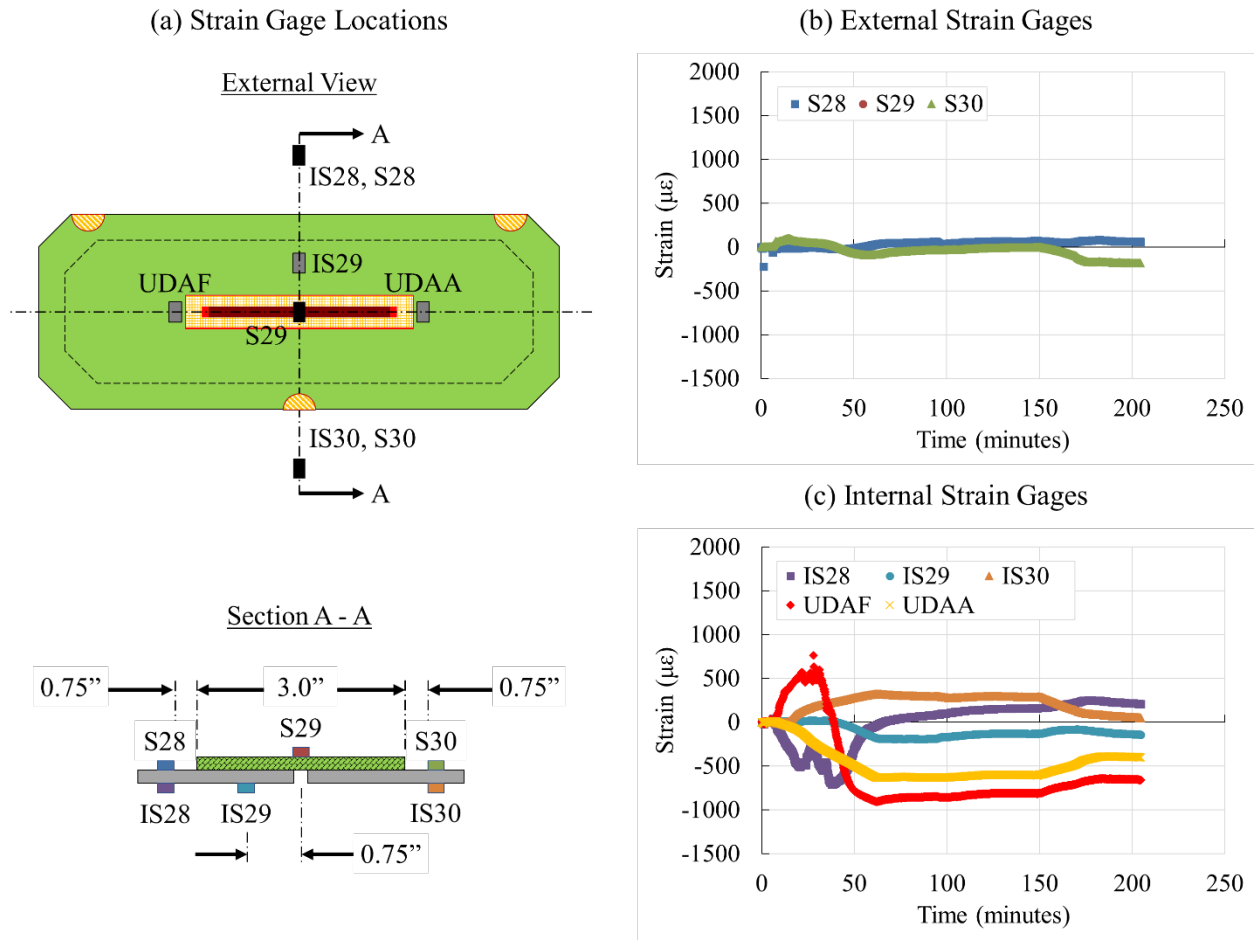


Figure D-9. Strain monitored during the UDA repair curing

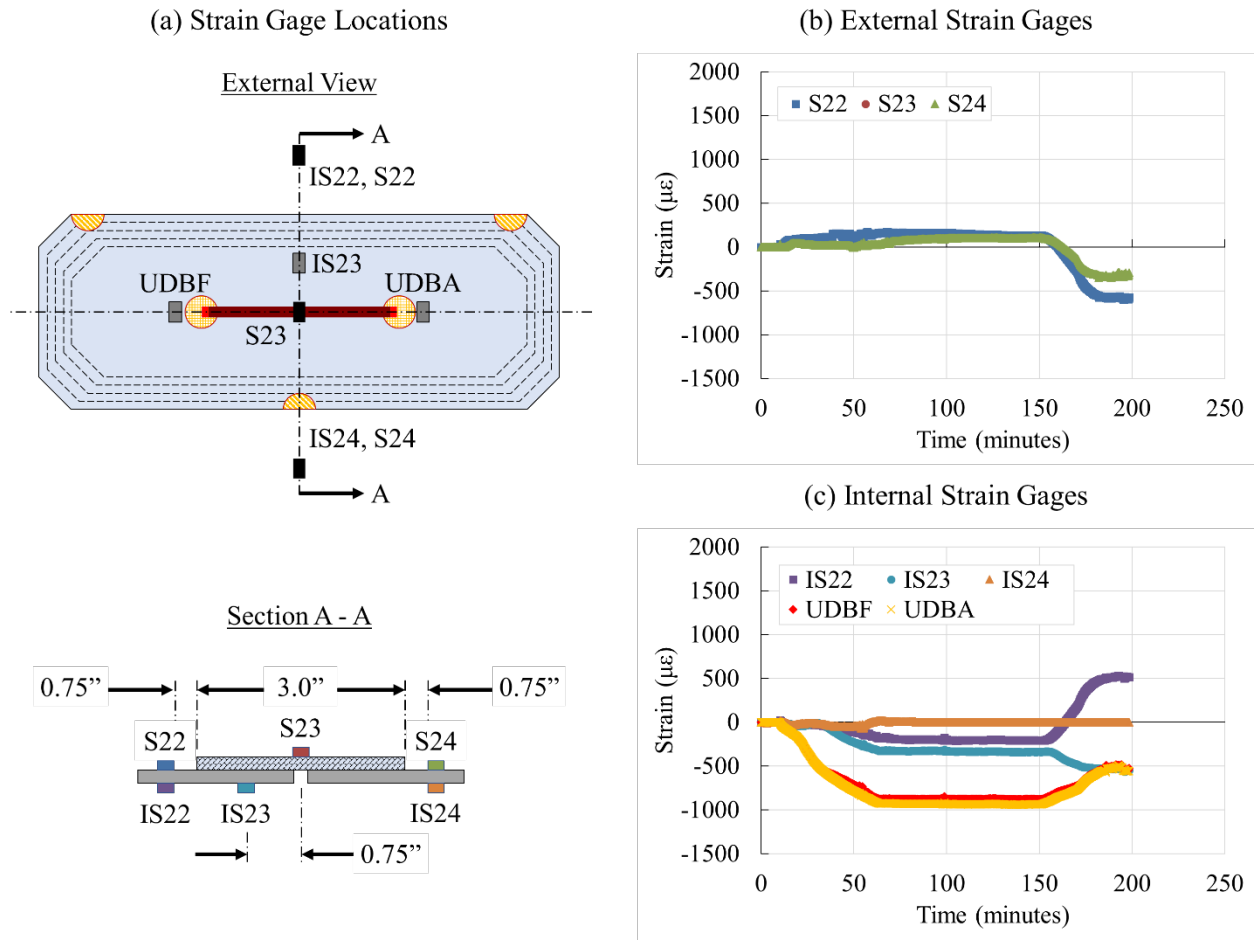


Figure D-10. Strain monitored during the UDB repair curing

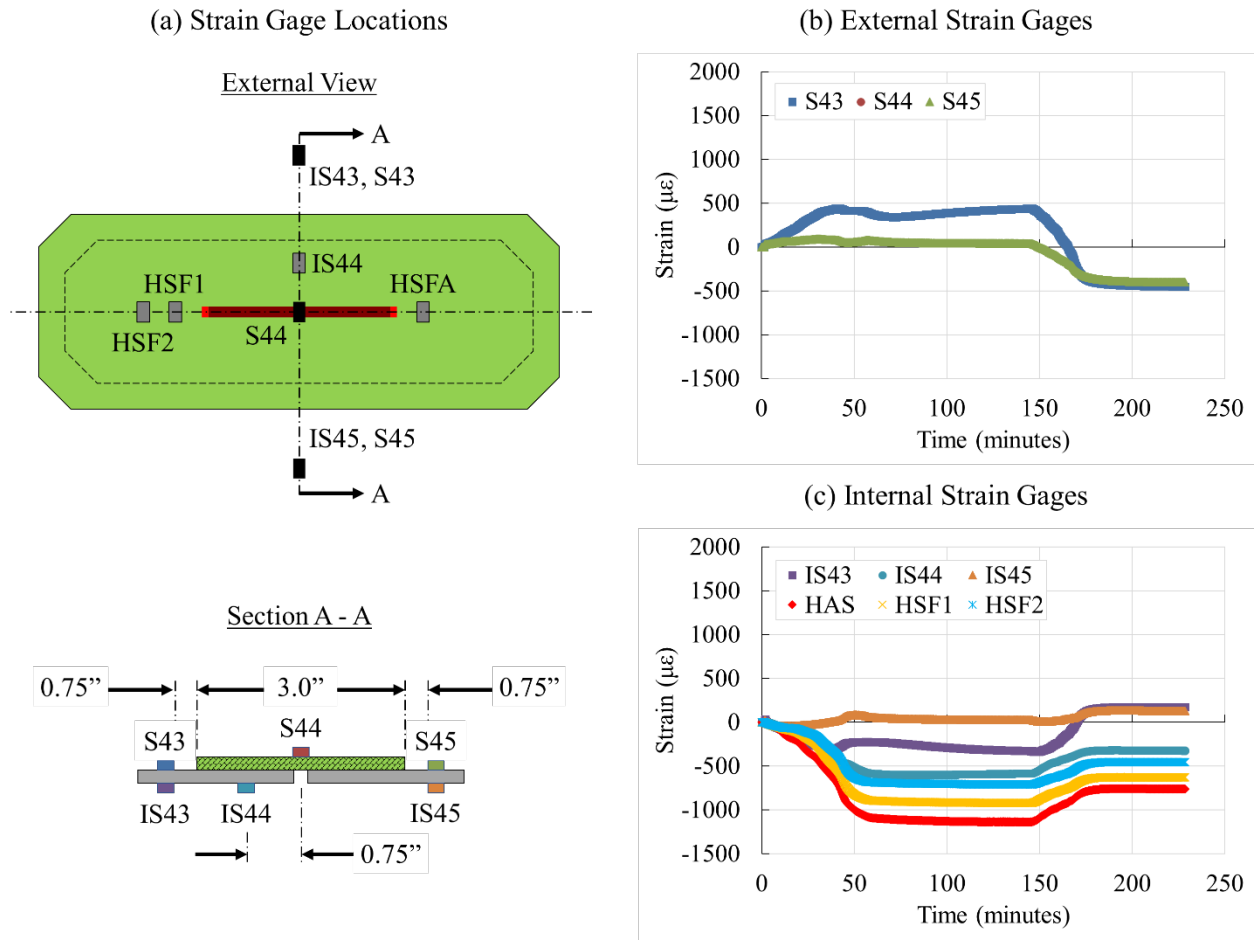


Figure D-11. Strain monitored during the HS repair curing

APPENDIX E—RAW STRAIN DATA

Strain surveys were taken at 75% of the simulated service load condition periodically throughout the fatigue test. Each strain survey was repeated three times to verify the repeatability, and quasi-static loadings were applied in ten increments up to the maximum loads. The loading conditions for the strain survey are summarized in table E-1.

Table E-1. Loading condition of the strain survey

Strain Survey	Cycles	Maximum Mechanical Load				Environmental Load (constant)	
		Pressure (psi)	Hoop (lb)	Frame (lb)	Longitudinal (lb)	Temp. (°F)	Relative Humidity (%)
Baseline	0	6.7	7140	1,133	6675	80	60
Hot-Wet	0 – 80,000	6.7	7140	1,133	6675	165	85
						Laboratory ambient	
Cold-Dry	80,000 – 10,000	6.7	7140	1,133	6675	-25	-
						Laboratory ambient	

The raw data from the strain survey for the strain gauges for each repair are provided in the tables below. For each load condition, applied loads and strains were measured at each gauge at each of the ten-equal-load increments up to the maximum loads listed. For the applied loads, the pressure is in units of psi; 12-frame load assemblies (frames 1–12) are in units of lb; 14-hoop load assemblies (hoops 1–14) are in units of lb; and longitudinal load assemblies (longitudinals 1–8) are in units of lb. The strains measured at the gauges are in units of $\mu\epsilon$.

For the entire test, the applied loads were within $\pm 2\%$ of the prescribed values listed in table E-1. Valid strain readings were obtained for most of the gauges, with the exception of a few gauges (particularly substructure gauges and internal skin gauges), which short-circuited because of moisture absorption from the environmental chamber. These gauges show scattered readings or the values dropped as the test progressed with fatigue cycling.

The strain survey was conducted every 5000 cycles in the first 20,000 cycles, and every 10,000 cycles between 20,000 and 100,000 cycles. To avoid overcrowded data, the raw strain data of each repair for every 20,000 cycles are provided in this appendix, namely pristine panel, baseline, 20K cycles, 40K cycles, 60K cycles, 80K cycles, and 90K cycles.

Note that the missing strain gauge values in tables E-2–22 are due to either removal of strain gauges or faulty strain values.

Table E-2. Strain survey raw data of pristine panel (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
Frame-1	-22.11	69.65	183.20	360.90	453.51	564.77	651.14	801.77	875.59	991.20	1176.40
Frame-2	-43.66	168.99	116.19	272.29	446.40	508.03	718.59	786.34	940.22	1080.36	1149.79
Frame-3	-47.18	66.00	220.41	386.14	400.44	509.27	705.15	822.32	929.16	1054.00	1178.24
Frame-4	-21.64	123.36	227.34	337.59	464.83	573.27	662.45	810.43	886.30	1058.49	1148.06
Frame-5	-42.43	126.60	226.89	323.58	452.03	588.75	672.67	786.57	900.05	1045.72	1127.27
Frame-6	35.98	123.68	269.79	290.27	451.71	549.04	626.48	762.99	854.14	1048.75	1142.03
Frame-7	-8.06	84.20	230.77	358.34	450.49	585.44	675.89	790.21	902.41	1024.43	1114.22
Frame-8	9.09	107.93	218.19	325.69	449.28	512.89	688.96	789.18	907.78	1044.91	1126.65
Frame-9	78.97	52.01	172.51	332.62	468.05	577.26	682.90	790.49	936.77	1029.94	1131.56
Frame-10	64.77	132.25	216.18	346.10	513.45	532.29	718.87	754.39	878.16	1052.82	1116.60
Frame-11	-81.43	195.89	287.99	283.87	481.69	560.19	728.26	847.01	971.07	972.23	1083.92
Frame-12	-41.93	46.70	239.71	337.74	428.01	603.43	697.94	808.87	932.57	1004.24	1159.61
Hoop-1	-84.91	772.79	1588.88	2165.96	2984.35	3602.92	4249.14	4965.62	5784.03	6366.76	7186.10
Hoop-2	343.41	595.76	1370.51	2205.16	2842.69	3673.50	4266.70	4927.32	5799.20	6530.22	7097.16
Hoop-3	-49.59	531.28	1450.15	2228.44	2911.68	3538.08	4257.88	4934.06	5803.45	6385.36	7102.35
Hoop-4	70.81	702.92	1322.45	2241.71	2946.90	3585.13	4221.93	4939.63	5762.54	6437.47	7159.90
Hoop-5	-80.64	497.86	1407.10	2205.81	3014.95	3547.47	4243.86	4988.17	5761.37	6560.23	7046.93
Hoop-6	36.62	604.35	1455.17	2232.48	2944.16	3559.75	4275.49	4996.07	5785.73	6568.65	7132.55
Hoop-7	-39.40	764.99	1462.29	2239.07	2829.63	3493.51	4374.09	4928.72	5703.38	6441.02	7066.48
Hoop-8	-10.47	633.93	1393.90	2233.84	2820.54	3472.52	4340.59	4949.22	5694.98	6447.99	7065.53
Hoop-9	12.09	602.42	1362.42	2253.33	2927.96	3629.56	4169.02	4954.75	5750.80	6471.72	6994.37
Hoop-10	57.52	685.67	1518.81	2106.70	2871.92	3482.87	4280.45	4954.65	5689.83	6389.92	7136.01
Hoop-11	-30.43	724.89	1389.80	2251.53	2907.93	3640.18	4194.62	4975.60	5812.04	6581.78	7016.51
Hoop-12	-77.58	591.64	1333.14	2229.11	2903.99	3557.24	4231.13	4920.72	5783.99	6436.89	7120.93
Hoop-13	-65.59	619.11	1361.81	2235.95	2986.43	3620.50	4202.45	4960.41	5761.66	6526.49	7111.33
Hoop-14	22.23	745.64	1461.45	2184.94	2755.11	3471.56	4347.65	4925.34	5707.21	6489.08	7163.48
Long-1	186.78	583.08	1400.61	1985.96	2680.52	3330.07	3993.92	4664.13	5324.04	5975.49	6659.86
Long-2	95.99	825.11	1377.01	1958.55	2637.31	3331.91	3941.49	4688.15	5409.20	5951.14	6698.99
Long-3	14.91	571.14	1419.50	2076.95	2607.67	3312.59	3706.84	4514.31	5165.30	5910.77	6477.74
Long-4	3.36	558.53	1359.35	2017.94	2684.27	3346.71	4027.79	4679.24	5417.44	5980.10	6682.92
Long-5	1.93	713.71	1253.56	2021.41	2642.27	3367.74	3979.94	4673.08	5375.68	6054.45	6729.50
Long-6	50.27	643.22	1375.48	1977.38	2683.38	3374.13	3981.60	4669.38	5367.11	6031.05	6711.72
Long-7	154.40	830.06	1410.76	1986.83	2684.21	3311.97	4071.84	4675.34	5363.47	6074.81	6679.26
Long-8	62.33	484.99	1352.09	2125.30	2619.20	3268.47	3720.46	4654.35	5367.40	5329.49	6567.04
S01	-24.21	106.05	232.18	349.76	436.18	507.69	584.07	659.54	747.05	826.53	879.40
S02_45	47.96	105.71	186.56	257.72	311.59	371.93	418.91	479.82	535.41	580.06	642.64
S02_A	24.06	33.43	69.31	111.05	149.17	199.98	239.62	284.48	322.76	360.65	427.99
S02_H	-4.52	155.18	288.44	413.14	501.00	575.22	653.18	730.38	820.52	900.58	958.94

Table E-2. Strain survey raw data of pristine panel (run 1) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
S03	3.94	183.16	320.18	444.36	534.10	611.01	689.91	767.13	860.18	942.65	1003.33
S04_45	-11.26	74.41	152.01	227.78	295.45	357.05	413.34	483.38	553.70	614.32	669.48
S04_A	30.22	43.53	91.67	143.08	199.04	259.24	309.50	370.47	422.31	474.67	542.86
S04_H	-24.13	131.45	258.59	375.96	460.40	533.88	610.10	684.14	772.14	851.14	910.01
S05_45	99.43	167.96	257.15	339.28	402.66	469.87	526.99	594.20	662.26	713.19	793.19
S05_A	16.58	163.02	288.91	403.77	487.17	558.32	635.72	710.69	798.24	875.33	932.34
S05_H	36.15	57.59	99.53	147.97	196.98	257.07	301.16	353.85	402.82	449.60	525.20
S06	-74.18	77.64	206.25	326.83	410.43	481.64	558.06	632.85	725.48	802.20	857.77
S07	281.72	461.15	597.27	717.95	806.79	883.26	962.19	1040.03	1131.75	1210.98	1272.65
S08_45	1.04	82.40	165.59	245.74	308.25	370.71	423.90	491.04	552.92	614.40	671.16
S08_A	29.44	53.33	106.30	166.33	221.93	283.60	334.73	399.98	453.63	513.12	582.91
S08_H	-16.60	147.36	275.62	391.66	476.43	549.62	626.20	699.34	786.78	863.02	922.10
S09_45	147.44	204.80	276.53	343.43	398.15	459.33	508.53	567.45	633.18	679.38	748.73
S09_A	71.48	88.67	117.68	150.72	187.40	236.41	273.07	315.71	353.80	394.54	454.19
S09_H	11.24	117.35	228.62	339.65	421.78	491.19	567.07	641.36	729.31	805.37	863.47
S10_45	472.38	540.18	612.27	681.51	741.00	801.91	849.96	908.20	966.54	1016.06	1077.37
S10_A	57.59	80.61	122.38	168.08	212.42	262.09	302.49	351.94	389.62	435.68	492.75
S10_H	21.55	146.03	265.89	380.49	465.86	540.38	616.66	692.07	780.63	856.94	919.30
S11	-2.36	144.42	271.69	392.75	477.62	551.61	631.16	706.00	794.87	878.79	941.03
S12	-0.81	81.23	195.34	309.59	394.27	468.25	548.70	624.63	714.40	793.07	855.49
IS01	-2.71	-0.53	41.49	104.25	166.70	223.98	288.00	354.43	436.69	508.28	556.61
IS02	13.28	34.49	95.41	167.67	232.77	292.43	358.24	426.94	510.56	579.33	634.49
F01	-70.02	-158.32	-118.81	-16.50	47.51	129.12	182.79	250.98	316.29	384.23	495.07
F02	47.24	180.78	217.84	246.03	285.27	300.54	335.38	365.14	400.01	436.22	429.01
F03	-11.82	133.98	201.30	240.72	280.29	298.64	353.95	394.21	429.97	483.38	491.95
F04	27.07	-29.20	-3.51	82.49	143.66	226.30	282.48	354.60	418.43	496.26	583.47
F05	-59.03	130.55	139.73	131.24	177.86	171.49	236.98	263.20	297.42	313.25	304.73
F06	-67.47	-112.61	-69.74	6.41	80.55	148.45	215.99	280.71	343.02	396.66	473.16
F07	51.93	193.35	256.28	296.64	310.02	309.32	379.70	399.16	436.48	480.67	499.04
F08	9.14	-53.90	-32.40	59.30	119.78	184.30	252.67	309.47	367.22	456.09	535.17
L01	38.66	100.15	138.79	155.92	173.74	194.17	206.56	231.02	248.25	252.37	254.49
L02	78.42	96.71	125.92	149.42	161.41	184.27	164.51	223.96	239.21	249.86	277.08
L03	27.86	53.78	86.08	110.34	130.31	161.33	177.47	203.95	222.29	240.20	279.04
L04	27.68	56.77	89.56	114.21	135.79	166.99	183.52	210.30	228.03	244.91	281.62
L05	23.07	67.54	112.23	142.48	166.65	192.81	207.34	228.40	245.12	259.60	289.40
L06	-6.24	27.47	68.81	97.41	119.18	148.19	163.78	189.52	208.75	214.69	254.04
L07	-19.44	27.04	71.90	100.90	131.60	166.84	193.53	227.48	254.38	277.74	319.53

Table E-3. Strain survey raw data of pristine panel (run 2)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
Frame-1	-12.61	98.17	208.33	355.80	420.12	538.47	657.00	796.45	885.37	970.37	1132.83
Frame-2	45.78	166.23	151.88	371.08	385.25	639.97	626.84	764.52	836.57	1072.84	1097.36
Frame-3	-47.57	149.48	221.01	403.96	488.99	485.17	678.48	789.97	858.37	1023.57	1176.27
Frame-4	-3.04	77.12	217.93	322.68	454.33	555.25	669.53	798.17	900.73	999.91	1140.19
Frame-5	-11.80	88.07	206.13	342.16	465.24	561.37	673.85	790.06	916.02	1006.46	1110.60
Frame-6	14.61	182.73	270.43	295.65	486.47	523.34	733.86	777.90	875.03	999.85	1096.70
Frame-7	-11.42	90.42	213.89	315.21	466.53	568.60	710.84	798.66	911.13	1030.69	1107.20
Frame-8	21.86	130.18	277.55	376.57	444.72	569.36	647.52	780.00	891.55	1013.08	1119.68
Frame-9	35.84	119.68	286.70	319.08	456.36	565.08	761.21	760.49	938.25	1053.31	1122.11
Frame-10	-28.64	125.63	301.65	288.83	516.06	645.55	725.41	838.69	887.74	982.33	1165.54
Frame-11	-41.55	186.60	190.90	407.66	486.24	596.66	626.83	728.84	896.64	968.22	1144.70
Frame-12	-14.43	139.84	239.32	382.79	424.81	592.64	677.11	776.03	954.31	1017.53	1151.24
Hoop-1	-72.23	598.34	1510.88	2297.44	2911.95	3613.47	4390.88	4939.69	5715.07	6398.92	7091.69
Hoop-2	-48.27	944.61	1508.43	2125.32	2855.50	3623.04	4316.79	4919.67	5754.54	6250.66	7093.63
Hoop-3	0.38	851.88	1524.42	2179.12	2844.74	3630.82	4283.74	4883.58	5644.88	6272.87	7047.12
Hoop-4	-16.10	789.85	1512.79	2168.12	2776.93	3604.70	4336.03	4926.46	5706.49	6465.92	7156.34
Hoop-5	-62.70	805.08	1452.16	2143.58	2945.18	3593.83	4313.93	4971.50	5752.47	6331.56	7282.33
Hoop-6	22.12	827.45	1495.23	2200.50	2906.36	3601.11	4340.79	4906.70	5720.52	6287.00	7110.87
Hoop-7	32.10	688.13	1544.68	2239.74	2801.31	3666.58	4295.44	4989.01	5606.95	6338.62	7209.52
Hoop-8	18.49	814.78	1517.26	2198.30	2799.37	3603.22	4254.14	5043.34	5723.94	6405.18	7159.68
Hoop-9	-55.88	763.27	1480.76	2017.82	2817.61	3597.71	4543.31	4893.93	5725.76	6291.67	7216.25
Hoop-10	-37.23	648.69	1469.98	2145.94	2788.25	3600.80	4270.35	4931.84	5663.51	6404.60	7206.21
Hoop-11	-50.25	829.28	1527.08	2163.86	2858.02	3608.09	4335.65	4941.35	5684.05	6306.60	7108.48
Hoop-12	11.29	796.42	1543.78	2208.00	2846.52	3608.38	4311.34	4927.97	5725.96	6335.96	7099.16
Hoop-13	-14.60	844.75	1515.05	2265.76	2877.74	3613.58	4370.40	4909.42	5652.40	6381.44	7104.05
Hoop-14	36.84	752.80	1403.28	2273.29	2784.90	3647.31	4267.70	4932.65	5634.14	6343.57	7097.69
Long-1	212.88	615.51	1275.18	2005.15	2757.40	3412.68	3978.33	4666.01	5347.88	6011.22	6671.70
Long-2	42.75	423.59	1272.28	1936.68	2604.57	3317.83	3925.45	4667.15	5387.63	6040.10	6640.91
Long-3	13.23	653.29	1364.22	2100.36	2691.52	3382.20	4058.36	4722.17	5399.93	6091.84	6745.89
Long-4	-0.42	706.78	1433.95	1965.80	2675.86	3349.71	4014.09	4667.22	5352.27	6050.29	6650.21
Long-5	19.86	671.29	1313.73	2014.73	2607.62	3337.45	4015.71	4705.15	5317.05	6007.05	6665.18
Long-6	54.80	667.62	1333.50	2024.56	2670.57	3313.43	3990.61	4671.90	5352.46	6078.79	6634.94
Long-7	178.73	703.28	1419.06	2032.86	2660.16	3370.30	3940.19	4733.74	5305.50	6019.61	6665.40
Long-8	64.66	449.71	1515.29	1802.81	2658.40	3358.77	3942.66	4542.18	5278.96	5822.22	6758.79
S01	-32.18	142.54	250.09	340.80	423.66	510.60	593.62	651.04	734.09	801.04	879.67
S02_45	40.31	115.45	193.97	246.55	312.93	369.48	431.87	477.10	540.13	593.86	648.12
S02_A	30.82	14.03	55.63	106.37	149.17	189.57	233.76	278.96	320.30	372.44	427.38
S02_H	-17.38	199.11	314.87	407.20	491.92	582.04	666.73	727.03	813.63	881.74	962.07

Table E-3. Strain survey raw data of pristine panel (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
S03	6.56	230.27	342.49	441.10	524.06	614.90	700.51	760.72	847.79	917.60	1001.80
S04_45	-26.07	69.89	165.17	223.36	293.13	358.53	423.85	477.42	544.72	607.63	665.93
S04_A	29.70	17.50	83.50	133.85	203.47	257.05	311.75	369.16	428.14	486.87	548.18
S04_H	-29.20	173.12	276.39	370.75	450.10	537.28	621.23	678.86	760.69	829.87	910.85
S05_45	89.74	180.39	262.23	330.55	405.21	468.43	535.31	593.68	663.58	725.70	802.01
S05_A	14.85	204.91	312.46	398.81	481.01	567.88	648.62	707.05	790.09	855.45	938.96
S05_H	41.50	40.52	89.16	151.41	201.91	248.56	301.18	352.65	402.50	463.66	514.85
S06	-87.94	118.84	226.23	314.93	396.29	487.12	566.84	623.94	708.46	774.92	855.41
S07	291.39	517.19	630.37	726.13	808.24	898.65	983.09	1043.19	1129.28	1196.80	1279.30
S08_45	-7.69	83.02	172.58	229.97	302.11	365.35	435.03	484.36	547.09	611.09	670.86
S08_A	30.13	32.66	104.83	159.23	228.29	283.98	345.68	403.59	510.64	3998.47	2345.37
S08_H	-16.78	188.37	292.51	385.38	465.84	551.67	634.07	691.63	773.26	840.79	920.88
S09_45	140.94	220.66	287.53	343.07	402.36	461.69	521.24	569.50	630.99	687.78	748.80
S09_A	83.25	71.86	112.24	158.06	199.55	236.23	278.09	320.76	362.84	411.27	459.85
S09_H	5.52	152.02	247.84	332.06	411.04	496.34	575.63	634.19	717.75	783.79	866.09
S10_45	466.72	543.26	614.19	673.55	733.76	792.27	853.21	897.98	956.80	1012.08	1065.42
S10_A	72.81	67.22	122.78	171.02	223.63	262.84	313.34	358.14	403.04	454.31	505.50
S10_H	16.78	182.48	283.18	373.96	454.51	543.04	624.97	684.30	768.40	834.59	917.14
S11	-4.35	187.95	291.21	389.24	467.84	556.32	643.96	703.34	786.10	857.13	942.94
S12	-5.89	112.60	211.65	301.17	384.13	472.41	554.81	615.39	701.10	770.68	860.65
IS01	3.41	12.40	48.61	106.05	157.35	232.73	300.13	349.74	427.93	487.46	557.03
IS02	9.83	55.89	102.28	164.64	221.90	298.24	365.45	419.94	499.63	558.54	637.10
IS14											
IS15											
IS16											
IS17											
IS18											
F01	-59.48	-141.66	-107.54	-27.75	50.04	98.65	190.39	240.61	318.80	397.87	507.09
F02	46.51	204.77	262.07	264.25	299.06	331.02	362.92	382.06	411.59	443.52	429.78
F03	-7.29	135.82	212.86	237.16	278.12	320.40	337.96	387.91	427.03	453.51	478.04
F04	22.81	-27.39	12.43	88.54	153.99	212.53	294.59	343.93	423.46	504.64	573.92
F05	-56.35	115.54	108.90	167.82	163.37	204.46	183.88	263.04	252.83	286.39	307.25
F06	-42.36	-96.51	-68.50	13.03	85.62	155.29	216.96	273.94	349.42	417.58	504.01
F07	10.05	203.12	265.54	275.55	313.57	338.42	354.34	389.57	399.84	427.34	471.81
F08	20.54	-50.24	-0.42	52.52	137.60	191.47	278.01	326.57	383.35	467.72	562.43
L01	33.57	85.50	130.64	148.16	169.15	192.49	201.01	223.62	235.29	249.22	241.98
L02	58.65	76.06	114.48	137.32	160.32	174.84	186.06	214.30	229.04	251.88	266.77
L03	32.75	36.20	77.72	106.74	134.48	155.89	181.26	206.43	226.26	256.18	277.07
L04	37.07	44.79	83.15	115.15	142.74	164.45	190.13	215.38	235.45	262.78	284.82

Table E-3. Strain survey raw data of pristine panel (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
L05	44.49	78.64	122.19	155.96	184.81	206.61	227.65	253.24	269.79	290.12	307.58
L06	-12.22	11.16	56.65	86.02	111.56	135.68	153.07	179.11	197.49	222.14	244.10
L07	-25.25	9.07	59.36	95.67	133.06	161.94	191.69	224.89	254.35	284.85	319.02

Table E-4. Strain survey raw data of pristine panel (run 3)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
Frame-1	9.57	142.51	183.95	345.84	439.11	550.17	726.08	822.38	902.61	992.05	1153.61
Frame-2	1.66	198.29	150.63	246.03	428.56	549.36	700.20	776.83	963.02	1049.42	1167.27
Frame-3	34.29	91.30	187.98	346.97	468.80	617.62	735.56	749.88	941.60	1045.24	1153.93
Frame-4	17.45	128.41	187.52	337.02	456.50	570.64	660.94	788.32	911.12	1006.70	1125.27
Frame-5	4.40	100.34	232.01	376.92	448.40	551.30	679.39	802.63	917.56	1008.68	1130.50
Frame-6	-21.72	125.46	244.11	403.19	471.71	536.65	701.91	752.89	950.61	1024.51	1149.68
Frame-7	38.92	145.39	255.58	327.45	454.13	554.71	683.06	790.05	920.06	1018.42	1106.05
Frame-8	146.49	107.15	210.60	429.72	449.96	562.90	685.82	803.65	879.91	1047.74	1106.83
Frame-9	-96.91	26.56	267.44	347.47	431.06	511.87	727.00	755.84	905.51	1006.82	1152.01
Frame-10	-81.21	116.29	275.64	372.53	503.00	665.81	757.56	823.67	946.14	1040.20	1129.72
Frame-11	47.09	72.17	261.09	312.15	494.81	501.38	653.51	823.35	921.36	1014.21	1201.06
Frame-12	23.91	66.91	250.00	324.31	455.14	552.42	696.36	798.65	910.52	996.54	1117.57
Hoop-1	-115.86	683.68	1547.08	2037.78	2893.49	3635.28	4384.05	5105.56	5845.24	6226.90	7238.47
Hoop-2	15.41	682.23	1433.14	2082.76	2861.68	3593.78	4307.62	4982.72	5765.85	6398.21	7197.76
Hoop-3	-17.81	923.28	1501.85	2147.63	3036.22	3665.78	4337.88	5125.22	5807.21	6235.10	7168.36
Hoop-4	-12.29	845.63	1523.84	2062.89	2962.32	3586.62	4268.24	5051.30	5726.53	6343.84	7206.57
Hoop-5	-0.04	823.15	1587.89	1974.34	2935.73	3657.29	4341.70	5091.53	5835.08	6352.93	7117.20
Hoop-6	44.15	745.71	1469.05	2054.03	2908.85	3530.38	4224.28	4998.42	5685.86	6402.67	7183.98
Hoop-7	468.84	817.51	1502.91	2120.16	2921.40	3617.67	4297.54	5032.88	5757.48	6192.24	7100.41
Hoop-8	-47.89	713.92	1520.82	2113.83	2911.68	3589.45	4241.07	5008.18	5752.89	6309.69	7153.67
Hoop-9	-65.01	849.53	1516.26	2077.77	2930.60	3682.58	4291.18	5091.78	5761.96	6397.73	7172.26
Hoop-10	-100.45	839.14	1459.21	2222.86	2905.36	3604.61	4323.34	5061.84	5755.41	6333.99	6958.59
Hoop-11	101.95	870.89	1496.89	2053.79	2936.90	3622.88	4275.92	5094.02	5792.41	6251.35	7076.01
Hoop-12	-25.11	732.75	1539.16	2043.31	2924.37	3589.70	4272.62	5012.75	5718.91	6369.65	7130.52
Hoop-13	192.26	815.02	1538.98	2111.39	2914.95	3545.28	4283.53	5065.07	5724.51	6369.61	7187.22
Hoop-14	38.93	806.43	1518.33	2105.49	2892.47	3637.08	4282.56	5037.04	5754.95	6294.08	6966.14
Long-1	209.36	790.04	1376.82	2060.65	2646.01	3324.53	3991.27	4720.52	5361.81	5963.75	6671.42
Long-2	107.25	638.08	1319.41	2092.76	2686.08	3300.23	3961.38	4632.03	5345.41	6053.60	6695.83
Long-3	17.55	753.82	1385.19	1961.23	2625.42	3422.39	4012.62	4847.90	5247.42	5853.50	6699.13
Long-4	14.49	489.25	1337.27	1970.95	2640.02	3311.87	4001.48	4655.48	5317.86	5955.02	6672.47
Long-5	72.47	656.36	1326.84	2020.43	2965.27	3312.39	4023.51	4665.27	5307.67	6008.23	6664.90
Long-6	57.56	663.78	1289.11	2007.26	2630.07	3314.34	3991.05	4669.52	5350.73	6033.00	6637.10
Long-7	307.82	743.57	1326.69	2083.30	2702.27	3359.69	4023.85	4607.29	5264.91	5981.50	6683.61
Long-8	71.38	416.52	1364.78	1952.83	2564.06	3247.24	3789.45	4783.70	5223.62	5972.90	6698.97
S01	-30.92	141.27	244.86	326.47	427.29	508.96	583.28	662.37	737.51	788.57	858.63
S02_45	46.38	118.83	187.65	249.65	303.08	363.00	417.79	477.09	528.71	583.44	624.05
S02_A	21.91	20.10	57.22	98.58	138.96	181.46	221.66	272.42	307.77	377.41	412.13
S02_H	-12.85	202.14	313.39	395.85	500.25	582.79	662.39	743.93	824.39	875.20	950.71

Table E-4. Strain survey raw data of pristine panel (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
S03	14.88	231.41	344.29	423.02	534.10	618.16	696.56	781.34	860.44	916.43	995.65
S04_45	-29.54	71.60	150.98	213.18	291.33	360.84	416.94	484.35	547.05	599.62	665.89
S04_A	31.57	44.06	87.61	154.72	201.79	257.24	309.84	368.48	421.14	491.07	535.18
S04_H	-29.63	166.40	275.95	350.75	459.29	541.85	617.87	699.82	776.32	832.31	906.47
S05_45	109.24	193.95	274.56	338.87	408.08	482.59	542.13	614.26	672.50	737.49	801.92
S05_A	22.98	209.21	312.30	389.53	490.20	569.93	645.22	726.01	802.62	855.06	928.32
S05_H	32.66	51.86	96.65	141.24	193.02	244.47	289.92	340.83	388.70	459.38	507.65
S06	-92.12	113.59	221.58	298.39	402.55	483.22	559.08	642.44	719.75	770.89	846.99
S07	313.18	535.21	648.71	727.40	836.47	919.29	997.33	1080.11	1159.56	1212.92	1291.07
S08_45	-7.87	90.96	168.90	227.85	302.30	367.52	426.39	491.54	548.68	606.38	660.06
S08_A	1577.79	1683.62	2059.18	1812.98	1812.01	1210.11	1079.45	1010.37	1196.27	1397.58	1149.89
S08_H	-11.00	186.83	295.57	369.65	475.31	557.18	632.58	713.22	789.75	843.80	916.12
S09_45	143.60	216.59	285.94	335.39	399.82	462.57	518.76	580.11	636.66	687.06	751.90
S09_A	86.26	94.12	126.65	164.41	203.67	243.52	284.16	327.83	366.32	426.08	463.54
S09_H	-3.81	150.66	245.57	318.99	418.68	497.00	571.17	652.96	728.82	782.57	856.43
S10_45	460.51	538.43	607.39	656.86	723.00	783.73	841.22	899.95	952.17	1000.69	1053.36
S10_A	68.06	88.66	130.87	179.66	222.74	268.91	312.40	360.27	399.15	462.67	493.45
S10_H	17.81	181.64	283.12	358.91	462.87	543.88	620.20	702.47	778.47	832.22	909.48
S11	-5.98	181.61	289.42	367.31	476.54	561.57	640.35	723.87	800.93	862.46	935.87
S12	-3.31	116.63	211.31	285.04	386.84	472.05	548.45	634.35	711.03	769.83	845.43
IS01	12.94	9.22	46.39	87.99	168.74	231.28	295.50	368.36	438.55	480.35	553.04
IS02	23.61	54.07	103.92	152.86	232.59	298.24	363.57	441.58	510.97	557.98	632.93
F01	-100.49	-113.18	-73.64	-13.06	53.31	124.58	197.34	274.35	332.83	448.78	488.95
F02	51.60	155.41	237.42	261.35	293.25	305.62	363.76	359.29	408.04	395.74	442.84
F03	34.25	121.67	185.50	253.67	260.17	294.83	337.88	375.31	415.69	441.31	478.94
F04	24.94	-5.28	22.27	99.87	154.53	228.12	290.51	359.82	426.08	525.82	562.32
F05	-55.55	69.38	125.04	117.33	173.65	173.26	214.51	248.50	280.92	284.34	346.20
F06	-49.62	-84.01	-69.32	2.20	69.77	133.91	204.97	281.00	341.51	428.94	460.52
F07	1918.97	2087.57	259.89	251.59	272.29	314.10	342.81	2635.16	2680.88	2944.00	2815.74
F08	4.92	-11.45	11.53	77.15	150.28	230.25	291.15	352.26	419.10	519.52	540.92
L01	22.05	70.89	103.56	125.69	148.87	163.13	177.74	195.43	209.10	206.72	230.32
L02	47.78	61.20	88.20	108.68	124.43	144.21	153.48	175.55	189.92	213.88	235.59
L03	23.86	41.10	73.20	99.85	122.33	148.82	167.35	192.14	210.89	247.37	268.36
L04	37.03	59.23	92.37	119.96	145.19	170.35	190.05	215.45	232.82	267.31	288.05
L05	53.58	97.52	141.09	175.38	201.51	221.86	242.24	263.23	278.56	307.64	327.19
L06	-24.01	4.82	43.97	71.52	93.80	116.29	136.25	162.67	176.32	208.25	229.78
L07	-27.25	10.52	55.91	93.49	124.16	154.13	181.76	214.02	240.06	280.03	310.85

Table E-5. Baseline strain survey raw data (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
Frame-1	-31.89	125.59	170.88	340.07	444.16	577.18	661.47	798.24	917.67	1035.99	1149.98
Frame-2	-67.96	134.69	282.19	280.00	366.27	531.01	716.15	838.32	951.20	1007.88	1208.46
Frame-3	-34.64	94.40	177.40	315.49	492.51	555.15	705.69	837.75	957.18	1071.20	1153.99
Frame-4	-8.54	145.82	183.30	357.81	393.35	510.06	623.10	820.82	969.72	1063.18	1161.73
Frame-5	48.89	110.61	181.92	255.59	412.68	548.93	758.67	932.03	1015.76	1107.67	1150.34
Frame-6	-11.54	215.24	304.72	406.40	524.93	500.13	771.03	884.86	928.54	1089.84	1081.18
Frame-7	-40.34	200.34	272.17	404.62	420.15	538.47	666.35	816.85	901.10	1034.16	1107.37
Frame-8	-58.07	73.89	241.73	277.96	420.67	580.49	748.33	818.56	900.64	1085.33	1176.96
Frame-9	2.01	296.18	223.51	525.29	430.99	592.27	621.38	744.63	915.60	1055.53	1141.98
Frame-10	-20.99	5.70	190.05	259.29	479.48	606.21	718.35	904.58	972.87	1114.88	1233.86
Frame-11	-0.45	77.86	170.46	277.14	453.47	571.91	720.38	882.82	866.05	985.94	1160.78
Frame-12	-6.68	91.59	195.54	386.28	450.07	558.96	633.50	795.70	939.80	1067.85	1174.48
Hoop-1	3.50	684.77	1333.38	1954.99	2936.23	3814.61	4391.66	5247.03	5629.63	6558.82	7238.40
Hoop-2	28.14	684.37	1131.24	1924.90	2712.89	3576.72	4241.75	5026.92	5622.19	6495.00	7046.84
Hoop-3	-63.15	753.86	1182.24	1854.82	2651.76	3508.52	4352.64	5264.15	5902.86	6459.69	7211.05
Hoop-4	8.98	585.44	1225.55	1860.39	2762.17	3525.93	4180.59	5388.60	5927.52	6473.17	7192.72
Hoop-5	-28.25	760.55	1279.11	1907.42	2812.88	3470.21	4332.05	5216.31	5735.50	6203.02	6954.76
Hoop-6	-8.15	643.94	1332.66	2124.17	2871.30	3618.64	4197.46	4915.98	5685.94	6382.13	7136.24
Hoop-7	456.04	750.08	1126.77	2305.51	2414.21	3607.07	4436.98	5151.71	5203.73	5901.44	6728.28
Hoop-8	1.53	661.55	1347.63	1921.70	2912.88	3751.24	4412.62	5213.63	5581.73	6369.77	7073.12
Hoop-9	-1.73	613.71	1260.14	2084.86	2790.45	3482.48	4246.44	5331.33	5934.18	6575.17	7303.31
Hoop-10	5.58	754.77	1351.02	2257.43	2744.81	3262.01	4001.87	5036.62	5994.91	6556.91	7241.41
Hoop-11	48.13	642.66	1315.50	2030.51	2808.07	3579.32	4222.58	5145.41	5818.25	6371.08	7051.20
Hoop-12	7.68	668.87	1265.68	1934.49	2829.83	3573.80	4225.67	5142.33	5776.77	6461.39	7079.69
Hoop-13	-21.61	631.78	1430.37	2033.15	2860.57	3564.79	4312.56	5162.48	5780.21	6477.30	7108.33
Hoop-14	68.59	608.48	1062.28	1831.96	2725.03	3539.37	4307.07	5353.32	5990.74	6521.78	7263.79
Long-1	22.84	823.65	1433.42	2287.86	2453.08	3476.02	3971.67	4448.03	5365.50	5771.09	6611.97
Long-2	-4.39	485.08	1483.44	1989.75	2615.99	3298.21	4197.16	4804.81	5353.46	6163.65	6696.75
Long-3	57.47	568.39	1370.79	2034.32	2836.93	3218.55	3935.08	4567.17	5237.35	5799.68	6669.48
Long-4	263.28	603.22	1297.09	1934.45	2960.66	3342.93	4078.07	4458.25	5418.11	5878.83	6482.87
Long-5	13.01	549.84	1498.69	1951.36	2803.91	3267.31	4055.68	4478.07	5398.67	5972.42	6724.09
Long-6	57.52	600.65	1407.76	2179.77	2628.12	3334.14	4038.44	4500.45	5409.11	5894.22	6651.28
Long-7	47.49	566.17	1514.89	1981.57	2730.17	3351.85	3960.52	4697.30	5359.80	5978.05	6741.62
Long-8	40.89	752.44	1353.92	2138.33	2652.34	3392.16	3883.14	4708.46	5179.42	6257.57	6474.23
S01	218.25	367.03	480.51	589.25	670.37	753.98	837.86	952.77	1017.50	1085.36	1154.25
S11	21.31	163.30	294.07	406.07	491.41	561.50	647.08	766.33	840.29	909.76	982.93
S12	7.47	96.30	202.09	303.20	379.47	459.36	536.94	659.60	730.30	803.44	872.43
S13	33.51	228.43	386.16	554.70	680.91	800.54	912.39	1063.43	1138.35	1218.61	1301.46

Table E-5. Baseline strain survey raw data (run 1) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
S14	308.91	-74.98	-479.57	-902.33	-1215.87	-1484.17	-1753.88	-2075.73	-2282.46	-2459.62	-2618.02
S15	66.10	259.22	418.26	587.19	709.11	831.40	939.77	1085.07	1152.75	1227.38	1304.17
S16	23.99	183.68	319.13	483.88	618.75	745.81	862.92	1020.44	1094.88	1178.80	1264.32
S17	146.26	86.84	-11.21	-87.11	-154.47	-206.72	-263.71	-322.59	-363.53	-401.73	-438.41
S18	89.46	248.51	385.52	552.07	678.00	814.37	930.31	1085.13	1155.44	1238.68	1319.54
S19	43.42	200.38	302.43	423.15	507.43	600.62	682.97	799.87	858.27	925.96	994.27
S20	12.19	-109.31	-310.27	-513.71	-692.16	-865.16	-1053.51	-1280.91	-1437.70	-1598.75	-1759.24
S21	31.50	82.39	114.03	196.13	261.61	345.14	424.16	541.17	602.88	674.68	747.84
S22	52.69	226.82	368.43	520.81	642.78	750.91	854.57	997.89	1074.35	1149.39	1232.95
S23											
S24	-195.18	7.31	188.59	369.75	504.99	631.11	742.73	895.11	966.22	1044.12	1122.49
S25	57.25	229.34	353.98	488.02	588.52	690.44	782.06	908.05	972.24	1044.48	1118.93
S26	44.70	-70.82	-238.49	-414.49	-540.40	-658.48	-789.21	-955.24	-1085.92	-1200.76	-1305.90
S27	38.90	201.16	334.23	471.64	566.13	671.18	762.12	885.37	945.04	1017.15	1089.55
S28	62.85	193.08	298.83	423.94	517.12	620.47	710.45	837.04	898.28	972.48	1047.86
S29	114.26	25.54	-100.48	-215.26	-289.13	-353.05	-422.98	-499.05	-553.65	-596.93	-629.70
S30	-38.93	-0.86	57.05	155.21	222.00	321.08	389.50	491.29	541.73	624.91	700.23
S4	23.62	187.12	304.03	415.69	505.61	584.93	667.36	783.67	852.39	918.14	990.92
S5	24.43	186.97	296.11	403.78	486.10	571.09	653.15	770.52	834.38	904.67	973.06
S8	37.62	213.17	335.22	447.34	530.84	616.72	697.06	810.86	875.32	943.92	1014.38
IS13	76.27	1.12	-80.57	-118.49	-115.23	-100.89	-82.38	-38.65	-19.76	13.28	57.75
IS14	183.69	268.34	327.65	410.99	493.41	570.06	640.38	736.57	772.75	821.24	873.35
IS15	-6.04	-76.37	-169.46	-214.18	-218.11	-213.57	-206.20	-173.28	-166.04	-139.29	-102.77
IS16	15.22	-20.35	-95.01	-133.22	-144.92	-134.85	-131.15	-102.28	-98.00	-73.04	-38.04
IS17	13.18	94.02	165.65	250.10	330.61	407.07	474.85	562.82	595.71	642.45	690.31
IS18	-21.76	-66.67	-155.95	-200.56	-217.30	-218.72	-221.47	-197.46	-197.64	-173.83	-140.63
IS19	151.43	110.36	53.06	51.59	68.38	107.81	137.57	201.72	219.76	263.31	312.77
IS20	-156.76	-128.32	-122.57	-89.30	-63.26	-26.65	-0.20	48.83	46.41	66.18	88.05
IS21	1.41	62.84	96.20	153.08	197.54	257.48	304.29	383.48	411.36	461.19	515.00
IS22	-4.21	-63.02	-130.79	-152.68	-145.63	-133.82	-115.38	-65.37	-43.08	-9.90	33.59
IS23	-5.74	81.50	139.35	229.34	307.20	376.14	439.82	533.85	572.57	616.38	665.12
IS24	-41.65	-115.28	-223.88	-264.76	-271.46	-264.02	-254.38	-212.81	-194.91	-159.15	-121.23
IS25	-15.61	-62.72	-110.96	-91.31	-63.49	-18.31	18.88	93.96	125.22	175.59	230.72
IS26	1.83	73.49	139.16	237.16	309.61	386.85	455.81	553.39	604.16	662.94	719.80
IS27	-64.42	-70.68	-97.49	-63.44	-35.36	16.76	55.41	128.86	159.86	212.98	267.86
IS28	-95.71	-149.50	-217.55	-213.57	-206.30	-166.01	-141.20	-83.39	-64.08	-16.96	31.24
IS29	-11.67	28.67	52.28	101.75	130.77	176.02	205.88	251.09	264.87	291.90	318.10
IS30	-11.23	54.21	78.17	132.69	163.73	223.60	266.78	340.38	365.47	419.06	471.66

Table E-5. Baseline strain survey raw data (run 1) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
F01	-102.44	-210.74	-45.21	58.91	-31.58	-69.37	-24.67	77.49	225.79	296.04	350.74
F02	294.43	594.06	400.65	522.06	572.97	721.33	725.77	742.07	753.56	776.60	801.33
F07	116.81	331.77	247.75	325.90	444.97	598.94	632.81	667.79	658.49	691.41	724.03
F08	65.67	-38.57	137.51	156.65	179.30	129.76	201.97	309.85	470.06	527.56	570.29
L03	168.97	156.79	188.07	187.87	187.87	177.14	186.07	178.50	218.64	234.57	253.47
L04	-30.51	-54.62	-21.51	-29.92	-31.97	-51.21	-43.57	-54.33	-17.28	-3.86	14.93

Table E-6. Baseline strain survey raw data (run 2)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
Frame-1	39.29	124.61	227.41	306.67	430.49	505.88	671.08	798.31	896.77	1024.50	
Frame-2	-28.55	86.25	212.06	421.42	376.76	511.26	706.72	718.08	891.81	1014.98	
Frame-3	-37.59	130.73	256.39	343.01	464.62	594.02	698.50	772.65	898.94	1020.81	
Frame-4	46.85	96.36	293.18	317.97	394.70	515.94	707.77	835.46	894.92	1055.37	
Frame-5	-64.47	120.24	273.92	292.95	525.83	486.94	665.60	859.25	850.98	1018.23	
Frame-6	-95.63	176.35	244.56	305.45	387.71	589.69	747.01	754.84	861.37	1085.18	
Frame-7	-16.70	118.05	217.81	326.22	446.54	554.94	699.77	788.77	901.49	1041.30	
Frame-8	16.63	62.48	203.85	346.54	461.49	530.96	718.54	841.92	883.47	1057.29	
Frame-9	8.62	191.46	391.20	323.11	480.06	525.23	647.09	823.36	866.77	1010.95	
Frame-10	1.26	193.42	234.70	375.68	337.71	589.78	699.84	729.59	917.68	1048.02	
Frame-11	64.68	59.64	240.05	286.40	336.92	575.29	666.90	816.13	879.21	1084.97	
Frame-12	33.04	103.57	207.92	366.77	447.05	588.53	718.38	813.19	922.20	1025.02	
Hoop-1	1.68	677.68	1566.56	2120.59	2836.33	3514.37	4388.90	5060.18	5639.30	6620.26	
Hoop-2	-95.02	686.20	1449.68	1991.56	2676.48	3566.17	4462.56	4917.83	5656.82	6501.39	
Hoop-3	-5.30	490.01	1854.64	1888.98	2426.30	3517.56	4525.25	5416.00	5719.70	6712.13	
Hoop-4	-36.48	705.53	1469.23	2020.23	2573.56	3584.13	4545.19	5024.87	5679.59	6610.75	
Hoop-5	-35.55	760.63	1425.19	2177.46	2711.17	3499.43	4610.51	4873.00	5698.40	6699.10	
Hoop-6	-15.48	687.97	1486.53	2065.35	3011.11	3545.37	4315.55	5077.19	5722.01	6388.82	
Hoop-7	357.40	689.32	2005.55	1910.69	2721.12	3282.79	4238.77	5229.59	5697.53	6467.71	
Hoop-8	4.99	566.69	1534.25	2118.52	2818.14	3450.92	4434.24	4898.13	5701.54	6467.83	
Hoop-9	-3.54	690.17	1434.44	2010.20	2623.69	3600.86	4412.53	5190.48	5640.58	6689.08	
Hoop-10	1.98	663.12	1759.87	1898.75	2741.49	3366.81	4364.73	5230.11	5709.07	6572.63	
Hoop-11	40.86	573.74	1482.79	2028.49	2773.80	3546.94	4332.54	4909.84	5629.69	6552.42	
Hoop-12	39.94	640.39	1398.29	2068.71	2828.32	3601.04	4486.38	5042.75	5621.41	6593.53	
Hoop-13	-36.13	675.41	1473.93	2003.90	2592.47	3484.93	4386.03	5162.48	5728.81	6571.04	
Hoop-14	11.18	481.18	1499.94	2032.67	2591.02	3612.91	4428.13	5177.52	5676.22	6600.06	
Long-1	19.30	736.05	1267.54	1954.32	2784.20	3272.04	4148.91	4756.76	5440.85	5847.21	
Long-2	17.93	865.06	1417.27	1903.47	2546.53	3478.58	4027.63	4758.93	5446.20	6046.05	
Long-3	50.98	760.15	1461.15	2156.37	2637.56	2970.97	4019.41	4689.67	5246.92	6006.26	
Long-4	-59.75	550.15	1362.09	2103.02	2847.71	3195.49	3880.27	4714.96	5377.17	6149.83	
Long-5	46.36	798.35	1305.19	2160.56	2636.16	3305.73	3959.37	4723.66	5393.88	5909.49	
Long-6	76.44	562.86	1329.33	2039.23	2547.14	3264.84	3943.08	4712.10	5384.61	5890.94	
Long-7	52.51	725.39	1416.37	2038.41	2727.65	3268.97	4120.70	4633.19	5294.66	5894.58	
Long-8	44.14	787.62	1478.10	1910.71	2867.60	3333.92	3942.66	4766.57	5258.40	6290.81	
S01	225.47	346.88	524.17	575.16	662.25	749.07	853.59	936.39	995.05	1091.65	
S11	34.40	152.08	339.61	402.96	498.00	568.22	671.89	760.40	822.39	918.57	
S12	10.20	83.97	239.29	290.07	384.77	460.26	560.31	647.53	708.76	806.42	
S13	46.47	220.01	486.03	558.03	680.11	806.53	948.07	1047.31	1116.50	1233.51	

Table E-6. Baseline strain survey raw data (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
S14	297.90	-47.33	-624.71	-879.34	-1234.88	-1483.49	-1817.24	-2072.72	-2247.44	-2470.94	
S15	63.53	241.48	507.12	573.95	698.99	825.76	964.60	1059.70	1125.56	1239.33	
S16	25.27	168.30	412.98	488.57	611.91	748.27	897.59	998.49	1072.03	1196.23	
S17	143.23	91.67	-21.52	-88.51	-161.25	-207.95	-272.90	-326.64	-364.92	-406.54	
S18	85.50	237.66	476.25	544.25	679.75	812.92	961.88	1064.07	1136.10	1255.89	
S19	62.55	199.83	380.40	423.69	510.58	607.04	711.56	788.64	842.84	938.33	
S20	8.02	-103.71	-362.11	-505.94	-715.62	-867.70	-1087.13	-1288.01	-1430.72	-1618.68	
S21	31.10	79.04	163.32	186.94	260.41	346.18	447.56	527.59	585.12	684.79	
S22	77.12	231.96	463.33	538.68	653.76	764.93	897.09	991.66	1061.53	1177.00	
S23											
S24	-189.61	-8.23	281.35	360.41	494.10	623.64	766.90	866.87	937.14	1056.62	
S25	57.91	217.65	427.03	487.44	589.86	691.30	809.18	895.72	957.19	1059.01	
S26	33.96	-65.19	-281.10	-394.24	-564.15	-665.95	-824.30	-975.82	-1074.55	-1205.44	
S27	50.62	192.08	405.19	467.25	570.90	673.00	787.13	873.04	932.93	1029.91	
S28	66.15	193.49	374.54	422.84	520.81	621.56	738.17	824.17	885.47	986.75	
S29	114.13	34.78	-119.30	-194.16	-300.03	-352.50	-432.17	-506.45	-549.35	-598.44	
S30	-44.97	-2.96	117.96	141.77	223.03	304.48	407.34	485.63	558.75	640.84	
S4	27.23	171.97	353.47	413.14	503.51	582.78	690.51	772.71	833.78	929.77	
S5	33.42	174.80	347.92	396.55	482.27	571.14	675.90	756.42	814.08	914.16	
S8	46.71	199.60	384.51	440.55	532.85	613.35	718.45	801.98	861.43	954.58	
IS13	61.41	-0.15	-79.65	-106.19	-127.58	-103.97	-71.48	-54.61	-29.20	30.17	
IS14	169.19	248.82	374.04	411.71	472.42	557.09	651.96	706.90	750.97	834.27	
IS15	-16.17	-77.82	-164.07	-198.08	-231.31	-215.76	-196.26	-191.72	-175.07	-122.83	
IS16	3.67	-20.35	-88.14	-129.30	-157.02	-142.68	-125.19	-122.95	-108.04	-56.84	
IS17	4.64	79.05	207.44	252.76	322.68	402.03	490.85	543.18	584.83	659.61	
IS18	-26.99	-71.37	-146.96	-188.11	-230.83	-219.65	-211.37	-215.32	-204.47	-156.87	
IS19	132.14	101.44	73.68	50.88	55.43	99.96	150.52	177.55	207.00	280.50	
IS20	-191.77	-162.38	-113.80	-114.21	-91.31	-51.92	-8.59	8.47	24.36	67.00	
IS21	-2.59	51.78	138.34	150.33	189.08	251.85	320.00	362.64	398.78	476.71	
IS22	-17.86	-66.26	-121.19	-145.28	-154.87	-135.64	-98.74	-79.66	-54.45	7.78	
IS23	-15.03	65.29	189.57	226.21	293.64	366.53	456.58	509.35	551.65	630.26	
IS24	-59.52	-121.25	-216.42	-254.45	-280.41	-267.74	-239.48	-226.11	-205.35	-141.32	
IS25	-23.14	-65.34	-82.15	-94.46	-71.12	-27.19	37.02	77.91	114.66	195.14	
IS26	0.61	64.93	185.58	228.17	312.06	382.84	477.67	546.05	595.04	677.12	
IS27	-74.42	-82.46	-67.03	-69.07	-38.56	6.85	72.23	115.37	152.58	230.87	
IS28	-105.26	-148.49	-191.25	-219.48	-210.23	-176.47	-129.31	-96.86	-68.27	-1.13	
IS29	-11.76	24.54	86.11	95.93	131.46	171.65	215.86	242.81	262.35	301.39	
IS30	-17.04	38.79	116.02	122.93	161.95	212.23	277.21	324.27	360.02	432.00	

Table E-6. Baseline strain survey raw data (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
F01	-68.67	-254.04	-139.33	-82.31	53.83	-41.57	-34.48	148.51	190.37	206.85	
F02	258.90	570.18	618.79	531.00	521.39	663.88	762.06	729.40	737.63	813.77	
F07	94.75	388.47	407.48	376.06	385.61	544.00	644.77	606.02	646.89	721.23	
F08	83.57	-46.31	30.13	124.65	213.21	175.06	202.87	352.27	412.25	430.92	
L03	177.76	172.27	148.43	186.85	204.06	184.78	184.41	206.60	233.39	226.78	
L04	-25.24	-41.44	-71.45	-32.43	-19.87	-47.07	-51.80	-27.97	-3.86	-12.82	

Table E-7. Baseline strain survey raw data (run 3)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
Frame-1	44.73	116.69	239.64	360.78	434.00	552.93	677.67	792.19	907.90	1042.33	1123.95
Frame-2	48.25	213.53	183.04	360.47	365.87	596.94	693.57	792.74	879.70	1037.06	1122.92
Frame-3	42.04	168.96	210.55	351.30	467.18	608.24	717.04	818.43	914.26	1045.08	1110.78
Frame-4	34.36	82.53	300.15	367.41	441.25	545.55	712.90	778.07	862.73	1054.76	1118.79
Frame-5	81.74	102.08	202.08	378.92	432.61	653.10	731.06	802.15	952.03	1041.97	1152.44
Frame-6	47.63	42.86	178.70	383.72	440.65	494.93	651.04	703.05	883.80	1073.30	1132.66
Frame-7	10.28	54.05	205.86	355.59	464.09	540.43	648.96	764.00	907.19	1053.77	1141.35
Frame-8	40.48	86.80	218.37	378.64	426.21	564.87	742.75	798.34	921.34	1044.77	1083.34
Frame-9	64.92	128.43	228.51	304.90	386.32	530.43	657.85	744.88	896.09	1079.01	1110.84
Frame-10	37.77	83.19	210.94	292.24	459.75	591.40	747.83	808.98	852.23	1115.30	1067.28
Frame-11	-7.81	170.75	308.49	401.33	383.29	566.23	757.43	803.05	907.05	1105.67	1110.07
Frame-12	55.56	119.08	216.23	317.87	486.54	546.22	675.43	779.15	870.48	1011.18	1121.25
Hoop-1	1.68	670.20	1532.41	2053.18	2774.66	3617.50	4444.00	5013.82	5656.40	6552.18	7116.33
Hoop-2	-80.96	774.10	1534.13	2216.98	2645.06	3582.00	4527.22	5046.27	5712.56	6329.59	7178.80
Hoop-3	97.74	663.48	1558.20	2187.44	2511.52	3532.02	4510.34	4994.81	5541.99	6703.76	7173.09
Hoop-4	14.44	723.65	1707.45	2442.36	2653.85	3525.93	4581.11	5061.24	5599.01	6684.16	7003.58
Hoop-5	-20.95	709.43	1454.40	2265.33	2755.28	3594.38	4646.57	4916.83	5690.53	6619.42	7159.28
Hoop-6	-8.15	687.90	1691.68	2138.83	2798.87	3589.33	4278.48	5040.55	5780.06	6462.74	7180.20
Hoop-7	317.94	660.42	1780.11	1996.78	2782.37	3370.00	4458.04	4897.02	5497.33	6841.96	6869.98
Hoop-8	-7.11	696.11	1463.84	2125.43	2768.30	3545.26	4460.60	4985.52	5738.42	6377.31	7252.85
Hoop-9	-3.54	582.85	1512.97	2246.26	2594.89	3469.43	4589.12	4953.64	5579.54	6599.43	7107.20
Hoop-10	-3.42	596.29	1616.27	2159.94	2848.04	3443.58	4437.22	4869.09	5580.05	6577.38	6927.98
Hoop-11	35.40	773.57	1528.71	2123.05	2794.08	3640.78	4352.97	4976.29	5692.21	6431.73	7127.58
Hoop-12	-28.16	769.21	1470.41	2230.01	2817.85	3627.20	4535.23	5079.60	5699.13	6610.80	7131.67
Hoop-13	65.52	704.38	1691.73	2265.49	2803.33	3615.60	4378.33	5024.53	5706.46	6477.30	7130.11
Hoop-14	-74.93	721.48	1578.87	2389.85	2609.22	3390.49	4555.05	4967.64	5551.89	6807.03	6922.96
Long-1	25.43	496.77	1070.50	2059.95	2927.31	3474.48	3994.60	4697.38	5552.94	6010.77	6839.84
Long-2	-4.14	446.97	1397.71	2040.21	2734.36	3398.84	3853.21	4551.10	5277.51	6177.94	6876.22
Long-3	49.29	629.16	1236.54	2028.11	2713.98	3263.31	4084.34	4743.49	5342.38	5671.41	6561.32
Long-4	154.10	780.23	1543.36	2070.44	2822.77	3451.52	3731.22	4011.86	5340.96	6015.89	6857.45
Long-5	6.62	533.52	1441.25	1984.30	2872.57	3281.13	3986.19	4516.42	5410.33	5817.92	6745.35
Long-6	79.21	760.08	1412.33	1888.41	2834.76	3376.85	3897.28	4607.96	5261.05	5890.44	6621.92
Long-7	52.51	556.11	1252.18	2015.57	2760.11	3261.42	3986.78	4785.07	5421.18	5925.00	6676.92
Long-8	45.76	583.68	1401.38	1886.11	2542.87	3360.88	3868.58	4715.89	5115.54	6075.79	6743.62
S01	240.88	346.16	501.52	576.59	662.45	749.51	874.76	913.40	987.46	1100.08	1136.55
S11	47.47	156.60	315.77	378.36	495.60	571.00	694.26	732.36	816.89	925.92	963.42
S12	22.50	81.42	211.96	274.75	380.89	460.86	580.10	625.50	701.50	816.69	851.09
S13	58.95	238.89	461.01	572.47	684.16	810.50	976.36	1020.35	1107.80	1241.40	1280.82

Table E-7. Baseline strain survey raw data (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
S14	306.06	-37.70	-563.36	-830.15	-1223.94	-1486.50	-1833.37	-1983.32	-2218.52	-2462.52	-2583.76
S15	76.71	248.33	474.00	590.40	698.83	826.38	990.38	1032.84	1114.99	1244.66	1280.10
S16	24.99	197.15	403.06	516.79	615.91	752.07	926.09	975.03	1064.27	1203.11	1245.45
S17	157.18	91.02	-15.35	-71.51	-164.62	-215.32	-278.39	-312.58	-362.43	-405.09	-431.96
S18	89.76	251.63	452.12	571.94	677.31	817.82	990.53	1041.88	1127.90	1263.76	1303.32
S19	78.68	212.86	366.90	447.26	511.96	608.37	734.65	771.27	837.05	946.38	979.41
S20	14.37	-114.04	-340.12	-477.00	-719.83	-880.67	-1114.67	-1235.11	-1424.20	-1631.03	-1739.38
S21	34.28	85.76	152.39	208.12	258.13	345.58	468.33	508.09	578.69	692.27	730.33
S22	105.42	262.52	457.05	560.06	664.16	778.84	929.95	973.73	1060.09	1191.08	1234.17
S23											
S24	-183.05	2.35	252.10	371.28	492.61	624.61	795.21	839.26	927.38	1064.17	1098.00
S25	79.73	235.68	409.91	500.12	590.31	694.69	831.85	873.62	950.61	1068.45	1105.53
S26	38.33	-55.71	-255.51	-358.44	-562.86	-670.57	-841.13	-928.53	-1068.91	-1214.06	-1295.64
S27	72.30	206.30	384.52	476.09	571.94	674.11	810.19	852.49	925.52	1040.96	1075.68
S28	79.40	206.00	358.33	438.02	521.14	623.80	760.74	801.74	877.03	997.36	1032.70
S29	125.69	53.79	-93.99	-160.80	-296.31	-350.55	-435.20	-479.25	-545.28	-594.76	-627.59
S30	-40.58	20.84	95.15	149.95	226.92	303.78	434.46	471.17	541.15	648.25	669.11
S4	43.85	179.89	335.99	408.06	499.09	585.64	710.01	747.68	826.36	936.83	972.99
S5	49.87	178.15	331.04	406.95	483.02	572.92	695.74	736.15	806.89	920.57	957.03
S8	65.87	208.37	367.73	438.68	530.49	616.64	739.00	776.23	854.08	966.69	1000.22
IS13	55.22	8.02	-64.07	-76.40	-125.99	-101.26	-63.33	-54.96	-30.46	30.71	52.49
IS14	164.13	264.00	368.25	432.66	471.74	556.37	664.92	690.91	744.60	832.10	857.51
IS15	-28.10	-59.92	-139.84	-160.82	-230.79	-214.86	-190.63	-188.81	-175.82	-124.64	-108.20
IS16	5.16	-18.86	-79.57	-92.98	-160.95	-141.75	-118.85	-117.91	-107.69	-57.40	-43.44
IS17	-2.26	95.56	208.00	274.94	322.72	405.39	504.70	534.87	584.29	660.50	684.78
IS18	-35.10	-52.96	-118.28	-143.71	-229.23	-221.09	-206.84	-208.08	-204.51	-158.31	-144.08
IS19	117.69	114.02	87.58	94.87	52.71	99.42	161.15	175.70	204.16	279.56	302.22
IS20	-212.06	-165.22	-126.19	-103.20	-105.99	-66.44	-13.13	-10.09	4.20	51.80	52.30
IS21	-7.89	66.79	142.66	182.93	189.04	250.79	333.12	355.11	393.64	477.89	502.85
IS22	-30.35	-61.62	-108.23	-123.44	-159.33	-136.33	-93.63	-87.10	-58.56	5.96	26.96
IS23	-18.74	75.03	184.34	242.70	287.52	365.76	467.36	491.59	543.08	628.34	651.55
IS24	-63.23	-107.11	-195.68	-218.70	-283.47	-267.02	-235.08	-229.06	-206.73	-144.28	-123.47
IS25	-44.51	-58.03	-67.68	-61.01	-76.94	-27.60	46.62	66.14	109.69	195.84	224.95
IS26	-4.39	71.01	180.03	239.68	307.94	384.56	489.84	527.52	590.93	680.97	714.94
IS27	-87.71	-71.85	-56.24	-37.66	-42.71	8.52	82.19	106.25	149.35	234.86	264.84
IS28	-128.20	-144.93	-176.81	-182.87	-214.34	-177.76	-120.21	-102.90	-71.33	3.60	27.24
IS29	-17.04	28.26	84.19	112.56	129.87	171.31	224.11	238.78	260.22	305.54	315.94
IS30	-14.14	47.40	110.95	141.05	158.91	211.05	289.69	313.09	353.86	439.37	463.64

Table E-7. Baseline strain survey raw data (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
F01	-49.94	-318.71	-264.63	-328.19	27.67	-68.65	-3.59	37.65	168.83	261.34	260.82
F02	260.30	615.94	666.33	794.22	501.17	696.67	745.55	766.42	754.71	810.06	850.87
F07	96.10	432.26	502.39	633.60	393.43	579.28	632.80	661.49	644.93	714.10	757.27
F08	134.76	-98.25	-81.88	-113.55	217.69	160.90	237.94	263.65	380.92	482.44	483.59
L03	181.18	146.81	141.40	140.64	210.12	187.52	167.38	199.68	232.00	226.75	268.58
L04	-24.06	-65.82	-74.98	-83.07	-12.14	-43.52	-65.46	-39.70	-4.63	-12.54	24.30

**Table E-8. Strain survey raw data at 20,000 cycles for RA, RB, UA, UB, UDA, and UDB
(run 1)**

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.02	0.69	1.38	2.02	2.67	3.34	4.03	4.65	5.31	5.99	6.68
Frame-1	-38.09	79.04	282.67	358.60	427.98	564.91	686.33	806.66	913.15	1018.16	1131.52
Frame-2	-75.90	49.36	159.90	310.30	448.03	556.68	700.98	784.51	924.01	1026.66	1147.26
Frame-3	-13.67	153.08	255.12	318.58	502.23	554.03	704.83	785.06	891.29	1024.97	1148.66
Frame-4	-6.84	102.82	278.77	387.67	494.63	547.42	688.53	775.61	916.46	1039.49	1150.57
Frame-5	-22.14	110.33	192.08	388.54	418.76	536.54	720.95	750.34	861.71	1057.74	1041.91
Frame-6	-76.66	114.08	184.99	338.66	550.63	517.70	784.66	820.97	795.39	889.83	1242.73
Frame-7	-8.48	136.55	268.68	349.32	459.00	522.89	705.60	795.33	895.03	927.83	1167.20
Frame-8	3.07	43.00	228.23	331.62	436.01	587.19	687.94	765.22	874.35	1023.94	1106.27
Frame-9	46.05	264.64	203.21	397.77	511.46	561.11	805.20	778.64	1038.66	1025.86	1149.27
Frame-10	84.62	53.13	274.25	501.04	447.43	627.99	727.55	677.37	807.03	945.89	1000.28
Frame-11	2.26	63.31	182.08	401.91	432.05	556.67	675.91	775.07	928.05	1007.56	1146.04
Frame-12	-56.33	204.11	257.98	350.03	457.78	539.09	675.59	794.27	915.62	1002.67	1139.81
Hoop-1	-18.77	733.69	1573.45	2189.20	2881.18	3582.12	4301.04	4973.83	5733.08	6443.63	7185.16
Hoop-2	36.20	647.82	1277.25	2227.76	2810.34	3631.28	4301.37	4882.99	5657.33	6313.79	7024.05
Hoop-3	6.80	611.66	1385.73	2049.27	2778.20	3458.61	4171.65	5048.32	5730.44	6407.87	7195.91
Hoop-4	-21.59	860.89	1507.17	2238.88	2904.93	3614.41	4283.71	4874.34	5621.97	6380.98	7154.52
Hoop-5	-0.52	725.40	1516.02	2196.85	2857.57	3573.99	4272.16	4957.15	5722.21	6206.76	7159.65
Hoop-6	7.32	689.26	1423.79	2118.39	2807.26	3525.07	4286.26	4910.50	5664.69	6364.81	7337.71
Hoop-7	39.74	702.86	1622.09	2229.59	2987.31	3569.31	4308.76	4954.45	5765.82	6561.55	6808.88
Hoop-8	106.50	665.53	1347.90	2081.77	2764.13	3541.10	4173.25	4921.24	5726.76	6409.97	7062.85
Hoop-9	0.19	832.55	1519.45	2149.67	2771.99	3555.99	4297.36	5052.73	6060.48	6382.25	6996.97
Hoop-10	-35.22	607.01	1569.31	2090.70	2746.85	3561.59	4271.17	4823.77	5590.51	6520.27	7181.27
Hoop-11	39.80	793.60	1384.58	2164.27	2865.51	3659.18	4357.45	5057.17	5542.99	6295.70	7144.78
Hoop-12	-27.10	609.45	1580.46	2153.92	2895.80	3543.31	4307.65	4751.50	5718.65	6388.63	7166.46
Hoop-13	-7.05	657.65	1417.17	2097.04	2841.95	3514.02	4244.96	4931.71	5669.04	6407.49	7181.20
Hoop-14	-54.47	707.61	1520.82	2122.26	2862.20	3558.39	4225.69	4885.30	5661.62	6373.10	7156.59
Long-1	1.92	921.36	1528.28	1886.06	2860.61	3234.39	4190.45	4573.69	5356.90	6228.56	6676.71
Long-2	26.97	743.95	1130.40	2137.28	2691.23	3412.90	3885.45	4885.81	5065.12	5735.84	6695.51
Long-3	5.20	523.62	1339.46	2155.29	2836.80	3499.78	4116.32	4472.59	5387.16	6081.45	6404.63
Long-4	-4.67	729.58	1249.96	1894.91	3003.69	3326.69	4192.53	4469.58	5452.30	5930.11	6762.52
Long-5	8.67	554.79	1321.45	2337.73	3003.52	3101.95	4286.55	4687.38	5500.41	5572.75	6580.24
Long-6	20.35	708.86	1574.97	1873.69	2529.14	3290.74	4129.69	4440.26	5317.98	5807.08	6460.64
Long-7	16.26	569.70	1216.17	1906.90	2459.33	3490.42	4110.59	4524.97	5301.95	6204.88	6413.62
Long-8	26.74	754.19	1215.67	2006.81	2575.67	3469.48	3881.79	4794.05	5246.93	6135.78	6483.64
F01	-58.42	-33.49	-1.49	57.42	101.31	135.98	182.17	233.51	252.77	304.30	343.67
F02	142.91	214.17	244.78	297.85	330.10	353.92	450.71	439.20	568.73	562.29	602.88
F07											

**Table E-8. Strain survey raw data at 20,000 cycles for RA, RB, UA, UB, UDA, and UDB
(run 1) (continued)**

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.02	0.69	1.38	2.02	2.67	3.34	4.03	4.65	5.31	5.99	6.68
F08	-81.17	-7.42	30.91	63.52	140.65	184.06	228.47	278.32	304.65	374.22	402.12
IS13	127.74	19.44	-31.42	-52.48	-61.24	-51.03	-32.14	-10.35	28.90	65.97	120.45
IS14	-47.32	11.02	72.44	114.36	152.46	196.35	240.27	276.77	323.74	360.48	408.00
IS15	6.38	-106.27	-167.20	-204.63	-225.04	-225.58	-216.20	-199.75	-168.11	-139.75	-92.55
IS16	25.72	-33.46	-75.32	-94.31	-104.63	-97.25	-77.90	-56.14	-15.95	18.54	72.57
IS17	-35.04	40.65	122.62	184.22	238.07	296.10	349.38	395.67	445.94	486.27	533.52
IS18	-32.83	-77.94	-106.62	-130.98	-142.69	-133.85	-118.53	-92.19	-55.39	-18.04	37.53
IS19	-5.45	-88.91	-112.85	-113.74	-107.61	-78.14	-45.08	-3.99	44.24	91.39	156.57
IS20	-51.60	-8.72	45.22	91.69	133.37	185.59	232.63	278.47	327.85	372.24	425.35
IS21	-8.30	64.11	128.92	171.48	209.67	262.71	309.88	363.75	419.93	473.24	542.80
IS22	47.68	-70.47	-121.78	-149.72	-159.66	-155.38	-139.19	-119.62	-81.22	-46.89	5.74
IS23	-44.48	10.97	70.49	105.69	140.01	174.96	210.45	238.85	278.27	306.66	347.01
IS24	24.42	-92.43	-160.18	-203.31	-219.09	-221.19	-208.54	-192.22	-155.73	-123.00	-71.61
IS25	23.27	-68.22	-82.10	-79.92	-60.57	-23.81	22.64	65.07	128.88	182.92	254.60
IS26	-4.22	80.47	171.41	241.07	309.47	381.33	452.23	510.03	580.16	637.43	702.87
IS27	-12.96	-45.45	-40.31	-29.23	-4.22	37.08	84.85	128.97	191.54	244.17	313.78
IS28	33.30	-60.30	-95.67	-107.44	-105.01	-80.05	-47.57	-12.49	37.76	81.79	143.47
IS29	-123.94	-82.67	-42.49	-11.86	15.00	47.71	77.75	104.72	135.48	160.28	191.54
IS30	24.82	89.15	125.53	150.53	178.40	220.32	262.35	307.38	361.83	411.01	474.72
L03	-102.37	-84.69	-71.98	-58.51	-30.35	-12.51	5.50	21.33	42.06	71.36	88.25
L04	33.91	42.36	54.11	70.12	97.55	113.55	132.40	148.38	164.98	188.46	203.98
RAA	0.09	105.11	217.83	305.52	396.62	490.32	584.25	662.91	757.88	838.53	928.58
RAF	-21.33	92.42	213.53	310.09	403.88	502.43	600.68	682.76	780.23	862.66	955.93
RBA	-179.26	-48.45	91.84	201.27	296.75	396.31	485.86	563.14	644.40	713.46	788.85
RBF	-47.81	74.16	206.30	309.37	402.06	497.32	582.86	658.63	735.05	803.01	875.80
S01	-40.14	143.94	264.77	353.47	431.26	512.13	593.44	665.49	745.84	814.96	895.12
S11	15.45	196.87	322.52	419.41	503.87	590.04	670.93	748.55	834.02	908.02	992.64
S12	22.35	141.52	249.31	332.47	413.43	502.94	581.07	659.76	740.75	824.15	895.50
S13	-65.63	156.31	334.34	452.92	556.58	658.05	756.20	836.29	927.78	1005.64	1096.17
S14	0.83	-236.34	-461.08	-636.01	-797.34	-951.93	-1088.36	-1203.55	-1318.60	-1420.76	-1510.58
S15	-80.01	137.24	309.36	428.74	528.16	626.54	719.59	796.49	882.56	954.33	1038.72
S16	7.89	200.47	381.80	507.11	619.10	734.85	837.86	928.78	1025.89	1107.85	1201.44
S17	-6.52	-196.49	-401.70	-570.14	-722.79	-868.52	-1001.36	-1116.69	-1228.12	-1334.32	-1430.20
S18	17.65	163.04	304.58	419.13	517.29	623.74	718.91	804.45	894.59	971.01	1059.48
S19	-36.34	154.22	289.54	385.48	469.45	560.81	643.73	719.58	800.99	873.19	955.85
S20	-5.02	-218.85	-479.37	-715.36	-932.48	-1153.89	-1361.39	-1550.33	-1735.06	-1917.38	-2095.86
S21	-14.87	25.20	85.87	151.05	216.50	298.13	375.57	451.33	531.56	605.05	691.91

**Table E-8. Strain survey raw data at 20,000 cycles for RA, RB, UA, UB, UDA, and UDB
(run 1) (continued)**

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.02	0.69	1.38	2.02	2.67	3.34	4.03	4.65	5.31	5.99	6.68
S22	-43.67	173.65	345.81	459.15	559.46	653.51	744.72	819.52	905.91	976.71	1060.49
S23	22.96	-336.53	-668.76	-908.08	-1132.94	-1337.93	-1534.50	-1682.46	-1842.45	-1973.88	-2088.37
S24	-2.94	202.42	376.13	494.19	594.51	692.48	782.87	861.64	949.58	1020.38	1104.13
S25	103.12	359.12	536.95	656.05	759.80	860.39	953.44	1034.44	1121.59	1195.99	1279.24
S26	2.96	-151.02	-309.85	-442.85	-572.04	-699.77	-824.42	-926.75	-1041.77	-1145.44	-1248.58
S27	-11.61	166.13	310.81	412.44	507.03	597.14	678.28	770.39	854.38	921.90	1005.13
S28	71.96	284.45	441.74	552.28	650.26	749.58	839.84	920.91	1003.08	1078.28	1159.49
S29	-7.22	-134.98	-256.97	-363.68	-455.82	-531.92	-607.29	-663.46	-717.63	-759.17	-793.94
S30	-1.35	67.52	155.72	239.49	314.77	402.04	484.57	558.89	632.46	701.12	779.26
S4	-18.17	185.58	316.53	406.49	493.59	577.34	658.12	727.29	812.55	885.24	965.48
S5	-16.94	194.15	291.69	387.79	485.23	592.56	492.77	795.80	846.29	891.94	983.37
S8	61.32	286.61	423.56	514.45	605.95	692.13	781.47	853.10	942.19	1022.91	1105.87
UAA	14.67	84.10	174.84	255.69	330.63	419.32	500.95	580.56	662.32	737.75	823.70
UAF	-25.73	91.94	232.77	355.48	467.09	587.75	697.77	802.57	906.51	1005.82	1113.73
UBA	-81.87	170.92	425.04	620.32	799.96	977.84	1140.27	1274.84	1429.74	1553.22	1680.97
UBF	-81.26	172.08	424.19	617.26	795.89	973.32	1134.51	1269.73	1413.74	1538.37	1666.58
UDAA	-28.59	147.81	336.42	504.76	664.88	839.93	1001.13	1139.10	1289.56	1418.37	1558.63
UDAF	-11.59	147.02	322.43	483.52	630.82	788.69	939.48	1068.33	1209.39	1330.02	1463.45
UDBA	-41.75	163.85	371.51	516.47	659.43	794.10	920.66	1019.42	1135.92	1229.20	1329.83
UDBF	-51.88	156.55	366.75	519.66	661.51	799.25	927.06	1026.53	1142.65	1235.55	1335.62

**Table E-9. Strain survey raw data at 20,000 cycles for RA, RB, UA, UB, UDA, and UDB
(run 2)**

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.02	0.63	1.34	2.02	2.68	3.35	4.02	4.67	5.33	5.94	6.69
Frame-1	42.94	158.05	263.14	305.63	461.36	545.89	679.23	792.43	886.87	1017.86	1128.36
Frame-2	-76.09	141.12	199.68	279.73	477.18	575.79	673.91	800.40	894.52	1035.43	1131.16
Frame-3	-42.97	88.24	233.10	337.90	489.94	553.39	641.36	780.11	910.19	1017.70	1138.16
Frame-4	-11.40	101.62	207.26	402.18	396.91	543.85	688.85	758.73	875.03	974.76	1124.92
Frame-5	-37.13	109.20	259.56	276.56	412.23	638.40	618.78	819.71	903.04	1010.16	1132.84
Frame-6	-5.50	31.88	259.28	425.29	494.87	508.67	748.62	820.18	929.16	1149.64	1247.54
Frame-7	7.71	45.45	233.38	366.99	438.93	514.82	707.39	804.79	944.63	1094.83	1141.34
Frame-8	-18.93	161.93	166.85	340.37	467.33	541.11	657.51	859.52	908.94	1012.57	1101.09
Frame-9	8.29	96.11	264.00	371.49	574.42	540.65	712.07	776.03	921.62	1050.84	1191.03
Frame-10	135.87	121.37	353.35	337.46	508.96	641.19	689.03	830.40	913.24	1011.36	1236.55
Frame-11	67.35	105.66	183.83	311.93	438.85	574.51	680.92	795.83	901.08	1011.12	1125.02
Frame-12	55.22	89.82	271.20	332.38	443.69	545.77	678.82	806.65	890.15	1004.39	1122.91
Hoop-1	59.57	586.06	1369.41	2285.98	2943.70	3571.91	4389.87	5046.71	5718.50	6385.97	7228.89
Hoop-2	-6.84	658.52	1366.92	2143.68	2853.94	3608.69	4096.50	4866.84	5587.38	6353.88	6995.35
Hoop-3	29.27	654.80	1451.39	2201.56	2780.49	3474.86	4216.16	4998.20	5694.15	6304.81	7073.21
Hoop-4	114.58	777.29	1332.87	2037.54	3034.43	3622.39	4314.15	5008.72	5696.42	6310.79	7199.92
Hoop-5	-25.74	718.13	1319.70	2121.41	3007.65	3621.53	4262.73	4935.53	5720.41	6374.92	7125.42
Hoop-6	49.14	758.28	1352.88	1940.39	2800.54	3673.06	4107.64	4921.41	5759.25	6279.97	7174.05
Hoop-7	70.20	711.75	1464.40	2193.97	2706.53	3380.06	4170.35	4891.71	5735.35	6469.00	7224.67
Hoop-8	-24.23	788.96	1370.22	2002.09	2771.12	3454.30	4071.58	4907.21	5640.19	6423.85	7092.61
Hoop-9	14.54	721.33	1367.53	2149.89	2764.54	3608.38	4092.82	4672.82	5739.92	6464.14	7254.25
Hoop-10	47.49	589.42	1518.89	2122.59	2728.98	3577.78	4360.92	4743.28	5698.42	6208.16	7153.82
Hoop-11	-39.76	714.06	1547.87	2186.19	2897.77	3500.43	4147.72	4945.57	5704.46	6356.54	7152.72
Hoop-12	-63.47	622.18	1590.18	2175.97	2684.54	3623.70	4467.73	5079.43	5711.95	6387.99	7145.34
Hoop-13	-36.27	701.48	1410.43	2075.33	2783.23	3558.21	4252.27	5005.27	5625.77	6399.55	7130.77
Hoop-14	70.12	648.99	1396.82	2071.16	2847.26	3580.74	4372.27	5142.33	5706.16	6306.51	7157.31
Long-1	45.52	715.30	1001.74	1692.79	2709.82	3142.08	3877.60	4796.90	4650.28	6133.99	6765.21
Long-2	34.00	751.40	1123.38	1810.76	2486.11	3216.13	3930.49	4510.84	5520.33	5801.15	6715.57
Long-3	1.12	756.58	1516.75	2112.53	2447.90	3020.62	3852.45	4754.14	5114.05	6209.48	6519.94
Long-4	-0.43	598.70	1205.98	1918.35	2752.61	3302.46	4046.94	4784.61	5507.77	5992.10	6515.85
Long-5	21.45	666.18	1066.61	1976.65	2106.32	3182.24	4134.57	4429.20	5482.74	6006.54	6411.95
Long-6	69.80	381.34	1102.94	1849.72	2836.44	3116.48	3855.58	4452.81	5331.13	6123.55	6350.74
Long-7	-3.60	537.46	1444.23	1824.17	2746.98	3159.36	3743.59	4852.84	5258.72	5935.85	6654.58
Long-8	-0.69	387.75	1421.65	1848.02	2760.05	3341.73	3913.80	4542.73	5354.64	5862.08	6804.13
F01	-55.49	-67.33	-44.59	48.17	106.43	123.82	184.99	248.04	236.58	289.90	335.26
F02	138.50	206.24	256.42	300.15	352.02	353.99	425.45	416.59	511.22	554.95	606.03
F07											

**Table E-9. Strain survey raw data at 20,000 cycles for RA, RB, UA, UB, UDA, and UDB
(run 2) (continued)**

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.02	0.63	1.34	2.02	2.68	3.35	4.02	4.67	5.33	5.94	6.69
F08	-86.30	-20.15	37.92	90.65	111.17	177.83	242.60	297.28	317.92	369.94	422.93
IS13	98.64	10.00	-35.77	-64.13	-68.52	-50.31	-34.34	-16.16	31.08	60.88	116.86
IS14	-48.42	16.80	72.99	114.36	153.20	204.32	240.12	271.19	326.66	356.07	408.24
IS15	-10.44	-101.20	-165.76	-206.44	-224.16	-218.37	-213.87	-203.93	-164.69	-142.79	-92.70
IS16	4.15	-50.61	-84.17	-108.14	-107.40	-93.21	-80.12	-61.31	-14.66	14.48	72.37
IS17	-38.34	43.26	118.42	178.39	239.14	302.91	348.19	391.73	446.48	481.07	532.23
IS18	-57.91	-80.27	-117.63	-138.74	-142.34	-128.63	-117.10	-96.89	-52.87	-23.09	36.62
IS19	-17.14	-88.39	-116.32	-122.19	-100.14	-68.47	-43.28	-8.01	47.16	87.00	155.54
IS20	-53.94	-4.37	43.95	89.01	143.21	194.35	235.47	278.99	331.30	369.12	425.70
IS21	-19.74	66.45	120.93	168.87	220.80	271.39	312.40	360.17	420.97	466.84	541.07
IS22	20.20	-82.60	-128.10	-157.02	-164.97	-151.91	-137.39	-117.06	-78.81	-51.62	3.47
IS23	-42.47	16.14	70.40	107.73	143.21	184.38	215.23	242.45	280.90	302.33	344.97
IS24	-7.59	-97.68	-160.92	-201.90	-216.90	-213.05	-206.41	-189.97	-153.50	-128.94	-73.87
IS25	11.81	-72.60	-88.86	-82.90	-56.23	-15.88	23.99	67.29	129.07	176.77	253.99
IS26	-6.12	73.62	162.69	240.46	313.90	386.82	451.42	511.88	579.28	631.82	703.25
IS27	-42.25	-63.20	-57.29	-37.97	-3.23	39.30	81.19	125.46	188.03	236.80	314.05
IS28	22.51	-66.42	-102.00	-110.71	-95.69	-71.83	-45.27	-13.03	36.85	77.04	144.25
IS29	-122.54	-83.75	-45.91	-11.36	23.38	54.10	79.97	103.98	134.21	156.26	190.35
IS30	5.64	73.51	110.69	145.24	184.52	223.64	261.56	302.42	357.04	403.82	474.41
L03	-109.43	-106.15	-77.98	-60.53	-48.73	-34.52	-4.51	24.78	34.42	71.17	91.38
L04	43.55	33.22	53.75	74.20	82.76	96.37	126.04	155.01	162.38	192.45	203.60
RAA	-1.46	94.78	206.91	307.64	402.90	497.52	584.18	667.57	757.70	832.62	930.59
RAF	-19.92	87.27	205.53	311.31	412.16	511.63	601.71	686.70	780.78	857.11	957.58
RBA	-176.08	-42.14	89.91	197.36	301.08	405.61	485.83	562.77	646.37	707.56	787.20
RBF	-45.98	81.08	205.03	306.05	404.32	507.03	583.15	658.92	739.95	799.48	875.97
S01	-36.85	135.45	251.31	348.88	430.98	517.14	591.37	658.14	746.57	810.87	897.12
S11	15.63	180.69	305.95	407.09	492.34	581.76	659.87	737.81	821.71	882.59	973.15
S12	18.89	134.49	247.49	335.33	424.78	505.76	579.72	660.97	743.29	811.89	907.31
S13	-21.67	187.87	347.53	471.42	573.55	677.97	763.18	838.41	934.38	999.68	1092.95
S14	-20.45	-257.63	-478.59	-652.05	-808.58	-966.96	-1097.48	-1217.31	-1326.68	-1420.66	-1516.72
S15	-63.24	140.02	303.17	429.82	535.74	637.59	719.77	790.76	882.74	943.85	1034.76
S16	34.46	234.23	393.27	525.52	639.26	756.29	848.12	929.60	1031.36	1101.55	1202.29
S17	-18.39	-206.21	-404.90	-570.56	-723.66	-876.32	-1001.45	-1127.04	-1234.06	-1331.72	-1433.15
S18	37.83	174.74	311.45	425.21	538.96	641.60	725.45	802.91	897.14	963.09	1059.54
S19	-26.15	160.83	289.54	392.91	487.01	574.74	647.69	718.06	800.26	862.91	952.59
S20	-21.15	-226.56	-477.65	-717.33	-946.50	-1168.67	-1366.57	-1571.76	-1754.10	-1921.45	-2105.18
S21	-10.09	25.66	83.82	150.11	232.47	310.29	380.77	452.01	534.02	599.44	692.05

**Table E-9. Strain survey raw data at 20,000 cycles for RA, RB, UA, UB, UDA, and UDB
(run 2) (continued)**

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.02	0.63	1.34	2.02	2.68	3.35	4.02	4.67	5.33	5.94	6.69
S22	-6.38	202.28	356.12	475.20	576.24	672.68	754.62	827.37	910.67	971.06	1058.54
S23	30.97	-310.24	-641.93	-899.02	-1119.26	-1334.37	-1517.77	-1682.70	-1835.89	-1961.11	-2098.00
S24	34.33	219.15	377.72	499.94	608.12	707.69	790.41	865.51	948.79	1011.55	1102.19
S25	115.81	361.26	534.04	661.40	770.14	872.19	957.55	1034.34	1120.86	1184.24	1274.66
S26	-5.84	-143.34	-305.52	-451.51	-580.18	-705.97	-825.56	-940.47	-1049.20	-1149.70	-1260.29
S27	-2.51	154.00	288.80	405.87	507.31	604.90	695.37	756.67	842.19	911.43	1007.36
S28	88.68	288.20	438.10	560.51	662.04	759.93	842.44	916.45	999.44	1062.88	1154.13
S29	-9.22	-125.37	-250.23	-355.94	-448.70	-524.96	-595.15	-661.38	-711.20	-756.58	-792.71
S30	-8.27	56.61	146.98	232.85	322.31	406.31	477.16	548.09	623.35	687.74	770.46
S4	0.58	186.22	312.88	411.79	498.83	585.08	664.58	739.93	814.09	880.48	966.94
S5	36.98	238.39	355.41	454.09	536.78	618.30	696.86	760.05	839.87	910.15	985.46
S8	63.55	265.18	400.29	504.78	599.93	686.78	769.73	852.92	934.04	1004.16	1097.60
UAA	15.94	91.23	174.66	256.70	346.52	433.23	506.83	584.68	668.69	736.22	826.03
UAF	-21.44	96.35	229.67	353.44	480.31	601.35	702.68	809.77	916.71	1004.99	1116.36
UBA	-68.09	188.38	434.64	629.45	806.82	995.42	1146.46	1280.68	1436.99	1548.71	1687.44
UBF	-67.42	188.87	433.09	626.23	801.69	990.96	1140.35	1274.51	1423.74	1534.58	1671.80
UDAA	-25.92	132.46	317.98	508.57	684.42	854.55	1001.63	1145.83	1291.84	1413.67	1565.34
UDAF	-9.54	136.29	307.09	483.25	649.35	801.41	940.68	1073.42	1210.67	1325.34	1466.95
UDBA	-43.37	153.40	362.26	521.21	659.38	802.06	921.30	1027.66	1138.10	1220.73	1330.54
UDBF	-48.15	155.16	364.21	524.95	665.64	809.02	928.25	1032.05	1145.19	1227.99	1336.70

**Table E-10. Strain survey raw data at 20,000 cycles for RA, RB, UA, UB, UDA, and UDB
(run 3)**

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.71	1.31	2.03	2.69	3.39	3.96	4.67	5.26	6.06	6.68
Frame-1	32.02	102.97	251.02	371.17	437.38	558.93	719.05	817.76	902.74	1017.90	1134.55
Frame-2	73.37	168.86	286.73	313.69	480.99	567.56	666.86	833.28	888.28	992.83	1100.75
Frame-3	-74.69	110.73	173.68	361.88	458.75	562.54	712.59	803.12	912.83	1002.50	1128.50
Frame-4	-24.41	131.30	172.35	408.47	444.45	555.03	657.15	818.06	847.00	1051.02	1091.33
Frame-5	-49.14	97.52	178.81	324.15	443.94	609.64	644.79	831.30	889.29	1046.84	1128.82
Frame-6	-89.25	36.39	402.15	420.10	544.54	666.17	665.20	928.71	894.04	1074.19	1215.41
Frame-7	-3.79	110.69	174.64	369.00	526.77	620.84	646.14	814.80	932.83	1090.34	1184.77
Frame-8	-31.81	91.99	235.91	406.78	440.33	562.90	637.72	829.93	923.59	1005.17	1109.07
Frame-9	-2.86	114.53	233.13	363.89	455.62	673.30	670.21	818.32	915.06	1081.91	1162.25
Frame-10	-56.51	304.65	219.15	227.08	476.47	625.78	558.02	831.49	942.35	1094.44	1113.82
Frame-11	-43.95	85.69	241.55	310.93	464.50	600.61	714.34	817.22	898.13	1043.35	1133.50
Frame-12	-45.84	182.84	214.12	363.76	469.50	589.74	677.92	793.14	903.20	1010.46	1123.53
Hoop-1	8.56	810.37	1316.71	2218.57	3073.67	3631.29	4014.99	5063.92	5570.93	6539.02	7238.34
Hoop-2	41.59	590.54	1295.31	2097.05	2763.02	3419.61	4147.12	4887.39	5678.85	6344.91	7090.74
Hoop-3	-43.32	627.34	1486.10	2068.49	2770.67	3398.11	4213.12	4888.34	5694.15	6415.43	7021.74
Hoop-4	-63.36	950.06	1218.61	2259.07	2786.22	3708.84	4258.29	4887.89	5538.44	6521.45	7153.03
Hoop-5	-25.74	761.58	1355.86	2222.28	2772.23	3649.64	4248.75	4853.50	5579.91	6533.45	7046.47
Hoop-6	25.50	785.79	1431.21	2056.77	2826.56	3588.67	4260.80	5096.80	5619.22	6536.40	7143.45
Hoop-7	-33.74	790.83	1371.35	2190.38	2974.17	3691.19	4233.49	5078.90	5665.45	6415.23	7171.25
Hoop-8	-2.45	680.32	1464.49	2059.98	2727.82	3447.73	4195.45	4898.97	5663.11	6431.76	7086.05
Hoop-9	1.99	875.95	1309.98	2413.42	2752.26	3481.68	4304.97	4926.64	5579.55	6879.25	7134.74
Hoop-10	-5.30	755.11	1464.19	2148.77	2922.82	3618.98	4023.43	4949.98	5738.28	6414.68	7107.02
Hoop-11	-3.60	830.08	1383.19	2225.74	2874.55	3573.47	4332.57	4897.58	5664.01	6434.92	7095.57
Hoop-12	-8.91	831.65	1484.52	2212.13	2895.80	3762.70	4002.46	5012.94	5647.59	6425.01	7153.33
Hoop-13	-14.36	716.37	1410.29	2089.73	2812.73	3602.76	4223.46	5055.41	5685.35	6407.49	7109.56
Hoop-14	-17.83	803.19	1367.37	2100.27	2869.53	3647.42	4182.13	5009.40	5597.34	6380.43	7114.04
Long-1	0.74	877.94	1279.04	1950.13	2367.59	3472.16	4031.15	4811.98	5374.11	6143.79	6699.89
Long-2	8.92	912.41	1197.23	1765.30	2436.21	3440.67	4027.10	4681.64	5361.29	6022.94	6808.28
Long-3	2.80	823.84	1118.56	1834.52	2817.34	3025.72	4170.66	4419.22	5470.04	5730.79	6405.27
Long-4	2.03	547.52	1315.50	1919.21	2772.88	3489.89	4099.55	4711.38	5147.12	5951.62	6622.54
Long-5	-7.42	100.74	1546.86	1661.40	2346.97	3427.95	4074.57	4722.40	5424.69	5716.54	6645.42
Long-6	63.50	793.78	1100.02	2217.53	2565.98	3516.97	4230.86	4549.96	5393.67	5757.55	6660.18
Long-7	-4.36	741.58	1487.13	2062.50	2563.42	3368.90	3813.76	4607.91	5078.66	6135.86	6791.78
Long-8	3.03	756.43	1484.56	1963.30	2775.35	3361.13	3879.69	4625.73	5259.72	6083.32	6624.17
F01	-66.60	-39.49	-27.13	14.88	93.99	151.32	200.57	228.26	244.66	302.42	356.95
F02	139.26	184.33	238.23	314.71	296.46	390.46	378.01	453.81	486.62	551.98	569.40
F07											

**Table E-10. Strain survey raw data at 20,000 cycles for RA, RB, UA, UB, UDA, and UDB
(run 3) (continued)**

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.71	1.31	2.03	2.69	3.39	3.96	4.67	5.26	6.06	6.68
F08	-72.68	11.00	28.88	75.72	163.62	209.21	257.09	306.00	333.87	373.04	452.25
IS13	97.93	-8.16	-46.67	-65.58	-69.20	-57.59	-48.86	-11.80	20.91	71.05	109.55
IS14	-49.15	17.17	61.43	118.34	155.35	198.92	226.79	278.24	316.33	368.21	401.24
IS15	-10.44	-120.58	-172.10	-205.01	-225.22	-226.89	-225.31	-198.32	-173.35	-131.05	-100.12
IS16	1.02	-61.87	-91.74	-107.05	-112.37	-99.67	-91.94	-54.31	-23.32	28.49	65.37
IS17	-40.43	46.25	112.56	185.00	240.33	298.01	338.37	396.16	438.48	493.13	525.74
IS18	-63.70	-96.36	-125.22	-135.32	-147.92	-138.39	-128.13	-92.92	-60.26	-5.41	29.05
IS19	-20.25	-101.87	-120.34	-116.90	-107.74	-77.44	-52.76	-3.81	39.50	106.53	148.35
IS20	-54.13	-1.28	41.58	97.91	139.48	191.30	227.59	282.86	325.77	385.61	422.08
IS21	-22.38	65.70	113.80	174.72	210.33	262.77	302.63	360.56	413.42	488.95	533.81
IS22	12.02	-96.07	-138.47	-159.79	-165.67	-156.62	-151.22	-116.63	-87.66	-40.97	-1.76
IS23	-43.93	18.31	58.52	108.68	142.75	181.42	199.43	243.36	271.73	311.91	339.85
IS24	-0.15	-114.01	-172.09	-204.13	-223.45	-220.53	-222.72	-189.26	-162.48	-115.53	-82.03
IS25	0.81	-81.65	-98.45	-79.96	-62.01	-20.08	8.11	70.25	119.94	194.64	246.26
IS26	-10.31	84.38	153.88	244.99	310.91	387.39	439.52	513.90	571.54	647.35	696.87
IS27	-41.71	-66.78	-67.03	-34.37	-12.38	34.49	65.12	128.18	179.69	255.91	306.08
IS28	13.36	-76.45	-109.51	-108.80	-106.91	-79.13	-59.64	-11.49	30.49	94.15	136.73
IS29	-127.03	-81.12	-52.73	-9.72	15.54	49.55	69.75	104.01	129.88	164.98	185.72
IS30	13.90	74.91	100.73	144.64	171.16	215.38	245.58	301.00	350.09	419.45	466.33
L03	-104.54	-88.87	-79.80	-65.26	-40.51	-23.79	5.68	16.23	44.80	64.25	95.16
L04	47.52	49.05	62.53	71.52	95.99	109.14	139.53	146.93	169.90	182.51	212.08
RAA	-6.88	110.03	197.07	313.84	399.16	499.62	571.62	670.44	749.55	852.93	923.84
RAF	-22.97	102.84	197.89	318.59	409.87	514.29	588.97	690.84	772.28	878.14	949.92
RBA	-176.90	-30.93	85.97	207.13	305.96	403.12	475.36	567.42	637.57	724.19	780.09
RBF	-48.16	90.47	201.41	316.56	412.37	504.78	575.55	664.86	732.19	815.35	871.27
S01	-46.68	147.22	245.12	354.53	431.77	517.06	582.09	667.01	735.87	826.80	889.66
S11	-7.25	180.94	289.79	403.00	498.67	590.46	659.62	751.94	826.64	919.46	995.78
S12	24.16	159.51	237.68	339.87	424.67	510.41	577.73	665.64	732.61	834.16	900.77
S13	-29.73	205.37	332.14	478.75	573.88	678.10	746.83	845.90	920.74	1018.63	1087.38
S14	-28.17	-290.10	-475.42	-667.12	-827.75	-977.23	-1095.06	-1223.19	-1323.94	-1435.40	-1515.71
S15	-72.90	155.63	285.50	433.28	529.53	633.16	699.15	795.84	866.79	961.97	1025.97
S16	30.19	245.97	378.34	535.54	639.00	753.53	830.93	937.98	1018.74	1124.01	1193.25
S17	-22.04	-233.88	-412.16	-585.67	-745.85	-887.78	-1006.86	-1134.84	-1235.53	-1350.86	-1437.92
S18	34.93	189.54	299.62	434.63	530.63	638.00	708.68	808.89	884.49	986.46	1049.48
S19	-31.25	175.31	275.00	398.01	477.94	570.49	632.94	720.38	792.50	883.92	944.94
S20	-19.80	-260.68	-488.53	-734.60	-963.97	-1181.10	-1371.10	-1577.38	-1748.78	-1952.67	-2109.82
S21	-14.23	33.11	78.64	158.67	224.44	309.12	371.33	455.38	526.54	622.48	686.00

**Table E-10. Strain survey raw data at 20,000 cycles for RA, RB, UA, UB, UDA, and UDB
(run 3) (continued)**

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.71	1.31	2.03	2.69	3.39	3.96	4.67	5.26	6.06	6.68
S22	-0.83	218.85	345.81	478.37	575.84	674.40	734.56	831.51	899.04	986.82	1054.94
S23	33.16	-362.45	-620.56	-912.00	-1132.14	-1351.55	-1508.29	-1688.33	-1828.78	-1987.02	-2090.06
S24	20.86	235.72	364.23	503.91	604.52	705.45	770.34	869.65	937.18	1028.89	1095.41
S25	119.28	384.92	520.23	664.31	768.87	872.37	939.81	1037.45	1108.83	1203.75	1270.52
S26	-9.07	-178.49	-310.53	-467.50	-593.08	-725.39	-832.42	-950.82	-1051.52	-1174.38	-1264.07
S27	-15.06	174.68	286.25	412.79	508.05	607.57	676.60	774.65	846.81	942.82	1013.14
S28	83.60	306.28	427.18	563.42	656.48	759.35	823.99	921.00	995.37	1088.99	1153.66
S29	-7.58	-152.66	-256.79	-372.67	-461.83	-544.72	-611.66	-672.41	-720.44	-771.78	-803.28
S30	-19.94	66.79	138.78	241.41	320.26	409.31	470.64	553.66	618.98	709.00	767.05
S4	1.14	203.95	307.08	414.46	501.57	589.50	651.05	739.43	806.80	895.12	963.84
S5	-21.56	206.89	290.09	391.72	471.83	561.71	615.00	684.05	748.96	851.76	907.33
S8	53.92	277.57	385.53	500.37	590.29	686.92	749.87	846.01	913.19	1013.24	1094.54
UAA	14.85	98.64	173.02	266.88	343.37	430.40	500.68	588.44	663.43	758.87	821.70
UAF	-25.54	110.70	230.58	364.73	481.61	600.56	698.09	814.13	908.97	1028.76	1112.27
UBA	-61.76	217.64	422.87	646.11	824.55	999.61	1128.73	1291.81	1423.65	1573.19	1678.79
UBF	-61.98	218.05	422.73	643.68	821.12	993.53	1124.56	1287.67	1412.35	1559.69	1664.40
UDAA	-34.67	158.83	307.15	519.03	673.29	857.01	986.88	1148.34	1281.58	1446.23	1556.34
UDAF	-15.23	158.76	298.94	493.86	638.97	803.76	924.92	1076.04	1199.92	1355.43	1458.90
UDBA	-44.46	184.88	342.13	528.83	665.80	808.75	902.89	1031.13	1127.19	1241.46	1322.57
UDBF	-47.57	184.82	347.49	534.20	672.79	815.35	910.56	1037.69	1134.11	1249.08	1327.82

Table E-11. Strain survey raw data 40,000 cycles (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
Frame-1	-38.09	79.04	282.67	358.60	427.98	564.91	686.33	806.66	913.15	1018.16	1131.52
Frame-2	-75.90	49.36	159.90	310.30	448.03	556.68	700.98	784.51	924.01	1026.66	1147.26
Frame-3	-13.67	153.08	255.12	318.58	502.23	554.03	704.83	785.06	891.29	1024.97	1148.66
Frame-4	-6.84	102.82	278.77	387.67	494.63	547.42	688.53	775.61	916.46	1039.49	1150.57
Frame-5	-22.14	110.33	192.08	388.54	418.76	536.54	720.95	750.34	861.71	1057.74	1041.91
Frame-6	-76.66	114.08	184.99	338.66	550.63	517.70	784.66	820.97	795.39	889.83	1242.73
Frame-7	-8.48	136.55	268.68	349.32	459.00	522.89	705.60	795.33	895.03	927.83	1167.20
Frame-8	3.07	43.00	228.23	331.62	436.01	587.19	687.94	765.22	874.35	1023.94	1106.27
Frame-9	46.05	264.64	203.21	397.77	511.46	561.11	805.20	778.64	1038.66	1025.86	1149.27
Frame-10	84.62	53.13	274.25	501.04	447.43	627.99	727.55	677.37	807.03	945.89	1000.28
Frame-11	2.26	63.31	182.08	401.91	432.05	556.67	675.91	775.07	928.05	1007.56	1146.04
Frame-12	-56.33	204.11	257.98	350.03	457.78	539.09	675.59	794.27	915.62	1002.67	1139.81
Hoop-1	-18.77	733.69	1573.45	2189.20	2881.18	3582.12	4301.04	4973.83	5733.08	6443.63	7185.16
Hoop-2	-35.22	607.01	1569.31	2090.70	2746.85	3561.59	4271.17	4823.77	5590.51	6520.27	7181.27
Hoop-3	39.80	793.60	1384.58	2164.27	2865.51	3659.18	4357.45	5057.17	5542.99	6295.70	7144.78
Hoop-4	-27.10	609.45	1580.46	2153.92	2895.80	3543.31	4307.65	4751.50	5718.65	6388.63	7166.46
Hoop-5	-7.05	657.65	1417.17	2097.04	2841.95	3514.02	4244.96	4931.71	5669.04	6407.49	7181.20
Hoop-6	-54.47	707.61	1520.82	2122.26	2862.20	3558.39	4225.69	4885.30	5661.62	6373.10	7156.59
Hoop-7	36.20	647.82	1277.25	2227.76	2810.34	3631.28	4301.37	4882.99	5657.33	6313.79	7024.05
Hoop-8	6.80	611.66	1385.73	2049.27	2778.20	3458.61	4171.65	5048.32	5730.44	6407.87	7195.91
Hoop-9	-21.59	860.89	1507.17	2238.88	2904.93	3614.41	4283.71	4874.34	5621.97	6380.98	7154.52
Hoop-10	-0.52	725.40	1516.02	2196.85	2857.57	3573.99	4272.16	4957.15	5722.21	6206.76	7159.65
Hoop-11	7.32	689.26	1423.79	2118.39	2807.26	3525.07	4286.26	4910.50	5664.69	6364.81	7337.71
Hoop-12	39.74	702.86	1622.09	2229.59	2987.31	3569.31	4308.76	4954.45	5765.82	6561.55	6808.88
Hoop-13	106.50	665.53	1347.90	2081.77	2764.13	3541.10	4173.25	4921.24	5726.76	6409.97	7062.85
Hoop-14	0.19	832.55	1519.45	2149.67	2771.99	3555.99	4297.36	5052.73	6060.48	6382.25	6996.97
Long-1	1.92	921.36	1528.28	1886.06	2860.61	3234.39	4190.45	4573.69	5356.90	6228.56	6676.71
Long-2	26.97	743.95	1130.40	2137.28	2691.23	3412.90	3885.45	4885.81	5065.12	5735.84	6695.51
Long-3	5.20	523.62	1339.46	2155.29	2836.80	3499.78	4116.32	4472.59	5387.16	6081.45	6404.63
Long-4	-4.67	729.58	1249.96	1894.91	3003.69	3326.69	4192.53	4469.58	5452.30	5930.11	6762.52
Long-5	8.67	554.79	1321.45	2337.73	3003.52	3101.95	4286.55	4687.38	5500.41	5572.75	6580.24
Long-6	20.35	708.86	1574.97	1873.69	2529.14	3290.74	4129.69	4440.26	5317.98	5807.08	6460.64
Long-7	16.26	569.70	1216.17	1906.90	2459.33	3490.42	4110.59	4524.97	5301.95	6204.88	6413.62
Long-8	26.74	754.19	1215.67	2006.81	2575.67	3469.48	3881.79	4794.05	5246.93	6135.78	6483.64
IS13	124.63	23.51	-16.36	-36.97	-28.24	-17.36	15.25	52.66	94.62	138.85	177.53
IS19	53.61	-36.06	-64.93	-54.51	-41.53	-24.01	20.00	65.84	111.87	167.95	210.55
IS20	44.43	88.61	134.94	193.88	239.09	278.23	331.94	380.73	425.85	474.97	509.62

Table E-11. Strain survey raw data 40,000 cycles (run 1) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
IS21	-28.18	23.76	80.84	140.07	184.84	223.24	281.86	339.82	394.25	456.81	504.40
IS22	183.94	85.00	38.90	21.11	23.06	29.53	54.93	89.50	126.24	170.36	203.51
IS23	-183.85	-138.41	-100.75	-62.75	-26.21	-3.70	32.56	66.28	96.19	126.75	142.65
IS24	193.07	85.93	37.32	13.15	5.17	0.50	19.63	46.93	75.95	111.69	138.07
IS28	106.19	-7.00	-55.15	-54.37	-45.30	-23.89	18.61	63.38	111.29	164.08	208.72
IS29	-100.35	-50.12	-13.71	13.96	41.62	86.79	100.59	162.49	173.41	192.36	245.57
IS30	-20.17	26.81	60.20	104.66	137.97	171.09	226.24	277.02	331.09	389.16	437.68
S13	-119.67	81.01	232.66	367.37	473.47	559.36	658.79	746.74	830.23	907.22	973.34
S14											
S15	60.81	258.42	388.25	517.22	616.25	695.26	789.82	870.83	948.11	1020.39	1081.13
S19	101.90	293.20	425.61	545.53	636.31	712.21	804.35	885.16	962.25	1040.17	1100.76
S20											
S21	140.89	204.61	261.62	347.14	418.12	487.64	572.11	650.96	727.49	808.82	872.34
S22	-19.68	180.65	322.01	445.77	552.74	631.64	727.59	811.43	890.10	968.86	1024.43
S23											
S24	16.65	207.97	345.48	468.34	573.69	651.04	748.30	831.29	912.03	988.50	1043.99
S28	-148.94	-21.58	51.21	109.42	142.15	169.14	209.11	236.79	263.72	292.86	303.84
S29											
S30											
UAA	-1181.67	-1103.98	-1026.28	-928.65	-844.87	-772.48	-678.47	-595.65	-517.12	-431.37	-367.46
UAF	-18.48	115.81	234.77	372.96	491.79	600.20	720.39	827.19	931.37	1038.93	1122.76
UBA	-21.51	160.54	322.47	482.11	618.95	730.54	857.64	964.86	1063.08	1156.69	1225.52
UBF	-22.45	169.97	334.13	502.01	641.90	757.37	888.93	998.00	1097.31	1194.91	1267.46
UDAA	131.69	308.25	441.34	607.41	739.56	874.55	1006.95	1124.43	1234.35	1342.76	1433.51
UDAF	69.73	231.35	355.87	511.72	639.11	761.12	891.72	1006.95	1113.13	1219.24	1306.34
UDBA	125.99	377.48	576.44	783.72	961.20	1122.96	1278.34	1419.88	1545.87	1663.52	1753.07
UDBF	64.53	307.41	501.25	701.63	873.47	1025.03	1176.42	1312.31	1433.39	1544.84	1632.19

Table E-12. Strain survey raw data 40,000 cycles (run 2)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
Frame-1	-38.09	79.04	282.67	358.60	427.98	564.91	686.33	806.66	913.15	1018.16	1131.52
Frame-2	-75.90	49.36	159.90	310.30	448.03	556.68	700.98	784.51	924.01	1026.66	1147.26
Frame-3	-13.67	153.08	255.12	318.58	502.23	554.03	704.83	785.06	891.29	1024.97	1148.66
Frame-4	-6.84	102.82	278.77	387.67	494.63	547.42	688.53	775.61	916.46	1039.49	1150.57
Frame-5	-22.14	110.33	192.08	388.54	418.76	536.54	720.95	750.34	861.71	1057.74	1041.91
Frame-6	-76.66	114.08	184.99	338.66	550.63	517.70	784.66	820.97	795.39	889.83	1242.73
Frame-7	-8.48	136.55	268.68	349.32	459.00	522.89	705.60	795.33	895.03	927.83	1167.20
Frame-8	3.07	43.00	228.23	331.62	436.01	587.19	687.94	765.22	874.35	1023.94	1106.27
Frame-9	46.05	264.64	203.21	397.77	511.46	561.11	805.20	778.64	1038.66	1025.86	1149.27
Frame-10	84.62	53.13	274.25	501.04	447.43	627.99	727.55	677.37	807.03	945.89	1000.28
Frame-11	2.26	63.31	182.08	401.91	432.05	556.67	675.91	775.07	928.05	1007.56	1146.04
Frame-12	-56.33	204.11	257.98	350.03	457.78	539.09	675.59	794.27	915.62	1002.67	1139.81
Hoop-1	-18.77	733.69	1573.45	2189.20	2881.18	3582.12	4301.04	4973.83	5733.08	6443.63	7185.16
Hoop-2	-35.22	607.01	1569.31	2090.70	2746.85	3561.59	4271.17	4823.77	5590.51	6520.27	7181.27
Hoop-3	39.80	793.60	1384.58	2164.27	2865.51	3659.18	4357.45	5057.17	5542.99	6295.70	7144.78
Hoop-4	-27.10	609.45	1580.46	2153.92	2895.80	3543.31	4307.65	4751.50	5718.65	6388.63	7166.46
Hoop-5	-7.05	657.65	1417.17	2097.04	2841.95	3514.02	4244.96	4931.71	5669.04	6407.49	7181.20
Hoop-6	-54.47	707.61	1520.82	2122.26	2862.20	3558.39	4225.69	4885.30	5661.62	6373.10	7156.59
Hoop-7	36.20	647.82	1277.25	2227.76	2810.34	3631.28	4301.37	4882.99	5657.33	6313.79	7024.05
Hoop-8	6.80	611.66	1385.73	2049.27	2778.20	3458.61	4171.65	5048.32	5730.44	6407.87	7195.91
Hoop-9	-21.59	860.89	1507.17	2238.88	2904.93	3614.41	4283.71	4874.34	5621.97	6380.98	7154.52
Hoop-10	-0.52	725.40	1516.02	2196.85	2857.57	3573.99	4272.16	4957.15	5722.21	6206.76	7159.65
Hoop-11	7.32	689.26	1423.79	2118.39	2807.26	3525.07	4286.26	4910.50	5664.69	6364.81	7337.71
Hoop-12	39.74	702.86	1622.09	2229.59	2987.31	3569.31	4308.76	4954.45	5765.82	6561.55	6808.88
Hoop-13	106.50	665.53	1347.90	2081.77	2764.13	3541.10	4173.25	4921.24	5726.76	6409.97	7062.85
Hoop-14	0.19	832.55	1519.45	2149.67	2771.99	3555.99	4297.36	5052.73	6060.48	6382.25	6996.97
Long-1	1.92	921.36	1528.28	1886.06	2860.61	3234.39	4190.45	4573.69	5356.90	6228.56	6676.71
Long-2	26.97	743.95	1130.40	2137.28	2691.23	3412.90	3885.45	4885.81	5065.12	5735.84	6695.51
Long-3	5.20	523.62	1339.46	2155.29	2836.80	3499.78	4116.32	4472.59	5387.16	6081.45	6404.63
Long-4	-4.67	729.58	1249.96	1894.91	3003.69	3326.69	4192.53	4469.58	5452.30	5930.11	6762.52
Long-5	8.67	554.79	1321.45	2337.73	3003.52	3101.95	4286.55	4687.38	5500.41	5572.75	6580.24
Long-6	20.35	708.86	1574.97	1873.69	2529.14	3290.74	4129.69	4440.26	5317.98	5807.08	6460.64
Long-7	16.26	569.70	1216.17	1906.90	2459.33	3490.42	4110.59	4524.97	5301.95	6204.88	6413.62
Long-8	26.74	754.19	1215.67	2006.81	2575.67	3469.48	3881.79	4794.05	5246.93	6135.78	6483.64
IS13	75.77	-4.55	-60.03	-58.77	-55.13	-20.03	14.20	35.38	75.53	132.07	180.24
IS19	20.19	-48.66	-79.53	-64.93	-53.59	-12.32	37.34	60.94	109.90	169.39	220.21
IS20	36.40	88.41	129.37	188.70	231.60	287.76	345.53	377.60	424.43	475.15	516.52
IS21	-25.59	35.10	73.97	134.87	175.52	235.72	300.23	335.58	393.86	457.62	511.61

Table E-12. Strain survey raw data 40,000 cycles (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
IS22	154.29	73.03	29.11	15.93	12.38	32.52	63.60	81.03	119.01	167.80	215.13
IS23	-181.31	-128.50	-93.70	-58.46	-31.61	9.49	49.63	64.77	95.55	130.46	159.40
IS24	157.39	77.21	29.43	7.98	-6.39	6.21	28.92	38.29	67.95	110.86	148.35
IS28	78.12	-17.47	-63.10	-58.43	-48.23	-14.97	32.75	60.91	108.79	166.62	214.70
IS29	-109.09	-35.55	-28.27	33.62	88.95	97.69	128.96	151.64	178.58	241.85	244.09
IS30	-7.80	34.35	66.46	104.41	133.99	184.70	239.74	275.84	328.67	390.62	440.96
S13	-53.02	141.05	268.50	390.15	483.08	593.67	687.94	753.71	830.57	915.92	990.09
S14											
S15	81.22	269.30	394.73	516.59	608.35	716.26	807.15	870.53	942.65	1029.04	1097.79
S19	125.17	315.68	432.80	546.36	633.53	731.71	823.09	885.60	960.45	1041.52	1112.29
S20											
S21	118.16	187.11	250.11	333.84	407.29	494.46	583.08	644.60	721.46	803.19	874.94
S22	8.00	209.75	341.61	450.96	542.65	649.73	746.38	808.92	888.27	970.22	1046.19
S23											
S24	45.74	234.11	357.78	468.43	562.89	669.09	769.23	830.25	908.75	990.58	1064.26
S28	-220.27	-81.25	-5.57	57.76	98.51	145.81	192.33	204.87	237.61	268.08	291.43
S29											
S30											
UAA	-1185.31	-1103.76	-1027.53	-928.83	-852.31	-759.24	-659.43	-599.58	-516.60	-431.33	-360.15
UAF	-16.20	109.96	236.55	370.31	486.79	612.83	740.64	829.25	933.75	1038.65	1133.58
UBA	-16.14	168.33	328.05	480.75	600.89	746.95	873.10	954.24	1049.68	1152.21	1231.58
UBF	-11.68	179.79	341.73	500.65	624.87	774.74	904.44	989.37	1086.97	1193.14	1275.73
UDAA	141.34	289.63	446.53	607.35	745.53	879.47	1020.39	1121.71	1232.66	1343.72	1436.28
UDAF	75.60	213.97	356.67	514.64	642.47	772.90	908.60	1001.90	1111.61	1219.89	1310.26
UDBA	152.10	381.22	594.09	787.87	956.13	1130.53	1293.67	1407.53	1531.80	1653.74	1759.61
UDBF	89.45	314.78	516.38	708.84	868.39	1037.15	1192.68	1301.36	1419.46	1538.89	1637.46

Table E-13. Strain survey raw data 40,000 cycles (run 3)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
Frame-1	-38.09	79.04	282.67	358.60	427.98	564.91	686.33	806.66	913.15	1018.16	1131.52
Frame-2	-75.90	49.36	159.90	310.30	448.03	556.68	700.98	784.51	924.01	1026.66	1147.26
Frame-3	-13.67	153.08	255.12	318.58	502.23	554.03	704.83	785.06	891.29	1024.97	1148.66
Frame-4	-6.84	102.82	278.77	387.67	494.63	547.42	688.53	775.61	916.46	1039.49	1150.57
Frame-5	-22.14	110.33	192.08	388.54	418.76	536.54	720.95	750.34	861.71	1057.74	1041.91
Frame-6	-76.66	114.08	184.99	338.66	550.63	517.70	784.66	820.97	795.39	889.83	1242.73
Frame-7	-8.48	136.55	268.68	349.32	459.00	522.89	705.60	795.33	895.03	927.83	1167.20
Frame-8	3.07	43.00	228.23	331.62	436.01	587.19	687.94	765.22	874.35	1023.94	1106.27
Frame-9	46.05	264.64	203.21	397.77	511.46	561.11	805.20	778.64	1038.66	1025.86	1149.27
Frame-10	84.62	53.13	274.25	501.04	447.43	627.99	727.55	677.37	807.03	945.89	1000.28
Frame-11	2.26	63.31	182.08	401.91	432.05	556.67	675.91	775.07	928.05	1007.56	1146.04
Frame-12	-56.33	204.11	257.98	350.03	457.78	539.09	675.59	794.27	915.62	1002.67	1139.81
Hoop-1	-18.77	733.69	1573.45	2189.20	2881.18	3582.12	4301.04	4973.83	5733.08	6443.63	7185.16
Hoop-2	-35.22	607.01	1569.31	2090.70	2746.85	3561.59	4271.17	4823.77	5590.51	6520.27	7181.27
Hoop-3	39.80	793.60	1384.58	2164.27	2865.51	3659.18	4357.45	5057.17	5542.99	6295.70	7144.78
Hoop-4	-27.10	609.45	1580.46	2153.92	2895.80	3543.31	4307.65	4751.50	5718.65	6388.63	7166.46
Hoop-5	-7.05	657.65	1417.17	2097.04	2841.95	3514.02	4244.96	4931.71	5669.04	6407.49	7181.20
Hoop-6	-54.47	707.61	1520.82	2122.26	2862.20	3558.39	4225.69	4885.30	5661.62	6373.10	7156.59
Hoop-7	36.20	647.82	1277.25	2227.76	2810.34	3631.28	4301.37	4882.99	5657.33	6313.79	7024.05
Hoop-8	6.80	611.66	1385.73	2049.27	2778.20	3458.61	4171.65	5048.32	5730.44	6407.87	7195.91
Hoop-9	-21.59	860.89	1507.17	2238.88	2904.93	3614.41	4283.71	4874.34	5621.97	6380.98	7154.52
Hoop-10	-0.52	725.40	1516.02	2196.85	2857.57	3573.99	4272.16	4957.15	5722.21	6206.76	7159.65
Hoop-11	7.32	689.26	1423.79	2118.39	2807.26	3525.07	4286.26	4910.50	5664.69	6364.81	7337.71
Hoop-12	39.74	702.86	1622.09	2229.59	2987.31	3569.31	4308.76	4954.45	5765.82	6561.55	6808.88
Hoop-13	106.50	665.53	1347.90	2081.77	2764.13	3541.10	4173.25	4921.24	5726.76	6409.97	7062.85
Hoop-14	0.19	832.55	1519.45	2149.67	2771.99	3555.99	4297.36	5052.73	6060.48	6382.25	6996.97
Long-1	1.92	921.36	1528.28	1886.06	2860.61	3234.39	4190.45	4573.69	5356.90	6228.56	6676.71
Long-2	26.97	743.95	1130.40	2137.28	2691.23	3412.90	3885.45	4885.81	5065.12	5735.84	6695.51
Long-3	5.20	523.62	1339.46	2155.29	2836.80	3499.78	4116.32	4472.59	5387.16	6081.45	6404.63
Long-4	-4.67	729.58	1249.96	1894.91	3003.69	3326.69	4192.53	4469.58	5452.30	5930.11	6762.52
Long-5	8.67	554.79	1321.45	2337.73	3003.52	3101.95	4286.55	4687.38	5500.41	5572.75	6580.24
Long-6	20.35	708.86	1574.97	1873.69	2529.14	3290.74	4129.69	4440.26	5317.98	5807.08	6460.64
Long-7	16.26	569.70	1216.17	1906.90	2459.33	3490.42	4110.59	4524.97	5301.95	6204.88	6413.62
Long-8	26.74	754.19	1215.67	2006.81	2575.67	3469.48	3881.79	4794.05	5246.93	6135.78	6483.64
IS13	56.19	-2.10	-37.71	-49.69	-50.77	-16.81	8.66	42.59	87.14	134.72	171.78
IS19	8.87	-47.93	-81.56	-63.10	-57.06	-11.59	17.63	64.03	109.88	168.13	208.31
IS20	48.45	90.05	124.69	191.87	228.74	289.57	331.30	379.90	423.62	473.88	508.48
IS21	-11.61	29.61	66.59	139.23	172.53	237.94	281.77	339.75	391.01	455.85	501.53

Table E-13. Strain survey raw data 40,000 cycles (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.34	2.00	2.67	3.34	4.01	4.67	5.34	6.01	6.68
IS22	124.07	60.53	15.79	12.11	5.06	26.70	46.11	75.78	112.80	161.04	196.01
IS23	-164.94	-123.20	-101.76	-47.30	-26.08	16.07	40.26	69.20	98.66	131.60	149.73
IS24	126.66	60.62	9.21	1.31	-18.86	-1.09	6.85	29.80	60.18	98.90	126.88
IS28	58.00	-15.92	-68.72	-59.66	-56.14	-17.70	8.96	56.43	101.26	159.53	203.40
IS29	-63.25	-35.55	-4.97	75.86	88.95	110.07	134.81	142.13	193.84	222.94	224.40
IS30	1.34	35.67	55.52	106.46	129.85	184.79	221.15	274.80	324.65	384.93	434.18
S13	-15.68	138.85	248.06	397.47	485.28	595.14	679.29	757.15	839.19	914.55	977.54
S14											
S15	114.82	272.95	376.62	523.16	606.90	717.72	794.19	874.65	949.03	1026.22	1082.37
S19	161.62	313.50	415.47	554.37	632.07	734.61	810.17	889.70	963.17	1040.90	1102.72
S20											
S21	129.59	192.71	239.72	335.97	402.56	494.73	568.88	648.50	719.81	802.00	866.39
S22	56.83	209.75	319.13	463.35	547.75	653.37	734.88	813.05	890.28	971.78	1029.33
S23											
S24	94.52	235.56	338.97	481.53	567.26	674.18	752.66	832.91	910.03	989.23	1048.15
S28	-194.16	-89.98	-23.77	53.39	88.32	137.08	161.08	191.70	215.72	252.10	268.84
S29											
S30											
UAA	-1174.26	-1103.76	-1035.84	-928.83	-855.21	-756.33	-678.47	-592.86	-516.50	-429.19	-366.66
UAF	5.93	119.24	235.89	375.41	485.34	613.37	721.12	832.83	931.01	1042.21	1123.81
UBA	19.75	179.10	323.05	492.94	611.62	756.41	859.82	959.77	1060.02	1155.23	1222.00
UBF	28.86	190.01	342.02	517.27	636.00	786.61	896.05	999.66	1103.00	1199.65	1269.03
UDAA	155.25	312.74	437.74	607.89	737.34	877.65	993.66	1118.46	1220.94	1340.22	1430.31
UDAF	92.94	236.81	352.95	515.46	637.32	774.76	885.49	1003.56	1105.61	1218.97	1305.94
UDBA	165.06	385.02	561.45	785.33	945.62	1120.20	1258.94	1388.43	1509.37	1634.69	1726.61
UDBF	107.82	319.49	490.79	705.21	858.42	1028.27	1162.47	1286.46	1404.49	1520.19	1607.75

Table E-14. Strain survey raw data 60,000 cycles (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.35	2.04	2.73	3.38	4.04	4.65	5.41	6.00	6.67
Frame-1	1.18	3.18	4.41	5.91	7.60	9.02	10.88	12.16	13.68	15.35	16.83
Frame-2	1.68	3.26	4.24	5.51	6.88	8.16	9.75	10.88	12.21	13.76	15.06
Frame-3	1.01	3.03	3.58	6.17	6.08	7.63	9.20	12.06	12.50	15.14	15.86
Frame-4	1.86	3.11	3.68	5.69	7.44	7.97	10.13	11.87	13.16	13.80	15.18
Frame-5	1.67	2.52	4.07	5.99	7.08	8.27	9.76	11.08	12.76	13.78	15.79
Frame-6	1.46	2.19	5.02	4.86	6.33	7.93	9.93	11.39	11.99	14.07	16.50
Frame-7	1.96	2.62	4.83	5.40	6.46	7.65	9.97	11.33	12.21	13.75	15.87
Frame-8	1.72	2.68	3.76	5.40	6.34	7.89	9.46	11.14	12.81	14.38	15.14
Frame-9	-1.18	2.58	3.14	7.39	6.09	9.60	7.31	10.94	14.66	14.48	12.02
Frame-10	0.97	3.25	4.33	5.36	6.38	7.32	10.94	12.67	12.08	13.44	15.83
Frame-11	1.85	3.33	3.65	4.95	7.58	8.12	9.55	10.84	12.19	13.43	15.02
Frame-12	0.75	2.98	4.27	5.52	6.33	8.28	9.54	11.03	12.57	14.33	15.36
Hoop-1	-66.96	933.39	1377.98	2135.77	2695.91	3522.96	4272.35	4775.36	5776.57	6303.79	7097.19
Hoop-2	31.32	623.26	1349.74	2153.14	2923.46	3497.24	4288.80	4929.30	5683.50	6412.41	7042.79
Hoop-3	4.12	774.95	1447.27	2102.10	2851.24	3644.33	4346.53	4776.97	5821.66	6240.53	7022.51
Hoop-4	-8.29	1159.40	1295.60	2165.25	2767.11	3391.60	4149.37	4790.54	5646.74	6428.26	7131.83
Hoop-5	-114.13	750.59	1467.58	2238.39	2965.20	3393.70	4276.94	4997.68	5704.66	6292.57	7242.77
Hoop-6	79.97	780.16	1280.29	2336.72	2934.07	3675.87	4276.52	4771.31	5634.23	6735.21	7394.38
Hoop-7	-64.52	1141.75	1462.59	1983.97	2915.00	3615.60	4128.68	5028.63	5303.65	6363.58	7371.73
Hoop-8	65.04	696.90	1467.05	2229.35	2876.03	3624.17	4300.11	4873.98	5628.91	6500.53	7123.77
Hoop-9	-22.94	956.80	1229.80	2361.82	2893.25	3306.01	4374.22	4858.81	5533.09	6437.56	7171.91
Hoop-10	-82.46	672.61	1463.16	2274.24	2712.76	3587.59	4121.34	5054.35	5657.60	6550.03	7129.48
Hoop-11	66.32	767.91	1469.80	2232.59	2786.19	3467.97	4110.37	5027.33	5632.65	6620.05	7112.34
Hoop-12	-104.11	721.82	1409.76	2142.62	2906.98	3481.91	4290.15	4916.08	5723.40	6494.82	7206.59
Hoop-13	0.76	738.72	1221.20	2134.28	2814.07	3610.57	4239.42	4911.76	5678.54	6314.28	7102.05
Hoop-14	32.77	817.05	1337.73	2187.72	2789.04	3485.44	4152.93	4908.04	5735.90	6461.62	7112.62
Long-1	5.58	757.60	1451.44	1930.69	2581.79	3488.54	4060.68	4719.47	5365.17	5874.60	6643.03
Long-2	60.90	499.08	1246.80	1652.98	2828.81	3540.73	3739.53	4636.71	5375.19	5993.93	6685.85
Long-3	23.18	344.91	1193.59	1958.45	2621.85	3442.97	4146.52	4812.96	5390.59	5896.84	6995.15
Long-4	-17.37	563.86	1459.31	2024.18	2748.56	3296.56	4123.44	4652.06	5230.13	6040.31	6599.98
Long-5	23.60	628.99	1600.60	1974.49	2342.70	3545.57	3757.55	4577.55	5028.42	6238.56	6764.31
Long-6	27.69	589.40	1309.09	1976.08	2847.14	3447.78	4150.28	4725.01	5385.93	5964.23	6775.67
Long-7	344.40	734.91	1441.40	1940.14	2712.20	3317.37	3946.07	4785.76	5275.70	5999.46	6568.96
Long-8	-22.02	478.85	1239.93	2046.36	2734.90	3396.51	3991.55	4655.55	5433.37	6034.73	6705.01
HSA	19.39	163.86	266.02	399.64	508.65	595.34	688.39	785.50	873.05	949.74	1016.81
HSF1	9.92	142.58	243.64	363.98	472.81	562.23	644.74	741.46	827.93	904.26	972.78
HSF2	14.47	139.56	234.09	345.25	446.42	527.91	602.67	692.56	770.84	840.68	902.32
IS13	-83.60	-181.71	-225.33	-245.71	-240.60	-208.62	-205.71	-158.51	-109.77	-81.42	-42.90

Table E-14. Strain survey raw data 60,000 cycles (run 1) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.00	0.67	1.35	2.04	2.73	3.38	4.04	4.65	5.41	6.00	6.67
IS14	-46.30	0.63	40.20	75.17	116.24	167.46	176.70	225.14	274.29	292.77	321.00
IS15	-102.63	-189.28	-260.51	-281.85	-290.20	-276.25	-283.45	-245.14	-204.99	-184.38	-152.55
IS19	-69.65	-115.32	-123.92	-106.39	-74.04	-32.56	-6.25	53.15	111.42	155.45	203.69
IS20	-499.07	-453.97	-408.23	-358.12	-307.95	-259.98	-225.10	-173.56	-123.36	-89.94	-55.06
IS21	-24.86	26.10	54.08	128.13	178.12	221.14	255.75	319.66	383.61	427.48	475.04
IS22	-63.60	-169.68	-220.92	-250.29	-253.45	-243.85	-257.68	-226.45	-185.34	-171.56	-126.29
IS23	0.45	44.34	84.74	112.28	144.42	186.00	182.92	218.12	258.64	262.99	290.52
IS24	-72.26	-176.13	-232.09	-268.27	-277.55	-268.47	-294.47	-270.60	-233.68	-229.55	-193.07
IS28	-55.11	-156.56	-187.03	-198.52	-180.02	-163.50	-167.46	-126.30	-75.28	-46.10	10.98
IS29	3.70	34.61	73.86	105.70	140.83	171.25	178.71	207.37	240.45	255.93	283.43
IS30	11.02	21.30	49.19	75.27	115.12	174.54	184.73	230.35	288.79	322.51	379.38
IS43	-120.82	-189.78	-215.11	-204.54	-170.58	-131.74	-106.47	-43.66	19.41	64.77	111.86
IS44	-44.92	43.36	110.72	189.16	261.50	321.18	367.98	433.88	496.66	540.77	581.85
IS45	-15.23	23.95	49.59	117.43	172.78	216.51	253.42	318.29	387.75	433.98	481.07
S13	82.80	272.67	424.36	534.39	645.04	756.46	803.07	896.57	1001.90	1050.69	1118.42
S15	85.83	236.81	396.58	482.71	594.99	710.98	750.37	841.80	946.59	990.36	1058.20
S19	90.29	223.58	346.00	440.02	536.14	633.03	682.57	764.40	864.70	914.97	981.99
S21	44.13	93.20	187.84	252.78	344.46	436.04	500.73	581.92	680.19	743.02	818.81
S22	624.29	787.45	986.49	975.65	1071.75	1273.62	1508.28	1327.95	1578.98	1574.60	1446.34
S24	55.40	238.03	381.42	483.35	578.63	691.43	738.73	820.48	918.48	955.59	1020.36
S28	59.55	246.92	398.64	516.88	621.17	732.26	791.45	871.29	970.10	1020.36	1091.93
S30	4.10	82.84	185.67	269.55	357.03	435.05	494.11	570.12	663.29	720.16	796.00
S43	126.38	331.94	488.63	615.59	735.16	836.63	901.81	993.78	1101.13	1160.31	1232.92
S44	-266.90	-531.99	-728.23	-972.59	-1166.19	-1318.43	-1522.39	-1681.17	-1810.00	-1966.98	-2094.15
S45	1.71	96.92	195.33	275.92	371.48	464.75	527.26	616.54	718.56	782.25	856.51
UAA	25941.22	25816.42	26112.89	26141.70	25981.96	26121.62	26214.74	25751.10	25667.70	25699.71	26013.96
UAF	-8.78	142.13	264.78	417.34	542.85	649.63	776.09	893.34	994.94	1098.26	1185.90
UBA	-34.85	215.77	388.86	589.28	749.55	884.22	1004.15	1135.88	1243.28	1333.72	1416.71
UBF	-20.27	242.16	410.39	620.13	780.43	909.55	1039.78	1171.26	1275.38	1367.43	1439.94
UDAA	27.88	153.77	288.81	405.10	527.69	586.00	639.57	723.06	807.20	872.44	965.91
UDAF	7.60	124.06	252.62	365.13	482.71	568.36	630.28	718.11	802.77	871.98	957.40
UDBA	46.61	270.77	473.59	652.13	820.39	923.96	990.53	1101.69	1213.09	1277.48	1385.76
UDBF	44.37	283.18	490.68	673.92	848.31	967.65	1047.99	1168.76	1282.12	1358.65	1462.93

Table E-15. Strain survey raw data 60,000 cycles (run 2)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.66	1.34	1.99	2.71	3.34	3.99	4.69	5.33	6.01	6.83
Frame-1	1.33	2.57	4.78	6.16	7.60	9.41	10.67	12.10	13.79	15.19	16.93
Frame-2	1.75	2.77	4.57	5.69	6.90	8.42	9.74	10.93	12.41	13.69	15.20
Frame-3	1.33	2.94	4.74	5.18	6.92	8.71	9.98	11.18	13.44	14.16	15.62
Frame-4	1.40	3.25	4.38	5.53	7.16	8.07	10.13	11.04	12.74	14.19	16.24
Frame-5	0.78	2.92	4.01	5.35	7.28	8.32	10.40	11.30	12.90	13.27	15.55
Frame-6	2.17	1.91	4.04	6.16	7.13	8.87	10.34	11.44	13.16	14.90	15.86
Frame-7	0.62	2.76	3.71	6.08	6.71	8.16	10.33	11.68	12.77	14.41	15.71
Frame-8	1.50	3.54	3.97	5.69	6.54	8.16	10.40	11.08	12.70	14.02	15.15
Frame-9	1.99	2.15	2.39	6.45	4.27	5.64	7.03	11.75	11.02	12.27	14.06
Frame-10	0.46	2.76	4.12	5.30	8.05	8.85	9.74	10.76	12.07	13.37	15.62
Frame-11	0.87	3.25	4.36	6.08	6.71	7.20	9.40	11.03	12.28	13.60	15.23
Frame-12	1.58	2.71	4.96	5.67	6.64	8.92	10.30	11.25	12.90	14.20	15.27
Hoop-1	-26.87	550.91	1429.14	2476.72	2987.21	3916.97	4138.90	5255.97	5998.87	6388.25	7247.74
Hoop-2	24.14	718.55	1468.28	2160.53	2883.71	3465.29	4263.25	4869.61	5696.06	6386.14	7101.29
Hoop-3	-70.20	621.32	1328.15	1993.42	2691.93	3535.79	4190.54	4918.23	5635.00	6439.95	7132.44
Hoop-4	-28.26	571.19	1215.82	2283.51	2621.54	3568.13	4192.54	5000.74	6177.01	6018.40	6796.94
Hoop-5	163.32	525.56	1494.75	2283.65	2775.73	3458.90	4215.26	5166.53	5618.19	6224.73	7146.56
Hoop-6	14.49	654.86	1562.35	2309.67	2822.82	3632.58	4423.43	5083.68	5375.98	6590.35	7269.95
Hoop-7	-39.43	602.43	1385.66	2150.86	2708.56	3549.63	3965.14	5202.01	5407.61	6215.42	7240.14
Hoop-8	-7.59	566.23	1249.12	2120.62	2701.43	3631.80	4300.11	5026.03	5744.55	6341.36	7096.14
Hoop-9	-5.00	472.36	1263.90	1786.00	2769.15	3570.17	4227.05	4998.30	5473.32	6382.56	6949.01
Hoop-10	-75.43	625.15	1442.03	2144.21	2812.81	3668.92	4390.68	4900.71	5885.84	6286.63	6956.64
Hoop-11	-53.04	520.23	1453.53	2138.77	2733.47	3598.53	4110.37	4930.98	5952.15	6363.89	6996.21
Hoop-12	-34.98	539.95	1373.37	2164.67	2732.05	3627.82	4006.29	5024.75	5686.45	6379.02	7157.08
Hoop-13	-6.55	665.72	1411.21	2061.42	2718.81	3727.86	4232.11	5050.11	5911.78	6482.99	7154.62
Hoop-14	3.45	604.55	1345.07	2019.34	2979.34	3647.07	4299.55	5010.18	5845.28	6454.93	7143.36
Long-1	18.08	854.42	1455.54	1924.19	2615.27	3340.01	4167.00	4568.34	5340.54	6070.61	6715.26
Long-2	45.84	661.00	1449.11	2056.89	2755.81	3198.82	3929.38	4719.74	5318.06	6144.12	6843.54
Long-3	0.59	820.35	1371.77	1779.51	2587.96	3338.20	3928.42	4956.42	5233.53	5823.00	6594.17
Long-4	21.05	870.60	1356.89	2069.45	2537.53	3251.01	3931.60	4657.42	5488.90	6160.18	6592.19
Long-5	41.59	828.90	1448.72	1542.84	2810.17	3525.92	4100.57	4907.97	5516.34	6160.73	6871.12
Long-6	51.42	789.67	1318.55	2269.45	2581.15	3211.06	4080.76	4580.15	5356.97	5812.32	6811.92
HSA	38.67	150.62	280.38	388.55	497.74	610.85	704.68	789.68	866.05	959.74	1054.61
HSF1	20.29	131.70	250.72	351.99	463.54	568.64	661.57	744.01	822.58	909.53	1006.76
HSF2	26.54	130.57	241.69	334.50	438.36	534.57	619.45	693.70	766.67	845.37	934.74
IS13	-92.35	-170.84	-228.24	-232.63	-238.42	-214.45	-177.35	-157.79	-122.84	-77.79	-16.73
IS14	-78.93	-7.91	11.16	65.13	92.47	135.56	184.28	206.44	240.59	273.88	322.83
IS15	-96.49	-201.74	-258.73	-277.12	-302.11	-286.37	-260.18	-248.45	-221.67	-186.00	-134.31

Table E-15. Strain survey raw data 60,000 cycles (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.66	1.34	1.99	2.71	3.34	3.99	4.69	5.33	6.01	6.83
IS19	-100.56	-108.77	-134.33	-99.81	-81.35	-35.85	15.31	49.68	97.52	153.08	219.77
IS20	-823.42	-765.84	-727.98	-667.73	-624.79	-573.97	-522.27	-491.22	-446.70	-403.87	-353.73
IS21	-2.60	8.12	66.84	126.22	157.41	218.30	276.02	319.89	368.22	429.53	494.11
IS22	-67.04	-159.29	-225.51	-238.09	-253.86	-254.97	-234.32	-229.81	-199.43	-170.01	-114.74
IS23	-7.90	53.37	71.82	117.27	141.15	167.42	205.79	214.81	243.29	261.72	296.01
IS24	-88.21	-170.05	-239.53	-257.52	-282.40	-288.83	-271.35	-277.22	-253.34	-233.63	-187.49
IS28	-76.26	-145.07	-202.51	-187.41	-188.17	-182.45	-150.78	-135.91	-98.62	-52.93	14.99
IS29	-7.77	40.68	63.98	109.75	135.74	159.24	189.08	204.64	229.14	253.20	286.53
IS30	-6.73	26.67	41.91	85.23	111.62	158.54	202.09	230.21	273.07	318.18	384.70
IS43	-139.76	-190.00	-219.83	-205.55	-182.32	-136.20	-84.72	-47.92	3.68	63.07	139.38
IS44	-44.76	38.18	109.18	180.97	246.63	315.89	379.36	427.92	480.01	536.18	599.68
IS45	7.09	7.27	61.50	107.11	143.87	209.44	268.17	315.16	365.39	433.52	508.89
S13	60.97	291.12	401.79	535.85	633.38	725.95	829.21	896.57	974.13	1047.05	1143.19
S15	31.86	279.17	357.92	495.11	590.62	678.22	780.93	841.07	918.78	985.98	1077.89
S19	83.76	236.74	328.51	443.66	525.21	607.60	702.90	767.31	845.68	914.24	1001.66
S21	-1.23	132.58	165.50	267.79	352.97	431.72	522.01	590.84	671.76	748.98	844.65
S22	1019.59	1122.15	1304.23	1394.01	1570.96	1630.88	1737.67	1855.74	1982.51	1991.46	2110.25
S24	41.59	240.26	350.13	473.89	570.63	661.66	760.49	819.03	890.73	949.77	1030.55
S28	51.55	251.15	385.71	513.42	614.07	711.39	804.66	876.21	952.15	1019.26	1107.77
S30	0.45	95.99	169.62	268.82	351.92	424.15	504.27	574.50	647.91	721.62	812.77
S43	125.51	339.99	477.56	617.04	718.64	818.56	919.69	998.14	1080.33	1161.40	1261.79
S44	-322.34	-507.21	-778.66	-958.83	-1184.36	-1387.91	-1539.81	-1716.38	-1846.62	-2014.28	-2171.07
S45	-35.77	116.36	171.51	277.92	371.66	452.68	547.03	618.94	704.65	781.93	881.92
UAA	-5396.31	-5313.74	-5230.28	-5127.50	-5044.06	-4944.89	-4864.62	-4794.53	-4724.24	-4643.24	-4561.04
UAF	-0.81	128.67	269.33	410.05	538.47	671.56	785.12	894.25	988.46	1102.81	1212.14
UBA	-45.10	168.99	365.88	555.20	703.83	863.52	992.72	1106.89	1200.89	1308.38	1417.39
UBF	-23.75	187.41	398.34	590.36	736.59	907.09	1036.93	1158.48	1246.95	1365.97	1476.47
UDAA	15.31	162.91	269.31	411.48	506.92	567.10	644.06	706.29	774.15	864.78	970.29
UDAF	-4.51	132.56	236.50	373.64	475.79	557.85	642.24	709.91	782.47	865.42	960.50
UDBA	30.30	275.00	450.55	653.58	790.83	886.50	998.41	1076.10	1173.24	1269.68	1391.93
UDBF	35.54	290.86	470.55	678.63	826.91	941.81	1059.49	1149.89	1251.34	1349.40	1470.91

Table E-16. Strain survey raw data 60,000 cycles (run 3)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.07	0.60	1.29	1.98	2.70	3.32	3.95	4.70	5.35	6.03	6.78
Frame-1	0.88	2.67	4.60	5.68	7.87	8.69	10.77	12.42	13.68	15.47	17.23
Frame-2	1.42	2.85	4.49	5.35	7.08	7.81	9.66	11.22	12.39	13.91	15.55
Frame-3	0.93	2.61	3.67	5.41	6.91	7.64	9.63	11.01	12.92	14.29	15.53
Frame-4	1.72	3.00	3.68	4.95	6.60	8.31	9.64	11.49	12.37	14.16	15.81
Frame-5	1.33	2.21	3.85	5.56	7.58	8.00	9.76	11.05	12.44	14.32	15.80
Frame-6	1.55	2.54	4.75	6.47	7.28	8.94	10.05	12.00	12.97	14.49	15.41
Frame-7	1.19	2.46	4.15	6.10	6.38	8.15	9.72	11.02	12.64	14.13	15.07
Frame-8	1.44	3.00	4.10	5.86	6.74	8.64	9.75	11.36	12.52	14.12	15.23
Frame-9	-0.44	5.49	1.80	6.49	8.72	6.36	8.95	11.52	11.99	12.97	14.62
Frame-10	0.35	1.62	4.51	4.70	5.99	8.58	10.04	11.48	13.54	14.53	14.73
Frame-11	1.07	2.86	4.46	5.67	6.96	8.19	9.17	10.68	12.50	13.78	14.22
Frame-12	1.77	2.19	4.29	5.45	7.43	8.02	9.85	11.36	12.71	14.19	16.06
Hoop-1	49.66	590.95	1325.14	1990.21	3027.30	3464.99	4433.67	4960.26	5719.40	6484.20	7097.60
Hoop-2	-45.82	626.98	1491.45	2126.45	2715.07	3558.59	4257.45	5026.98	5743.84	6389.09	7084.44
Hoop-3	-42.55	557.30	1730.72	2154.15	2882.07	3655.07	4281.72	4957.49	5760.58	6466.96	7105.80
Hoop-4	527.49	680.11	1566.19	1940.28	3182.74	3190.33	4282.92	4818.64	5491.66	6250.27	7262.98
Hoop-5	98.46	619.21	1539.64	2143.13	3141.47	3595.84	4169.80	4994.88	5763.46	6350.22	7320.59
Hoop-6	-21.89	656.62	1436.70	2024.14	2580.91	3745.36	4193.83	5188.65	5875.47	6611.52	7205.58
Hoop-7	-87.82	609.54	1491.27	2089.92	3129.81	3746.83	4194.17	5223.00	5864.05	6204.05	7527.99
Hoop-8	333.86	580.75	1401.67	2011.67	2970.45	3588.21	4241.57	5033.80	5723.33	6515.06	7132.46
Hoop-9	-119.88	716.42	1269.28	1938.54	2864.54	3536.07	4327.13	5023.93	5646.15	6302.96	7121.29
Hoop-10	-6.77	614.59	1398.02	2019.24	2936.31	3424.23	4288.15	4876.55	5636.48	6335.28	7069.29
Hoop-11	-239.35	628.74	1458.95	1894.64	2990.54	3325.43	4326.97	4815.73	5648.93	6375.92	6996.21
Hoop-12	41.45	629.10	1515.30	2113.73	2856.04	3504.09	4333.39	4952.47	5716.12	6451.16	7106.14
Hoop-13	44.61	673.03	1469.67	2171.03	3040.60	3625.55	4165.93	5006.77	5788.15	6438.50	7191.15
Hoop-14	128.09	699.85	1396.38	1953.36	2942.98	3537.10	4211.16	4974.03	5853.19	6373.65	7180.01
Long-1	29.39	745.96	1360.05	2146.56	2790.25	3469.91	3878.26	4831.93	5462.91	6037.16	6500.62
Long-2	45.59	800.74	1410.73	1791.78	2777.41	3185.77	4132.50	4791.24	5390.06	6146.85	6763.62
Long-3	-2.54	381.99	1299.68	2066.26	2526.70	3442.01	3589.32	4313.12	5486.36	6061.82	6550.30
Long-4	4.30	781.94	1266.89	2114.13	2567.04	3401.07	4107.63	4591.76	5278.07	6124.34	6565.14
Long-5	5.13	910.10	1457.95	2144.83	2772.10	2955.50	4096.35	4326.65	5602.51	5708.70	6808.10
Long-6	136.21	544.85	1426.06	2179.63	2559.19	3495.48	3932.83	4838.83	5432.44	6162.25	6635.34
Long-7	21.16	693.04	1497.85	2035.35	2657.38	3540.22	4067.66	4715.59	5569.31	6187.25	6596.63
Long-8	-1.79	692.91	1406.32	1870.49	2494.92	3205.58	4038.59	4663.23	5310.49	6075.99	6549.42
HSA	46.11	141.23	284.22	399.14	501.01	612.18	700.56	810.25	886.95	956.57	1051.70
HSF1	27.37	123.39	260.38	360.39	465.54	569.06	656.70	762.94	840.57	911.26	1001.13
HSF2	31.08	120.15	248.45	339.14	437.45	531.66	612.53	709.68	780.92	844.63	926.72
IS13	-105.41	-181.82	-220.27	-245.74	-250.05	-214.47	-197.81	-146.12	-109.76	-79.97	-22.55

Table E-16. Strain survey raw data 60,000 cycles (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.07	0.60	1.29	1.98	2.70	3.32	3.95	4.70	5.35	6.03	6.78
IS14	-80.70	-24.26	32.48	56.96	85.00	143.17	168.20	224.96	255.23	280.90	323.91
IS15	-110.79	-202.14	-249.09	-278.21	-306.39	-275.55	-270.49	-228.37	-205.03	-178.57	-130.87
IS19	-114.97	-120.33	-110.96	-108.78	-84.09	-31.11	1.97	69.22	110.86	157.48	224.34
IS20	-839.89	-789.42	-725.87	-684.51	-640.77	-583.48	-546.58	-483.86	-449.61	-413.36	-364.63
IS21	-3.56	7.89	71.80	129.46	154.55	230.04	265.01	339.72	383.52	433.79	498.70
IS22	-76.75	-163.50	-213.71	-242.53	-257.68	-258.19	-256.53	-220.35	-190.51	-158.34	-115.65
IS23	-9.57	41.69	90.83	114.51	134.67	169.53	186.32	227.74	251.50	273.36	296.82
IS24	-105.56	-171.79	-229.48	-264.49	-285.80	-287.54	-294.21	-265.14	-244.90	-220.13	-187.58
IS28	-89.30	-155.29	-174.85	-195.04	-185.76	-187.89	-176.01	-131.51	-89.93	-39.32	14.99
IS29	-5.40	31.13	79.15	105.48	137.37	158.17	175.52	208.97	234.24	260.51	286.71
IS30	-7.32	22.63	46.28	75.41	111.52	157.10	180.96	233.90	278.07	329.00	384.02
IS43	-169.34	-195.35	-203.39	-209.79	-184.25	-134.79	-97.12	-25.53	20.10	64.36	135.57
IS44	-46.93	24.45	116.19	177.35	242.67	313.74	367.07	441.71	489.83	533.82	594.13
IS45	11.32	1.00	66.60	113.94	139.14	215.96	260.64	336.82	383.39	434.15	505.34
S13	66.41	263.54	433.15	523.52	621.00	731.85	803.48	915.32	987.23	1053.71	1138.09
S15	36.96	248.63	403.19	472.54	577.49	681.94	753.66	861.33	929.72	995.56	1072.79
S19	85.92	225.18	349.68	434.24	523.76	613.49	682.19	785.37	853.69	921.62	999.48
S21	-5.37	110.46	199.09	251.53	352.74	428.76	500.98	604.33	679.49	754.51	842.65
S22	975.55	1207.91	1272.29	1314.70	1446.34	1553.05	1665.08	1670.24	1721.64	1910.03	1942.63
S24	40.12	212.69	379.27	467.38	553.89	664.64	734.00	833.42	898.01	959.33	1023.27
S28	55.00	233.76	392.48	506.00	609.16	710.91	785.65	884.59	955.43	1026.29	1101.40
S30	-5.38	74.14	190.79	268.12	354.84	416.90	484.88	578.03	653.74	728.99	809.85
S43	156.70	322.42	491.77	606.93	716.28	820.64	902.08	1015.37	1090.13	1165.15	1254.71
S44	-350.17	-508.52	-765.67	-998.32	-1199.96	-1389.06	-1564.82	-1729.65	-1877.72	-2012.09	-2169.60
S45	-36.85	103.29	200.25	261.66	371.75	451.41	527.07	635.15	710.64	784.24	874.93
UAA	-5433.24	-5365.37	-5248.99	-5164.39	-5081.16	-4981.04	-4906.85	-4811.76	-4741.69	-4670.62	-4589.41
UAF	13.31	116.69	274.10	413.73	541.93	671.08	779.03	907.56	1003.22	1098.18	1214.51
UBA	-14.51	148.67	368.83	563.81	704.74	872.52	984.03	1126.87	1225.64	1316.16	1423.40
UBF	6.94	160.62	390.16	598.63	739.51	919.42	1033.35	1180.71	1277.81	1365.74	1481.40
UDAA	33.71	139.64	290.66	403.14	521.13	550.03	611.08	697.95	784.53	878.17	965.73
UDAF	9.60	112.70	257.06	363.11	479.93	544.97	613.83	707.03	788.30	876.44	959.22
UDBA	62.03	246.80	462.93	645.67	802.07	872.80	954.91	1081.51	1184.85	1286.67	1386.67
UDBF	67.54	261.40	484.75	666.91	831.45	927.03	1021.84	1156.01	1262.77	1365.49	1467.82

Table E-17. Strain survey raw data 80,000 cycles (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.08	0.69	1.35	2.00	2.72	3.35	3.99	4.67	5.30	5.96	6.59
Hoop-1	43.78	540.77	1602.57	1995.81	2751.69	3660.76	4301.27	5018.92	5809.55	6498.93	7028.74
Hoop-2	65.67	518.59	1609.06	2041.55	2702.44	3507.46	4325.12	4926.69	5719.58	6380.32	7106.86
Hoop-3	20.27	688.70	1543.90	2150.87	3077.83	3465.92	4183.38	4731.92	5664.97	6322.98	7017.32
Hoop-4	-27.84	766.76	1481.80	2249.68	3008.85	3465.92	4444.32	5001.09	5832.95	6397.40	7183.48
Hoop-5	625.37	640.05	1507.44	2178.97	2501.44	3586.91	4283.60	4876.62	5434.52	6202.67	6905.30
Hoop-6	70.81	327.19	1296.80	1938.86	2799.93	3235.00	3894.73	4796.48	5349.90	6255.68	6824.49
Hoop-7	2.20	670.45	1469.58	2087.04	2835.54	3627.07	4048.39	4978.22	5509.61	6612.67	7173.45
Hoop-8	4.27	187.32	1305.48	2165.17	2867.21	3656.61	4128.64	4925.51	5472.21	6246.46	6766.49
Hoop-9	-40.53	569.99	1282.33	1945.96	2653.61	3478.67	4067.33	5005.91	5741.61	6403.65	7251.58
Hoop-10	84.09	661.43	1437.83	1800.47	2867.55	3548.53	4286.14	5000.86	5507.19	6623.94	7190.46
Hoop-11	-4.81	483.46	1277.49	1968.38	2782.53	3371.86	4120.62	4939.92	5847.20	6455.53	7234.68
Hoop-12	-49.34	407.34	1397.23	2172.37	2813.14	3642.59	4304.91	5083.69	5958.27	6350.11	7086.63
Hoop-13	38.93	433.52	1427.46	2092.49	2772.42	3532.18	4379.91	4847.62	5638.02	6323.85	6990.27
Hoop-14	10.07	721.13	1439.66	2150.79	2840.21	3536.40	4379.49	5039.30	5846.90	6366.25	7137.45
Long-1	14.57	804.69	1478.25	2126.68	2817.04	3423.94	4149.65	4536.46	5224.75	5813.16	6812.26
Long-2	44.20	555.89	1201.86	1848.31	2762.28	3205.83	4177.41	4675.55	5438.24	6180.02	6758.22
Long-3	6.13	886.48	1536.95	2175.28	2473.86	3416.27	3461.67	4596.37	5314.49	5963.53	6675.12
Long-4	3.15	540.42	1522.86	1978.89	2740.46	3491.95	4212.22	4557.37	5247.98	5986.01	6487.77
Long-5	29.02	384.20	1530.65	2032.47	2166.49	2859.71	3776.40	4711.95	5426.87	6142.85	6262.90
Long-6	-41.01	558.60	1296.05	2113.55	2680.60	3561.00	3949.00	4464.29	5295.94	5903.36	6568.11
Long-7	83.29	608.68	1426.42	1887.93	2600.53	3523.29	4133.67	4618.55	5377.98	6016.32	6789.06
Long-8	-29.81	552.97	1461.16	1944.65	2711.69	3465.70	4049.40	4626.83	5376.25	5986.88	6807.89
Frame-1	36.84	162.48	224.36	308.49	448.04	562.63	683.15	765.42	898.76	939.10	1076.09
Frame-2	75.74	184.48	171.44	272.95	539.38	509.31	546.11	663.65	774.33	1088.56	990.15
Frame-3	44.33	86.16	302.96	332.67	395.75	538.85	588.79	816.09	915.16	921.84	1224.71
Frame-4	-58.77	133.97	156.06	359.47	409.62	625.82	717.54	782.87	875.18	1063.13	1096.93
Frame-5	29.10	137.77	154.21	345.82	432.04	558.16	636.29	783.83	862.54	917.29	1033.58
Frame-6	75.21	60.20	300.01	317.53	575.75	534.20	523.17	741.41	879.24	890.33	1134.42
Frame-7	56.12	183.19	320.84	436.47	568.59	527.54	579.20	757.49	906.86	927.05	1197.51
Frame-8	16.98	68.37	203.46	357.68	434.57	538.68	619.16	785.79	865.17	994.93	1094.95
Frame-9	63.68	166.34	319.05	461.60	346.71	475.76	752.48	797.63	926.84	942.43	1142.06
Frame-10	-68.07	-52.78	217.53	274.68	470.55	560.64	650.52	783.11	891.34	1110.90	1097.42
Frame-11	-6.03	133.97	182.62	282.59	570.36	476.16	536.80	555.25	724.87	1273.46	1015.19
Frame-12	-2.94	196.91	232.72	324.37	425.25	547.36	632.58	827.79	913.35	971.69	1129.34
HSA	62.42	189.07	326.55	427.77	563.40	652.18	747.45	841.63	935.53	1024.46	1107.99
HSF1	70.99	195.01	330.72	431.26	560.76	651.22	749.26	842.75	933.79	1024.93	1106.32
HSF2	62.39	174.87	298.26	387.90	503.72	584.50	671.78	754.15	835.54	916.43	989.43
IS13	-102.19	-190.49	-212.68	-230.11	-218.30	-206.87	-181.06	-151.07	-107.23	-64.73	-23.47

Table E-16. Strain survey raw data 60,000 cycles (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.08	0.69	1.35	2.00	2.72	3.35	3.99	4.67	5.30	5.96	6.59
IS14	-66.66	-48.86	22.64	50.75	93.69	122.86	157.10	187.79	225.10	258.65	286.13
IS15	-133.07	-199.84	-225.49	-252.13	-250.14	-246.29	-229.70	-209.25	-173.98	-136.87	-102.68
IS19	-67.99	-120.78	-94.66	-86.42	-48.23	-23.38	20.49	56.68	112.57	167.64	217.88
IS20	-24.45	-4.23	69.28	108.20	165.85	203.08	248.87	285.76	333.05	377.35	415.61
IS21	-54.00	-36.90	43.20	71.45	131.41	170.37	219.62	262.23	323.15	379.31	434.25
IS22	-85.59	-159.28	-183.87	-194.77	-197.73	-179.96	-150.88	-124.30	-80.00	-49.40	-2.02
IS23	-14.35	5.02	71.24	99.72	130.65	159.15	192.49	213.85	247.70	265.95	290.82
IS24	-111.31	-176.03	-202.32	-224.80	-235.88	-224.92	-203.32	-186.03	-150.49	-126.18	-87.60
IS28	-121.94	-206.73	-195.73	-193.98	-182.01	-149.79	-104.66	-70.92	-17.96	20.97	78.89
IS29	-10.45	3.94	61.14	90.28	120.70	150.22	183.38	204.87	235.59	255.90	283.57
IS30	-64.08	-69.15	-11.66	12.72	53.29	104.43	164.65	214.33	280.66	329.17	399.19
IS43	-84.29	-122.32	-99.91	-97.46	-49.66	-19.21	26.64	74.69	133.22	195.62	254.60
IS44	20.77	74.84	159.60	211.94	283.82	330.98	383.56	433.32	485.44	537.08	583.34
IS45	14.36	56.17	111.08	160.16	226.51	272.17	328.90	385.62	448.58	515.13	578.71
S13	71.71	205.73	392.24	489.82	595.44	681.46	763.78	841.73	920.87	993.36	1057.37
S14	214.22	-56.28	-317.21	-530.52	-740.04	-883.38	-1015.75	-1151.39	-1256.87	-1351.63	-1435.20
S15	163.17	237.54	412.68	499.47	595.04	670.26	749.06	815.46	888.16	954.93	1013.21
S19	57.74	141.52	293.84	375.42	470.14	544.52	621.04	688.08	764.37	832.46	896.50
S20	-120.47	-347.00	-550.02	-757.51	-967.78	-1128.01	-1286.92	-1443.92	-1585.33	-1725.47	-1848.66
S21	-14.28	20.67	118.23	194.66	280.57	348.31	427.67	491.75	570.21	643.25	712.36
S22	-319.44	-216.38	-37.78	51.46	161.77	236.71	304.79	390.02	464.67	517.76	576.26
S23	312.95	57.84	-217.67	-437.52	-611.50	-780.49	-956.77	-1104.05	-1214.27	-1280.08	-1405.36
S24	693.69	835.35	1052.47	1157.38	1298.52	1284.35	1415.07	1506.94	1597.92	1673.64	1739.01
S28	119.17	277.23	425.18	518.39	624.04	702.07	783.68	855.08	932.04	998.73	1067.85
S29	8.53	-128.19	-249.63	-374.70	-439.65	-529.00	-597.65	-652.82	-689.52	-711.39	-741.76
S30	-29.22	36.43	168.46	249.40	345.67	420.11	498.88	566.72	643.84	710.48	779.70
S43	113.43	228.83	394.58	513.97	625.95	715.50	801.72	882.68	962.99	1043.79	1115.21
S44	109.50	-158.07	-361.78	-527.60	-760.96	-898.31	-1042.63	-1188.98	-1335.66	-1461.32	-1597.00
S45	19.15	43.08	149.71	220.76	304.89	376.73	455.06	523.97	599.22	674.90	747.37
UAA											
UAF	48.26	173.46	331.33	471.08	635.30	752.38	878.52	996.63	1118.06	1233.53	1338.40
UBA	50.25	330.73	612.75	862.24	1117.61	1303.77	1482.90	1653.29	1809.66	1950.57	2072.71
UBF	115.85	475.14	858.12	1186.31	1539.97	1787.13	2021.71	2264.33	2475.52	2673.11	2843.12
UDAA	20.45	125.78	299.13	433.06	529.28	657.11	775.58	872.55	971.05	1035.97	1138.30
UDAF	-1.41	88.81	244.14	367.85	470.33	578.92	687.68	770.95	863.42	938.29	1021.64
UDBA	136.28	462.43	803.94	1131.14	1363.90	1639.10	1878.60	2083.98	2265.47	2402.10	2576.77
UDBF	181.28	518.79	851.19	1170.35	1412.87	1666.26	1891.93	2087.31	2264.41	2409.38	2564.96

Table E-18. Strain survey raw data 80,000 cycles (run 2)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.12	0.65	1.35	2.02	2.69	3.33	3.99	4.63	5.34	6.02	6.70
Hoop-1	54.55	678.78	1224.09	1704.99	2702.43	3629.90	4253.77	5011.74	5610.98	6604.93	7305.71
Hoop-2	32.83	814.03	1412.03	1999.86	2838.18	3541.68	4364.01	5028.69	5645.82	6484.22	7252.76
Hoop-3	-72.34	962.78	1496.68	1979.94	2828.09	3654.45	4211.60	5151.50	5660.08	6226.79	6999.86
Hoop-4	-110.71	705.36	1559.26	2121.53	2777.34	3494.40	4229.06	5046.13	5633.53	6502.02	7027.45
Hoop-5	261.64	563.54	1471.06	2053.25	2749.87	3300.99	4133.62	4902.08	5804.33	6280.92	7113.34
Hoop-6	171.19	576.26	1079.92	1994.23	2673.61	3263.36	3829.43	4518.60	5531.50	6257.55	7235.67
Hoop-7	-34.11	735.89	1455.05	1978.28	2864.60	3482.13	4200.94	4774.34	5740.96	6337.26	7040.56
Hoop-8	7.86	806.53	1156.51	1879.99	2344.88	3448.77	4200.43	4804.78	5630.85	6426.57	7353.09
Hoop-9	-38.71	478.77	1131.09	1688.83	2499.75	3312.49	4301.57	4830.95	5481.57	6072.06	6756.63
Hoop-10	40.07	858.66	1471.27	1915.08	2814.73	3566.49	4405.84	4625.43	5588.83	6263.68	7003.48
Hoop-11	34.97	803.64	1192.49	2344.80	3133.43	3515.09	4158.60	5011.76	5525.91	6344.03	7221.66
Hoop-12	254.49	616.63	1424.52	2434.63	3016.95	3577.44	4203.01	4821.19	5702.34	6489.05	7208.23
Hoop-13	46.23	718.58	1368.99	2129.24	2882.05	3400.97	4284.90	5102.90	5585.74	6353.71	7046.64
Hoop-14	-4.59	735.87	1351.69	2114.35	2832.88	3720.05	4284.18	5024.13	5625.80	6432.87	7106.00
Long-1	0.18	469.44	1174.40	2185.89	2849.41	3479.45	4005.63	4595.67	5245.97	5946.65	6589.90
Long-2	32.66	513.88	1471.23	2049.82	2383.33	3336.54	4077.84	4644.72	5419.17	6140.40	6754.78
Long-3	0.84	679.84	1420.52	1930.55	2401.74	3541.35	4061.56	4242.07	5292.14	6014.74	6496.33
Long-4	-0.87	833.14	1363.96	2066.02	2826.98	3558.46	4177.31	4964.80	5324.61	5904.86	6490.92
Long-5	-8.63	365.19	1071.72	2092.85	2694.32	3498.05	4093.33	4677.86	5361.99	6067.28	6616.71
Long-6	-54.65	952.01	1194.20	2069.12	2743.23	3431.78	4209.38	4780.15	5294.18	6026.62	6473.29
Long-7	4.28	874.47	1488.46	2159.43	2787.01	3476.02	4053.71	4704.64	5377.23	5919.02	6599.43
Long-8	7.41	660.55	1622.51	1833.22	2718.71	3342.72	3903.61	4521.69	5360.43	5901.95	6577.38
Frame-1	22.63	154.77	230.79	322.61	417.92	511.56	643.18	761.63	833.16	964.88	1068.64
Frame-2	0.14	132.19	145.84	234.02	444.02	534.45	556.04	646.73	902.01	1073.26	1080.12
Frame-3	-14.68	70.55	170.16	239.04	435.29	540.90	653.28	777.15	886.96	1050.76	1145.58
Frame-4	39.89	164.22	143.23	360.20	427.84	484.71	620.35	797.31	902.54	1069.02	1183.28
Frame-5	44.32	169.15	244.26	232.23	329.95	516.85	660.19	735.87	791.24	930.39	1045.33
Frame-6	-138.16	57.03	122.69	225.90	477.14	638.37	568.64	773.46	846.62	1059.54	1096.60
Frame-7	-30.18	103.18	175.16	388.58	604.30	625.19	609.13	761.72	866.58	1129.13	1181.61
Frame-8	44.04	116.33	167.20	314.54	502.23	500.92	708.89	838.31	825.19	943.71	1077.70
Frame-9	5.81	25.42	82.18	285.21	332.39	525.84	597.70	778.41	983.48	1006.87	1070.63
Frame-10	97.36	209.98	162.46	310.04	425.16	621.84	696.61	749.71	889.51	966.91	1088.01
Frame-11	38.05	136.78	182.98	181.03	417.22	564.90	555.85	621.82	894.89	1116.71	1012.18
Frame-12	14.02	149.49	211.03	301.69	434.30	531.48	638.90	758.51	860.13	1007.09	1110.84
HSA	74.67	196.93	336.66	426.59	551.93	651.52	746.21	843.09	936.44	1030.69	1115.15
HSF1	86.42	200.14	336.29	434.44	554.74	653.29	745.47	844.21	939.07	1031.54	1113.85
HSF2	76.91	179.81	301.51	389.25	497.32	584.19	665.83	755.24	840.07	922.88	996.42
IS13	-124.14	-173.26	-229.54	-237.79	-226.36	-213.80	-188.29	-155.61	-122.52	-70.53	-15.65

Table E-18. Strain survey raw data 80,000 cycles (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
IS14	-79.33	-22.19	0.90	41.72	86.42	114.76	149.31	184.65	213.21	252.77	292.11
IS15	-147.75	-190.39	-236.91	-259.55	-256.32	-253.24	-235.53	-209.23	-184.30	-140.65	-94.34
IS19	-99.94	-95.03	-111.27	-102.53	-61.41	-29.05	10.62	61.98	105.83	166.13	224.99
IS20	-43.25	14.17	57.14	98.00	155.50	198.24	241.83	289.40	328.67	375.92	420.07
IS21	-70.88	-26.87	24.61	59.42	120.00	163.07	212.99	270.05	317.95	382.01	440.79
IS22	-80.96	-131.37	-190.84	-194.31	-191.46	-185.44	-157.90	-122.48	-94.80	-51.53	6.03
IS23	-27.68	27.29	51.73	95.07	131.69	151.81	182.79	217.07	233.78	262.24	293.70
IS24	-131.73	-179.10	-214.75	-230.84	-231.82	-232.88	-211.71	-183.35	-165.04	-129.78	-81.37
IS28	-151.49	-173.62	-215.04	-206.22	-182.47	-157.59	-113.47	-66.55	-30.94	20.60	86.89
IS29	-23.88	17.42	48.01	83.37	119.28	147.50	178.42	208.70	228.89	256.92	287.36
IS30	-78.06	-85.18	-41.31	-7.30	50.39	97.52	157.16	218.15	267.80	332.90	408.07
IS43	-99.41	-110.34	-111.98	-106.71	-57.70	-22.32	20.76	77.46	133.39	198.33	261.07
IS44	19.13	85.99	153.76	205.80	275.27	326.24	377.44	433.14	484.90	537.83	587.42
IS45	16.72	68.54	114.15	153.64	212.76	262.92	319.20	383.44	449.21	516.97	585.01
S13	67.32	237.10	363.03	484.81	595.62	673.52	756.35	836.64	910.85	989.42	1069.65
S14	214.86	-59.65	-318.65	-524.81	-712.47	-865.49	-1008.47	-1120.16	-1243.87	-1338.88	-1420.71
S15	141.22	286.48	366.64	484.97	587.92	662.30	737.97	814.00	878.13	951.72	1024.78
S19	46.06	165.60	260.26	367.48	465.18	540.93	614.36	690.27	757.24	833.66	903.70
S20	-129.09	-332.32	-594.70	-755.94	-949.73	-1124.13	-1287.57	-1436.98	-1592.23	-1733.84	-1866.40
S21	-39.02	53.44	105.11	188.15	271.92	346.89	419.58	496.11	567.41	646.70	721.02
S22	-355.28	-179.07	-39.59	70.95	168.97	203.03	312.57	387.29	482.46	479.31	572.38
S23	368.02	105.26	-134.45	-403.83	-590.07	-751.03	-876.41	-1029.11	-1170.16	-1270.22	-1403.76
S24	789.63	932.59	1036.55	1106.83	1244.20	1376.95	1442.66	1539.10	1607.03	1691.98	1759.33
S28	103.09	267.09	397.41	506.11	612.56	695.58	774.05	852.90	920.57	996.24	1071.39
S29	-0.51	-119.18	-285.37	-384.00	-455.47	-524.07	-596.05	-643.04	-682.28	-702.13	-732.65
S30	-51.08	83.13	145.09	241.42	335.56	417.96	492.95	568.18	635.95	713.91	789.84
S43	113.57	254.11	381.43	505.54	614.70	703.23	792.49	877.24	961.54	1043.84	1124.53
S44	195.92	-7.01	-287.36	-450.17	-650.04	-829.58	-988.68	-1137.96	-1287.09	-1418.95	-1509.51
S45	6.09	56.87	132.27	215.73	302.08	370.24	445.55	523.97	601.52	677.60	752.37
UAA	-18081.97	-17992.81	-17890.63	-17818.15	-17718.77	-17633.31	-17545.06	-17459.08	-17382.39	-17298.44	-17221.59
UAF	45.33	183.15	351.12	467.90	620.90	751.73	877.43	999.55	1117.19	1239.72	1351.02
UBA	95.92	376.31	653.21	892.63	1113.03	1305.54	1485.51	1644.91	1800.01	1955.08	2093.43
UBF	176.63	531.88	916.58	1228.21	1532.40	1798.28	2043.23	2248.26	2469.44	2681.81	2871.33
UDAA	4.40	136.20	297.43	423.66	540.20	646.60	769.78	870.73	955.02	1040.03	1150.21
UDAF	-18.72	104.31	238.53	356.63	468.74	569.50	676.80	774.77	854.30	938.38	1033.75
UDBA	180.12	488.65	844.60	1165.85	1406.42	1629.83	1875.32	2070.92	2250.68	2409.36	2602.63
UDBF	230.18	560.81	892.01	1205.06	1440.15	1659.53	1888.47	2078.79	2253.08	2415.54	2594.82

Table E-19. Strain survey raw data 80,000 cycles (run 3)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.02	0.67	1.35	2.07	2.66	3.32	4.03	4.63	5.32	6.00	6.68
Hoop-1	6.11	668.08	1224.21	2080.13	2655.78	3656.81	4229.08	5075.32	5681.61	6360.93	6991.77
Hoop-2	67.40	549.65	1368.96	2067.48	2675.70	3602.18	4210.61	4975.83	5601.49	6243.94	7090.28
Hoop-3	338.07	879.33	1495.01	1980.13	2691.88	3636.29	4186.59	5005.19	5544.55	6274.01	6999.86
Hoop-4	-60.27	808.13	1465.73	1945.17	2851.21	3606.10	4155.61	4901.01	5709.87	6464.18	7036.46
Hoop-5	-32.99	845.52	1212.93	2058.91	2644.38	3302.81	4190.42	4830.18	5748.61	6219.07	6845.96
Hoop-6	6.29	673.12	1296.93	2241.83	2659.27	3259.78	4277.95	4727.41	5447.94	6418.90	7267.93
Hoop-7	2.20	779.40	1317.03	2225.29	2646.39	3605.27	4280.42	4709.91	5588.41	6475.30	7034.70
Hoop-8	-17.26	770.56	1515.46	1984.09	2568.99	3487.91	4230.52	4656.76	5241.39	6414.01	7394.05
Hoop-9	-58.75	595.45	1127.56	2170.13	2820.47	3356.23	4137.99	4873.72	5635.36	6268.88	6829.53
Hoop-10	99.92	777.60	1455.43	2233.75	2717.63	3546.77	4188.90	4885.16	5384.62	6258.40	7038.33
Hoop-11	-46.40	412.94	1284.73	2319.48	2888.96	3456.86	4111.17	4694.42	5788.16	6090.80	7233.95
Hoop-12	-100.27	412.80	1295.33	2500.14	2878.36	3700.81	4297.20	4880.38	5840.63	6234.28	7253.34
Hoop-13	38.93	594.28	1295.91	2195.02	2874.45	3524.87	4255.25	4935.81	5658.82	6280.63	6945.72
Hoop-14	-11.92	691.81	1337.03	2114.35	2744.62	3661.03	4349.73	4981.14	5640.46	6293.57	7100.08
Long-1	1.36	533.04	1505.84	2178.59	2724.08	3548.21	3892.41	4779.62	5400.58	6107.52	6764.15
Long-2	37.16	537.13	1350.14	1795.68	2812.94	3030.80	4030.95	4728.53	5478.31	6043.00	6670.13
Long-3	4.69	660.09	1213.19	1802.48	2536.11	3548.21	3890.40	4641.34	5246.37	5888.28	6803.49
Long-4	-11.15	830.70	1412.52	1890.69	2571.32	3471.87	4151.49	4695.63	5279.54	6014.61	6538.26
Long-5	35.88	335.93	1351.68	2043.16	2125.32	3388.78	4080.98	4185.15	5210.81	6247.74	6739.31
Long-6	31.44	811.40	1327.61	1540.04	2839.62	3354.44	4114.46	4954.85	5446.61	5977.84	6567.60
Long-7	14.09	896.12	1538.62	2143.87	2750.48	3350.87	3908.33	4717.47	5353.76	5954.67	6787.04
Long-8	59.28	511.61	1304.15	2079.85	2778.41	3478.95	3962.23	4599.85	5338.89	5989.20	6744.61
Frame-1	8.49	151.54	235.60	343.93	452.63	579.41	668.65	782.15	874.21	956.05	1115.48
Frame-2	16.13	94.62	171.64	278.79	577.11	435.52	744.81	850.71	1006.32	1027.21	1003.95
Frame-3	58.12	15.59	250.46	290.82	363.49	564.70	622.37	760.07	861.12	1000.59	1140.16
Frame-4	53.59	128.25	156.25	287.70	382.83	540.47	732.54	742.75	816.80	982.49	1053.27
Frame-5	-47.81	53.95	174.66	380.44	427.19	512.72	649.72	770.13	819.22	970.61	1077.23
Frame-6	-73.15	121.89	280.62	388.63	516.62	586.84	674.54	875.12	861.11	918.02	1060.35
Frame-7	53.03	239.30	247.21	293.02	488.54	545.99	760.93	856.97	953.86	907.63	1098.82
Frame-8	-59.28	45.02	175.76	376.32	450.27	533.57	701.45	742.54	869.36	980.05	1048.23
Frame-9	-17.00	172.27	314.77	339.68	476.63	536.54	814.29	736.80	786.07	1057.86	1142.18
Frame-10	110.43	244.99	201.02	375.39	502.03	463.03	708.96	772.67	931.30	886.35	1172.30
Frame-11	-159.59	84.46	119.15	196.73	726.69	391.70	768.11	991.84	1129.39	1105.62	925.19
Frame-12	9.99	147.02	206.40	344.70	424.72	549.51	644.75	756.41	873.55	959.80	1065.07
HSA	55.84	196.34	323.64	441.45	545.32	655.12	750.50	846.90	945.08	1015.83	1107.92
HSF1	72.82	207.01	333.81	446.04	550.50	660.71	757.58	849.85	947.34	1020.85	1112.07
HSF2	59.36	183.73	296.94	397.58	489.45	587.76	674.48	755.96	843.98	908.16	989.35
IS13	-112.21	-178.31	-228.50	-225.59	-229.98	-214.63	-190.82	-163.24	-117.96	-83.47	-24.92

Table E-19. Strain survey raw data 80,000 cycles (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.02	0.67	1.35	2.07	2.66	3.32	4.03	4.63	5.32	6.00	6.68
IS14	-80.34	-31.91	7.68	61.14	82.47	117.51	150.31	177.37	215.79	241.71	284.73
IS15	-133.05	-206.19	-235.98	-247.95	-259.52	-249.60	-235.46	-215.20	-180.28	-151.17	-102.86
IS19	-83.36	-97.39	-115.13	-85.52	-61.03	-25.04	12.26	57.59	109.66	155.59	213.15
IS20	-41.18	11.76	53.33	111.08	154.21	201.43	242.76	285.67	330.68	367.98	410.79
IS21	-61.28	-41.49	19.75	68.59	111.99	169.56	211.01	264.78	320.42	369.12	427.84
IS22	-72.32	-137.39	-193.34	-190.61	-201.91	-180.70	-161.52	-138.77	-95.84	-64.15	-4.98
IS23	-29.01	19.17	54.14	105.58	122.69	156.57	182.00	203.87	235.17	249.82	284.00
IS24	-115.28	-189.77	-209.76	-225.14	-243.87	-225.64	-215.78	-199.46	-167.66	-141.54	-92.69
IS28	-123.70	-169.85	-212.44	-194.41	-191.79	-147.46	-120.43	-82.40	-38.49	11.68	73.43
IS29	-19.16	19.10	51.67	92.66	114.34	151.77	175.31	201.05	225.41	249.92	279.22
IS30	-72.47	-91.90	-28.58	7.81	36.74	107.58	150.23	205.05	260.31	321.75	393.78
IS43	-81.25	-108.55	-110.04	-92.07	-63.15	-18.45	25.68	75.31	137.39	181.34	252.85
IS44	9.18	88.93	151.38	217.23	269.79	328.63	381.95	431.51	487.22	526.46	581.08
IS45	0.36	60.35	100.54	159.81	207.65	265.97	324.98	381.99	451.53	504.08	577.13
S13	54.97	221.02	379.86	510.26	584.63	676.77	762.83	829.35	910.03	975.98	1058.21
S14	293.10	-37.99	-287.53	-533.48	-683.35	-852.66	-995.66	-1115.80	-1239.93	-1339.41	-1419.18
S15	135.46	292.26	387.15	514.84	584.95	663.36	743.73	803.06	876.58	938.24	1016.23
S19	37.34	164.83	275.62	385.66	460.04	539.75	617.94	683.71	756.43	820.15	895.14
S20	-90.39	-332.30	-551.15	-766.48	-947.09	-1132.41	-1291.02	-1451.82	-1604.42	-1746.39	-1857.06
S21	-38.32	62.89	109.50	201.97	272.62	344.88	420.27	491.75	565.90	633.12	710.24
S22	-456.18	-334.66	-159.63	-29.80	56.13	98.59	213.89	279.53	359.63	392.29	487.84
S23	435.55	140.25	-171.40	-424.48	-518.71	-773.03	-903.43	-990.73	-1106.97	-1209.50	
S24	869.17	1024.76	1117.60	1269.00	1356.32	1395.05	1471.79	1554.22	1642.62	1684.69	1766.15
S28	82.01	254.65	406.23	525.00	605.22	690.82	771.79	840.51	913.19	979.88	1057.76
S29	37.89	-124.13	-257.74	-364.03	-424.97	-532.46	-584.37	-631.42	-673.35	-719.40	-739.44
S30	-43.09	89.67	148.76	266.20	339.90	415.98	492.90	563.80	632.97	701.07	779.05
S43	79.14	259.51	384.42	522.73	609.74	705.76	799.12	871.43	958.00	1033.00	1116.59
S44	279.64	57.22	-184.24	-362.73	-539.47	-708.80	-855.57	-1033.91	-1170.05	-1272.59	-1395.77
S45	-0.44	77.17	142.45	226.59	297.70	374.05	451.30	519.62	599.28	665.54	744.54
UAA	-18085.58	-17984.10	-17900.77	-17793.80	-17712.63	-17630.51	-17534.57	-17458.35	-17374.10	-17303.20	-17230.14
UAF	27.85	180.93	326.40	486.99	619.57	758.49	880.08	1004.65	1128.74	1233.84	1338.72
UBA	30.78	354.03	631.31	921.12	1105.64	1311.66	1491.55	1645.28	1811.84	1949.86	2082.56
UBF	100.52	508.94	891.19	1271.93	1521.28	1802.10	2045.21	2259.22	2489.65	2674.11	2866.79
UDAA	-0.33	150.93	295.49	435.47	511.53	668.45	755.12	846.67	938.34	1036.62	1137.13
UDAF	-26.29	116.13	232.98	368.39	455.43	584.92	671.09	758.56	843.84	937.11	1017.74
UDBA	114.16	483.48	840.96	1171.53	1346.76	1661.87	1863.52	2032.46	2225.78	2405.97	2587.91
UDBF	156.27	551.08	885.47	1218.18	1401.73	1685.24	1885.92	2048.85	2236.71	2414.52	2577.38

Table E-20. Strain survey raw data 90,000 cycles (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
Long-1	-16.91	641.08	1349.59	1990.90	2676.61	3357.75	3997.49	4669.48	5340.84	6020.17	6675.61
Long-2	14.24	678.17	1351.83	1994.31	2676.41	3348.44	4019.96	4681.76	5352.45	6015.19	6685.24
Long-3	-11.25	686.30	1371.57	1998.26	2675.07	3345.73	4037.42	4671.60	5341.07	6017.10	6685.38
Long-4	6.92	670.44	1335.56	2002.67	2689.08	3332.87	3999.77	4687.24	5337.33	6007.54	6683.31
Long-5	1.14	678.36	1346.34	1995.34	2680.23	3348.00	4008.52	4681.59	5350.96	6024.29	6689.04
Long-6	-3.23	686.78	1355.95	2006.75	2684.45	3353.83	4023.38	4679.76	5354.32	6020.60	6684.17
Long-7	1.06	657.91	1324.38	1990.74	2675.42	3349.99	4052.43	4702.68	5367.43	6029.40	6696.03
Long-8	0.70	669.63	1346.34	2002.65	2682.02	3343.64	4012.38	4684.11	5348.28	6009.98	6687.19
Frame-1	-1.41	107.14	255.04	336.64	476.05	555.21	645.12	789.57	901.58	1026.15	1169.66
Frame-2	78.25	66.78	231.56	337.09	459.64	571.26	684.44	797.64	909.47	1022.48	1139.90
Frame-3	0.80	113.97	226.33	348.58	461.74	572.96	682.93	795.60	906.26	1024.54	1136.56
Frame-4	63.12	65.59	235.23	340.29	462.50	568.49	688.89	800.16	912.03	1025.55	1137.33
Frame-5	-0.39	109.67	228.96	340.39	452.55	571.56	683.12	795.33	899.36	1019.90	1143.99
Frame-6	0.28	126.79	244.81	343.93	463.94	575.35	683.36	796.13	908.10	1025.85	1139.04
Frame-7	26.62	24.35	236.36	346.30	462.28	568.30	681.53	799.57	910.47	1024.47	1141.63
Frame-8	14.15	96.93	227.91	343.86	453.98	567.47	673.87	795.16	906.16	1025.31	1137.50
Frame-9	52.27	50.66	237.16	341.00	457.33	566.14	682.37	795.30	908.24	1019.97	1137.49
Frame-10	2.73	108.64	231.75	355.27	454.08	569.40	686.75	803.78	903.93	1023.54	1135.46
Frame-11	23.46	21.06	230.99	343.15	456.25	572.81	687.58	792.16	908.55	1025.50	1138.52
Frame-12	47.42	40.16	228.90	350.30	458.60	574.92	685.47	797.89	910.18	1026.97	1143.11
Hoop-1	58.02	737.46	1410.78	2174.94	2832.53	3562.84	4281.95	5009.92	5711.73	6428.19	7140.42
Hoop-2	61.73	694.69	1421.53	2176.17	2833.13	3565.83	4260.36	4988.28	5708.50	6419.41	7138.80
Hoop-3	-2.78	737.67	1443.81	2161.88	2853.16	3565.70	4273.29	5004.59	5720.39	6418.22	7145.66
Hoop-4	33.64	737.92	1424.49	2174.11	2850.67	3556.69	4262.96	4981.61	5714.89	6428.90	7155.04
Hoop-5	-7.51	709.35	1405.91	2181.66	2822.03	3547.26	4262.95	4981.89	5717.52	6422.44	7146.50
Hoop-6	153.82	718.02	1411.80	2173.59	2839.89	3549.89	4278.28	4995.90	5707.12	6425.50	7141.73
Hoop-7	-17.15	724.94	1421.94	2226.08	2843.93	3551.99	4279.83	4988.15	5720.20	6428.94	7143.08
Hoop-8	166.89	423.06	1395.29	2183.61	2839.61	3553.67	4262.10	5006.40	5715.15	6438.14	7149.73
Hoop-9	68.82	620.46	1460.75	2170.24	2862.38	3555.00	4298.75	4988.87	5729.00	6440.99	7161.27
Hoop-10	-6.25	708.39	1412.64	2165.15	2834.73	3563.32	4269.80	4980.35	5731.03	6422.52	7141.15
Hoop-11	121.60	690.20	1435.02	2168.44	2782.03	3561.77	4279.15	4997.36	5701.43	6420.82	7150.89
Hoop-12	205.56	398.15	1438.61	2198.01	2853.66	3549.82	4266.14	4987.09	5734.82	6426.47	7160.84
Hoop-13	112.22	627.07	1402.03	2159.30	2880.14	3496.60	4262.66	4995.10	5701.63	6392.69	7150.95
Hoop-14	31.10	708.27	1392.66	2152.26	2852.52	3563.71	4273.11	5005.51	5730.00	6432.44	7133.67
UBF1	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
UBF2	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
UBF3	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
UBF4	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11

Table E-20. Strain survey raw data 90,000 cycles (run 1) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
UBF5	63.38	393.68	633.93	875.55	1031.60	1210.50	1376.73	1516.64	1650.64	1764.84	1869.14
UBF6	58.45	375.93	610.67	840.71	997.76	1170.61	1339.96	1485.52	1626.21	1745.91	1862.91
UBF7											
UBF8	42.89	335.14	544.81	755.02	898.51	1056.62	1210.42	1344.02	1472.27	1581.82	1688.75
UBF9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UBF10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UBA1	0.42	-0.17	-0.73	0.04	-1.19	-0.45	-0.02	-0.03	-0.46	-0.35	-0.44
UBA2	42.89	323.88	552.82	769.92	917.98	1079.73	1237.94	1373.79	1502.89	1613.07	1720.66
UBA3	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09
UBA4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UBA5	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
UBA6	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UBA7	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UBA8	-0.98	-0.24	-0.54	-1.03	-1.11	-0.97	-0.91	-1.39	-1.53	-1.38	-1.39
UBA9	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
UBA10	0.82	-1.27	2.98	0.64	0.53	-1.63	1.85	1.23	-0.01	-1.84	0.07
IS13	-78.22	-205.28	-239.70	-258.29	-256.54	-247.44	-234.09	-203.31	-172.21	-129.46	-80.88
IS14	22.10	41.91	101.39	145.99	180.42	216.04	246.43	283.82	315.02	351.63	388.66
IS15	-24.11	-167.40	-214.77	-248.18	-256.05	-257.90	-255.13	-234.12	-211.80	-176.69	-135.84
S13	0.19	0.95	3.10	3.89	3.78	3.35	2.33	1.77	0.70	-0.26	-0.43
S14	-10.16	-149.80	-231.72	-299.70	-355.54	-409.14	-462.36	-499.87	-534.47	-554.78	-571.51
S15	79.74	234.19	397.57	514.74	600.31	685.01	761.25	836.91	907.84	977.85	1047.98
RBF1	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09
RBF2	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
RBF3	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
RBF4	43.40	233.95	358.69	493.76	585.44	690.45	794.40	885.64	975.83	1053.99	1131.96
RBF5	45.33	229.37	350.84	480.33	569.33	670.30	771.01	859.31	945.79	1020.76	1094.80
RBF6	29.56	209.20	327.60	453.44	540.07	637.89	735.16	821.33	904.67	977.76	1050.31
RBF7	34.04	208.48	324.29	447.47	531.66	627.36	721.80	805.07	886.28	957.63	1028.07
RBF8	27.92	198.00	310.53	429.91	512.97	606.35	698.23	779.29	857.95	927.74	995.88
RBF9	25.46	191.70	302.87	419.99	500.19	591.46	681.30	761.20	837.91	905.22	972.31
RBF10	-2272.35	-2325.64	-2507.09	-2585.27	-2632.15	-2677.06	-2683.94	-2665.31	-2694.62	-2659.56	-2612.88
RBA2	74.59	213.32	316.12	420.46	493.16	574.12	653.81	724.89	793.48	854.37	914.66
RBA1	14.41	152.04	250.77	351.05	420.53	497.94	574.18	642.63	706.98	764.91	822.09
RBA3	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
RBA4	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
RBA5	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
RBA6	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Table E-20. Strain survey raw data 90,000 cycles (run 1) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
RBA7	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
RBA8	-4.76	-2.24	-3.07	-3.57	-3.50	-3.01	-0.07	-4.44	0.21	1.17	-2.20
RBA9	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
RBA10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IS16	8.74	-60.91	-69.00	-80.16	-77.09	-70.68	-63.70	-37.99	-13.62	23.98	66.70
IS17	23.38	84.79	151.56	211.21	254.26	299.62	339.79	381.76	416.59	452.43	487.23
IS18	0.10	-101.44	-120.33	-135.09	-131.04	-121.61	-108.11	-76.84	-45.03	-2.16	46.85
S16	51.37	177.47	332.59	455.54	553.65	655.42	751.91	843.70	932.99	1016.82	1101.02
S17	-25.75	-293.29	-413.35	-543.99	-652.08	-772.46	-894.98	-989.55	-1089.78	-1168.27	-1244.68
S18	79.90	236.74	393.33	517.35	612.16	708.87	798.99	884.39	966.49	1044.12	1121.57
UDBF1	33.70	269.51	480.99	669.15	798.98	937.72	1071.68	1186.70	1296.25	1390.43	1482.39
UDBF2	25.17	239.06	431.00	601.24	718.93	844.92	966.80	1072.25	1172.72	1259.52	1345.02
UDBF3	-3.15	-0.58	-2.00	-3.33	-3.48	-2.70	-3.22	-4.52	-4.97	-4.25	-4.45
UDBF4	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
UDBF5	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
UDBF6	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UDBF7	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
UDBF8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UDBF9	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11
UDBF10	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
UDBA1	7.20	6.59	7.82	12.62	11.61	14.87	13.48	9.80	11.56	8.05	6.23
UDBA2	5.11	4.45	5.79	9.20	9.40	10.87	10.03	7.36	6.40	4.25	4.08
UDBA3	5.36	5.36	8.36	10.71	11.42	11.41	10.71	8.67	4.88	4.12	4.07
UDBA4	-10.65	234.51	414.95	582.97	729.25	882.82	1038.07	1176.94	1314.66	1437.53	1558.79
UDBA5	3.93	241.14	415.58	577.89	718.24	865.69	1014.24	1147.12	1278.93	1396.84	1513.18
UDBA6	18.13	247.46	416.56	573.03	708.18	850.37	993.48	1121.09	1248.08	1361.34	1473.43
UDBA7	31.40	251.32	413.46	564.46	693.97	831.91	969.57	1092.60	1214.63	1324.13	1432.02
UDBA8	35.03	246.95	402.79	548.08	671.80	804.73	936.86	1054.47	1172.36	1276.11	1378.97
UDBA9	10.90	217.16	370.23	513.09	633.04	761.59	889.62	1002.54	1116.48	1216.91	1316.71
UDBA10	15.77	214.41	359.09	494.33	609.84	732.71	855.75	965.10	1074.53	1171.63	1267.91
IS22	-51.72	-146.07	-195.23	-220.54	-223.04	-218.01	-204.86	-176.07	-144.27	-102.67	-53.28
IS23	17.79	41.45	101.45	142.48	171.85	201.06	226.68	258.11	282.99	311.78	342.01
IS24	12.34	-109.89	-132.45	-155.05	-162.45	-167.22	-169.55	-157.94	-148.00	-128.91	-105.88
S22	87.12	225.25	400.30	515.54	597.94	682.91	762.63	838.57	911.37	980.96	1050.81
S23	-60.53	-400.64	-694.01	-939.61	-1096.76	-1264.25	-1425.47	-1551.43	-1669.22	-1757.03	-1834.17
S24	22.57	213.10	359.64	472.74	546.74	625.42	697.04	769.26	835.14	900.73	967.61
UDAF1	31.09	174.21	323.69	466.75	573.54	691.37	809.31	918.52	1025.29	1121.61	1218.60
UDAF2	20.61	140.67	269.58	393.87	487.13	589.64	691.73	787.22	879.97	964.23	1049.64

Table E-20. Strain survey raw data 90,000 cycles (run 1) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
UDAF3	-1.29	-1.15	-1.18	-1.39	-1.03	-1.19	-1.58	-1.98	-1.70	-1.55	-2.15
UDAF4	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
UDAF5	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11
UDAF6	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
UDAF7	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
UDAF8	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
UDAF9	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
UDAF10	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UDAA1	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12
UDAA2	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
UDAA3	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
UDAA4	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
UDAA5	-94.86	197.17	476.65	725.36	895.49	1079.36	1258.05	1411.89	1555.81	1679.54	1800.37
UDAA6	30.27	305.99	569.11	801.94	960.53	1132.05	1298.89	1443.00	1576.51	1692.34	1805.43
UDAA7	36.50	297.91	548.58	769.87	920.65	1082.94	1241.14	1377.92	1505.27	1615.79	1723.54
UDAA8	28.27	277.14	515.52	725.41	868.72	1023.12	1173.45	1302.98	1424.55	1528.91	1632.31
UDAA9	29.29	267.31	494.40	694.97	831.17	978.10	1121.11	1245.81	1361.23	1462.49	1561.33
UDAA10	29.44	258.99	477.46	669.81	801.72	942.70	1080.55	1200.71	1312.40	1410.27	1506.10
IS28	-18.14	-140.80	-166.49	-173.01	-159.51	-138.46	-112.03	-67.88	-26.05	25.83	82.97
IS29	10.99	44.71	90.05	131.68	163.42	194.88	222.61	255.75	281.79	311.31	341.05
IS30	-12.29	-55.38	-0.22	38.25	73.44	113.21	154.50	207.09	256.19	311.59	370.63
S28	45.81	262.15	418.65	540.04	632.62	727.98	819.40	903.25	986.60	1063.84	1142.04
S29	-4.58	-200.31	-315.30	-415.61	-498.04	-576.78	-651.39	-703.68	-750.60	-781.51	-805.11
S30	23.58	173.13	252.58	339.43	412.59	492.07	572.21	648.18	725.43	798.09	872.57
UAF	7.41	143.44	242.87	367.96	458.66	560.92	664.71	765.39	859.28	948.64	1038.52
UAA	9.42	77.07	163.83	262.91	339.88	425.01	511.48	602.26	684.27	767.21	851.14
IS19	-18.09	-103.74	-105.64	-95.50	-76.16	-49.97	-21.21	24.00	65.87	117.74	174.05
IS20	4.55	36.50	90.54	145.92	186.76	229.22	267.10	316.27	352.85	397.66	441.90
IS21	-21.75	-10.05	24.00	61.14	95.22	133.87	171.94	222.34	267.76	321.22	377.46
S19	71.27	245.39	395.32	507.92	596.02	686.86	774.36	858.43	941.28	1020.31	1100.64
S20	-4.47	-260.11	-412.59	-585.47	-737.08	-903.86	-1083.55	-1230.26	-1385.85	-1513.67	-1641.09
S21	52.49	128.10	228.81	318.95	393.94	475.67	559.78	640.62	723.64	801.74	882.48
RAF	26.94	131.93	246.30	356.93	439.81	533.86	631.18	723.24	815.84	901.10	989.12
RAA	54.54	145.21	258.01	365.79	445.82	536.53	630.53	722.85	812.09	897.14	984.92
IS25	4.05	-37.85	-24.93	-5.29	21.44	56.12	95.00	145.88	196.08	252.55	314.86
IS26	20.37	87.65	174.81	255.10	314.52	380.30	445.70	510.69	571.17	629.33	688.46
IS27	8.51	-80.90	-48.05	-21.62	9.11	47.17	88.73	141.80	193.82	251.71	314.87
S25	26.88	174.55	319.00	426.37	507.79	592.22	673.79	749.54	823.02	892.18	961.69

Table E-20. Strain survey raw data 90,000 cycles (run 1) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
S26	-8.85	-171.27	-289.12	-401.52	-501.48	-610.43	-729.64	-828.16	-934.41	-1023.56	-1114.35
S27	-17.89	188.51	302.95	399.25	469.64	547.91	622.93	695.11	763.06	829.35	896.56
HSF1	583.66	749.46	899.61	1045.33	1154.72	1264.52	1366.46	1458.96	1551.80	1640.32	1722.90
HSF2	1173.57	1372.29	1531.89	1634.26	1702.86	1775.65	1846.10	1924.57	1986.80	2054.06	2119.31
HSA	11.35	187.90	293.90	424.14	517.13	622.20	728.43	829.05	925.46	1014.75	1103.81
IS43	-5.72	-117.61	-131.73	-118.12	-94.41	-63.42	-29.43	24.25	69.70	127.95	188.73
IS44	19.80	99.47	161.98	228.42	275.87	327.79	377.38	430.07	476.04	523.52	570.61
IS45	-34.97	32.97	72.88	122.03	159.38	203.76	249.55	306.02	355.08	412.39	471.99
S43	46.06	308.95	478.63	604.24	701.00	799.74	896.39	982.92	1068.75	1147.86	1227.05
S44	31.17	-308.48	-467.26	-639.69	-792.27	-951.01	-1117.33	-1253.52	-1393.62	-1509.15	-1622.11
S45	35.70	95.75	189.21	275.64	349.16	429.17	512.26	590.77	671.81	747.91	825.40

Table E-21. Strain survey raw data 90,000 cycles (run 2)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	-0.01	0.62	1.35	2.05	2.71	3.34	4.02	4.72	5.37	6.07	6.73
Long-1	1.01	688.32	1361.09	2002.37	2661.11	3333.23	4022.75	4660.22	5314.74	6030.39	6643.41
Long-2	-18.16	685.01	1359.87	2006.71	2668.90	3353.97	4010.89	4682.75	5353.34	6012.33	6681.80
Long-3	-10.17	692.93	1368.90	2027.81	2672.28	3317.98	4014.02	4691.96	5360.90	6029.71	6693.92
Long-4	-10.13	691.23	1361.34	1997.97	2667.31	3334.06	4003.33	4694.89	5338.52	5999.15	6670.84
Long-5	0.84	690.03	1345.92	2003.10	2673.08	3353.38	4015.07	4683.12	5357.80	6010.21	6679.56
Long-6	-0.62	669.97	1357.73	2000.72	2674.55	3349.78	4012.63	4677.86	5346.80	6010.99	6677.82
Long-7	-4.44	676.80	1346.16	2027.87	2678.76	3352.18	3997.91	4665.29	5332.12	6016.08	6700.91
Long-8	6.38	671.12	1342.54	2011.71	2678.92	3348.12	4014.50	4683.04	5349.57	6012.80	6679.05
Frame-1	5.38	114.88	230.66	352.47	446.09	576.98	677.47	785.49	905.50	1002.90	1137.31
Frame-2	68.87	68.85	227.44	347.37	461.39	567.19	684.73	799.30	910.89	1024.45	1135.98
Frame-3	1.08	105.43	227.18	343.05	459.53	570.74	691.30	797.08	905.34	1025.20	1136.64
Frame-4	67.22	72.14	231.80	344.07	457.18	579.28	686.53	799.87	911.74	1023.40	1141.25
Frame-5	-4.71	122.21	225.55	339.40	464.02	569.19	681.57	789.37	901.55	1024.54	1136.09
Frame-6	0.80	148.34	246.43	351.07	466.42	572.14	686.58	797.69	911.69	1024.17	1137.27
Frame-7	27.25	22.70	226.91	344.15	456.79	567.36	688.50	802.65	910.58	1027.30	1138.57
Frame-8	24.34	16.09	227.61	339.62	453.88	563.49	680.17	790.49	909.00	1025.09	1136.41
Frame-9	50.56	62.87	230.71	346.38	458.07	569.86	681.40	796.69	910.69	1023.28	1136.82
Frame-10	6.09	117.28	219.86	339.58	447.74	570.01	686.39	795.72	898.30	1022.41	1139.67
Frame-11	18.46	31.65	224.60	345.62	448.03	573.71	684.85	798.19	907.63	1025.42	1143.82
Frame-12	48.59	49.50	231.40	337.31	446.97	566.18	685.16	798.47	908.99	1027.41	1139.15
Hoop-1	65.83	687.07	1413.03	2159.60	2862.14	3542.83	4286.16	5011.02	5718.79	6430.18	7135.02
Hoop-2	46.26	670.75	1420.66	2155.65	2878.44	3550.30	4279.39	5017.35	5716.54	6436.84	7152.23
Hoop-3	2.11	682.25	1429.91	2139.28	2861.79	3565.25	4271.93	5004.91	5721.12	6446.60	7149.86
Hoop-4	-26.29	689.44	1431.92	2140.94	2863.74	3551.60	4285.56	4993.97	5728.69	6437.18	7143.76
Hoop-5	-23.17	657.22	1417.24	2147.02	2870.77	3543.07	4283.03	5016.18	5722.95	6439.69	7146.70
Hoop-6	-21.24	679.78	1405.32	2150.40	2860.76	3550.48	4285.18	4997.13	5701.97	6435.52	7140.84
Hoop-7	4.53	661.14	1425.11	2166.11	2877.98	3577.77	4285.10	5017.84	5737.38	6450.55	7152.29
Hoop-8	198.09	446.97	1395.54	2161.45	2875.13	3547.00	4276.34	4999.67	5714.18	6432.66	7154.98
Hoop-9	108.43	328.72	1437.23	2114.93	2848.60	3564.01	4282.17	4999.86	5712.57	6428.69	7133.73
Hoop-10	13.14	677.80	1412.80	2145.97	2884.92	3539.07	4278.92	5017.39	5720.42	6441.94	7145.29
Hoop-11	107.43	283.43	1437.35	2149.67	2855.09	3567.62	4293.09	4996.53	5723.97	6429.31	7138.75
Hoop-12	305.09	447.14	1421.69	2149.70	2907.66	3554.65	4279.77	5037.38	5731.61	6473.12	7168.95
Hoop-13	136.13	285.98	1505.86	2147.19	2887.83	3536.47	4293.96	4995.57	5709.83	6439.49	7143.89
Hoop-14	36.99	678.71	1429.35	2177.14	2843.72	3566.13	4285.66	5005.27	5717.80	6437.61	7147.00
UBF1	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
UBF2	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
UBF3	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
UBF4	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11

Table E-21. Strain survey raw data 90,000 cycles (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	-0.01	0.62	1.35	2.05	2.71	3.34	4.02	4.72	5.37	6.07	6.73
UBF5	58.94	288.58	611.45	837.41	1031.89	1196.40	1348.58	1495.69	1610.79	1743.69	1852.66
UBF6	68.97	288.51	601.45	823.46	1018.65	1180.40	1345.47	1498.22	1631.85	1755.08	1866.97
UBF7											
UBF8	49.57	251.65	536.17	738.07	916.51	1064.39	1214.97	1354.31	1475.82	1589.39	1691.12
UBF9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UBF10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UBA1	-0.55	-0.79	-0.55	-0.89	-0.27	0.30	-0.13	-0.05	-0.55	0.00	-0.18
UBA2	47.94	232.33	532.09	739.42	923.03	1074.43	1229.58	1372.88	1496.48	1610.01	1711.79
UBA3	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09
UBA4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UBA5	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
UBA6	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UBA7	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UBA8	-1.55	-0.91	-1.32	-1.02	-0.86	-1.28	-1.23	-1.17	-1.28	-1.57	-1.03
UBA9	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
UBA10	3.53	-0.33	0.06	2.07	-4.06	-0.62	-0.09	-0.66	-0.84	-0.75	0.57
IS13	-72.15	-185.84	-231.20	-251.46	-253.16	-248.74	-226.88	-200.45	-165.33	-122.54	-76.91
IS14	20.80	29.65	103.67	144.66	182.81	211.17	249.16	282.70	317.44	353.05	387.89
IS15	-23.59	-142.78	-206.04	-240.68	-254.32	-261.01	-249.52	-232.80	-205.79	-171.39	-132.42
S13	-1.19	-2.00	-2.49	-2.13	-2.33	-2.79	-3.32	-3.33	-3.84	-3.59	-3.98
S14	-9.12	-97.75	-211.58	-285.28	-348.98	-403.21	-449.46	-492.13	-521.00	-544.06	-558.64
S15	82.68	203.94	399.13	514.06	610.10	684.93	767.56	840.55	911.73	982.05	1049.53
RBF1	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09
RBF2	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
RBF3	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
RBF4	49.77	189.67	357.29	486.38	600.77	697.70	800.17	896.23	981.21	1061.45	1136.36
RBF5	51.40	185.68	348.46	473.08	583.72	677.11	775.88	868.31	950.60	1027.94	1099.07
RBF6	35.91	166.73	325.49	446.70	553.36	644.10	740.58	830.30	909.38	984.46	1053.39
RBF7	38.22	166.60	320.58	439.08	544.31	632.47	725.92	813.28	890.53	963.78	1031.11
RBF8	30.82	156.03	306.61	422.49	524.67	610.83	701.77	786.79	861.86	932.39	998.38
RBF9	28.42	150.63	298.81	411.10	511.22	595.59	684.28	766.80	840.27	909.51	974.20
RBF10	-3903.73	-3808.14	-3703.50	-3623.48	-3532.61	-3459.29	-3381.77	-3303.34	-3237.32	-3175.73	-3121.51
RBA2	74.63	176.63	313.85	414.48	503.08	577.07	656.71	730.04	796.78	859.11	917.20
RBA1	1.70	103.41	237.09	334.78	421.51	493.14	570.58	641.96	705.62	765.17	820.11
RBA3	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
RBA4	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
RBA5	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
RBA6	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Table E-21. Strain survey raw data 90,000 cycles (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	-0.01	0.62	1.35	2.05	2.71	3.34	4.02	4.72	5.37	6.07	6.73
RBA7	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
RBA8	-4.24	-2.01	0.24	-2.52	-3.77	-2.68	-4.10	-2.02	-3.94	-2.68	-2.93
RBA9	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
RBA10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IS16	15.73	-33.92	-60.57	-74.00	-75.27	-74.63	-57.54	-37.38	-8.62	28.77	68.49
IS17	26.00	70.49	154.54	211.09	261.22	300.10	345.17	384.85	421.72	457.69	490.24
IS18	1.19	-83.14	-111.95	-129.33	-130.54	-126.23	-103.89	-76.29	-40.44	2.74	48.74
S16	48.42	137.70	328.97	453.55	565.33	657.82	757.74	849.55	937.02	1022.00	1103.23
S17	-32.45	-212.99	-395.44	-539.07	-667.40	-779.54	-893.31	-999.75	-1087.74	-1168.22	-1240.80
S18	110.57	228.19	414.26	539.09	646.56	733.20	826.85	911.17	991.86	1070.27	1145.56
UDBF1	30.41	179.27	468.42	650.28	808.42	938.86	1071.01	1190.52	1296.11	1392.99	1481.22
UDBF2	21.15	155.15	418.67	583.14	726.62	844.99	965.13	1074.62	1171.78	1261.19	1343.10
UDBF3	-4.47	-2.10	-4.43	-3.25	-2.64	-3.90	-3.54	-3.65	-4.04	-5.44	-3.24
UDBF4	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
UDBF5	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
UDBF6	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UDBF7	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
UDBF8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UDBF9	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11
UDBF10	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
UDBA1	5.35	5.56	3.26	2.61	1.74	0.33	-1.79	-1.96	-1.35	-2.59	-3.10
UDBA2	1.55	2.28	-0.62	-1.22	-2.14	-3.52	-4.17	-3.95	-4.98	-5.24	-5.94
UDBA3	0.58	0.82	-1.86	-1.63	-3.02	-4.97	-4.08	-4.03	-5.85	-5.75	-6.60
UDBA4	-19.27	156.07	393.82	572.78	741.57	891.07	1041.89	1185.60	1316.17	1442.25	1560.41
UDBA5	-2.10	167.59	397.33	569.55	730.93	873.53	1018.06	1155.40	1280.27	1401.07	1513.99
UDBA6	15.86	180.19	401.75	566.76	722.13	858.97	998.05	1130.02	1249.92	1365.84	1474.71
UDBA7	27.59	186.69	400.10	559.33	708.71	841.02	974.91	1101.87	1217.82	1329.11	1434.68
UDBA8	32.69	185.87	390.73	542.79	686.03	812.56	940.40	1061.50	1172.58	1278.76	1379.77
UDBA9	21.73	169.38	368.30	514.73	653.37	774.00	897.14	1014.08	1120.73	1223.53	1320.37
UDBA10	17.35	160.53	353.01	494.45	627.94	744.63	864.02	976.59	1080.05	1179.16	1272.92
IS22	-47.48	-120.31	-188.63	-216.28	-222.14	-220.34	-200.80	-175.19	-140.47	-98.41	-51.84
IS23	16.98	25.25	102.85	140.07	173.27	196.39	228.85	256.09	284.11	312.89	339.95
IS24	3.04	-104.11	-135.54	-162.93	-176.25	-186.67	-183.64	-178.05	-166.30	-150.81	-133.89
S22	85.71	173.43	393.97	511.40	607.43	683.57	767.20	842.48	913.90	984.03	1051.10
S23	-71.38	-286.72	-684.86	-920.34	-1116.11	-1277.16	-1430.49	-1567.17	-1675.40	-1767.21	-1840.60
S24	31.59	186.19	359.35	466.45	555.20	620.81	699.28	769.92	836.85	902.82	965.79
UDAF1	31.87	134.77	315.85	454.62	581.64	692.74	811.25	923.45	1026.90	1126.30	1219.71
UDAF2	17.11	103.93	262.86	382.96	493.33	589.38	692.63	790.44	880.57	967.60	1049.30

Table E-21. Strain survey raw data 90,000 cycles (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	-0.01	0.62	1.35	2.05	2.71	3.34	4.02	4.72	5.37	6.07	6.73
UDAF3	-1.97	-2.45	-1.84	-1.88	-1.78	-1.48	-1.75	-2.09	-2.34	-1.87	-1.52
UDAF4	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
UDAF5	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11
UDAF6	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
UDAF7	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
UDAF8	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
UDAF9	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
UDAF10	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UDAA1	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12
UDAA2	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
UDAA3	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
UDAA4	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
UDAA5	-90.89	87.09	462.80	701.04	912.01	1086.58	1261.94	1421.30	1558.66	1686.79	1801.72
UDAA6	32.77	200.46	554.98	778.11	975.17	1138.47	1302.15	1451.02	1579.14	1698.38	1805.41
UDAA7	39.42	198.60	535.73	748.29	934.64	1088.78	1244.61	1385.93	1508.43	1622.19	1724.71
UDAA8	30.27	181.75	503.60	704.52	881.73	1028.35	1176.49	1310.28	1427.02	1535.40	1633.23
UDAA9	31.20	174.93	482.46	673.94	842.90	983.24	1124.21	1252.31	1363.53	1467.34	1560.75
UDAA10	29.61	168.39	465.16	649.89	812.12	946.66	1083.11	1206.61	1313.72	1414.69	1506.05
IS28	-17.58	-108.61	-158.08	-168.46	-157.84	-140.65	-105.66	-65.57	-21.13	31.90	84.07
IS29	11.81	37.62	92.25	131.65	167.17	194.76	228.15	258.42	285.56	316.12	341.94
IS30	-22.91	-81.97	-6.34	31.06	71.19	106.81	156.37	207.14	258.35	315.69	370.30
S28	49.48	201.70	409.71	536.33	644.03	732.09	824.17	909.33	989.56	1068.04	1143.90
S29	-3.75	-140.46	-297.60	-408.09	-502.15	-581.95	-649.38	-707.33	-748.84	-781.47	-804.32
S30	31.13	161.21	252.45	339.97	423.38	496.47	576.76	654.28	728.50	802.70	875.15
UAF	0.39	108.47	234.04	354.90	465.34	563.56	669.23	771.04	859.35	952.59	1034.46
UAA	3.80	56.14	160.82	255.43	345.35	426.29	517.78	608.03	686.26	772.62	847.53
IS19	-18.40	-87.45	-98.62	-92.39	-73.17	-53.14	-15.36	25.97	70.16	122.98	174.01
IS20	3.17	26.81	90.15	141.62	188.41	225.70	272.57	318.22	355.22	401.63	437.36
IS21	-22.95	-15.35	25.81	59.90	96.72	129.35	175.36	222.58	269.69	324.37	375.05
S19	73.98	207.62	391.22	505.31	605.81	689.19	779.61	864.00	945.29	1025.36	1103.34
S20	0.49	-175.80	-383.36	-572.23	-749.31	-915.67	-1079.90	-1241.30	-1381.21	-1514.47	-1637.38
S21	52.63	108.25	226.43	316.92	403.00	479.34	564.28	646.70	726.85	806.55	884.94
RAF	26.35	96.22	241.72	348.45	448.02	536.60	634.20	728.93	817.73	905.98	990.01
RAA	61.23	114.78	257.12	358.74	454.58	541.41	636.93	729.54	814.72	902.87	985.08
IS25	11.70	-26.56	-19.95	-4.44	23.58	52.55	98.03	145.97	198.39	256.10	314.49
IS26	20.75	62.30	172.82	249.96	320.62	381.48	449.84	514.63	573.56	633.84	688.45
IS27	11.10	-84.92	-42.86	-19.71	13.10	45.26	93.78	144.38	198.41	257.65	316.55
S25	21.31	129.95	310.54	420.59	515.39	593.22	675.92	752.89	824.06	893.75	960.08

Table E-21. Strain survey raw data 90,000 cycles (run 2) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	-0.01	0.62	1.35	2.05	2.71	3.34	4.02	4.72	5.37	6.07	6.73
S26	-6.24	-100.18	-268.15	-390.36	-507.69	-617.09	-725.90	-834.57	-930.79	-1024.78	-1113.21
S27	-10.89	153.87	292.13	390.22	476.63	544.73	622.61	695.26	761.66	827.53	890.68
HSF1	834.82	968.74	1113.31	1239.76	1345.06	1427.99	1526.10	1621.73	1707.14	1801.52	1868.31
HSF2	1337.68	1436.00	1531.03	1623.63	1705.85	1776.83	1853.65	1929.24	1986.14	2057.90	2110.07
HSA	4.14	147.02	282.35	408.61	523.21	623.17	730.33	832.66	923.70	1016.77	1100.38
IS43	-12.08	-99.87	-130.94	-120.46	-94.97	-67.60	-23.19	26.21	71.51	132.13	184.17
IS44	14.68	78.54	156.05	219.95	277.39	325.01	379.26	430.30	475.14	524.40	566.57
IS45	-41.58	9.46	60.65	109.10	155.50	196.43	249.23	304.14	353.29	412.90	465.23
S43	47.71	243.09	465.28	597.72	710.05	802.64	898.79	987.81	1070.41	1150.97	1228.17
S44	36.26	-221.98	-436.92	-626.69	-801.17	-960.00	-1112.41	-1260.08	-1387.50	-1507.40	-1616.36
S45	31.67	74.21	186.88	273.43	357.70	433.64	516.52	597.05	674.61	752.15	827.62

Table E-22. Strain survey raw data 90,000 cycles (run 3)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
Long-1	-16.91	641.08	1349.59	1990.90	2676.61	3357.75	3997.49	4669.48	5340.84	6020.17	6675.61
Long-2	14.24	678.17	1351.83	1994.31	2676.41	3348.44	4019.96	4681.76	5352.45	6015.19	6685.24
Long-3	-11.25	686.30	1371.57	1998.26	2675.07	3345.73	4037.42	4671.60	5341.07	6017.10	6685.38
Long-4	6.92	670.44	1335.56	2002.67	2689.08	3332.87	3999.77	4687.24	5337.33	6007.54	6683.31
Long-5	1.14	678.36	1346.34	1995.34	2680.23	3348.00	4008.52	4681.59	5350.96	6024.29	6689.04
Long-6	-3.23	686.78	1355.95	2006.75	2684.45	3353.83	4023.38	4679.76	5354.32	6020.60	6684.17
Long-7	1.06	657.91	1324.38	1990.74	2675.42	3349.99	4052.43	4702.68	5367.43	6029.40	6696.03
Long-8	0.70	669.63	1346.34	2002.65	2682.02	3343.64	4012.38	4684.11	5348.28	6009.98	6687.19
Frame-1	-1.41	107.14	255.04	336.64	476.05	555.21	645.12	789.57	901.58	1026.15	1169.66
Frame-2	78.25	66.78	231.56	337.09	459.64	571.26	684.44	797.64	909.47	1022.48	1139.90
Frame-3	0.80	113.97	226.33	348.58	461.74	572.96	682.93	795.60	906.26	1024.54	1136.56
Frame-4	63.12	65.59	235.23	340.29	462.50	568.49	688.89	800.16	912.03	1025.55	1137.33
Frame-5	-0.39	109.67	228.96	340.39	452.55	571.56	683.12	795.33	899.36	1019.90	1143.99
Frame-6	0.28	126.79	244.81	343.93	463.94	575.35	683.36	796.13	908.10	1025.85	1139.04
Frame-7	26.62	24.35	236.36	346.30	462.28	568.30	681.53	799.57	910.47	1024.47	1141.63
Frame-8	14.15	96.93	227.91	343.86	453.98	567.47	673.87	795.16	906.16	1025.31	1137.50
Frame-9	52.27	50.66	237.16	341.00	457.33	566.14	682.37	795.30	908.24	1019.97	1137.49
Frame-10	2.73	108.64	231.75	355.27	454.08	569.40	686.75	803.78	903.93	1023.54	1135.46
Frame-11	23.46	21.06	230.99	343.15	456.25	572.81	687.58	792.16	908.55	1025.50	1138.52
Frame-12	47.42	40.16	228.90	350.30	458.60	574.92	685.47	797.89	910.18	1026.97	1143.11
Hoop-1	58.02	737.46	1410.78	2174.94	2832.53	3562.84	4281.95	5009.92	5711.73	6428.19	7140.42
Hoop-2	61.73	694.69	1421.53	2176.17	2833.13	3565.83	4260.36	4988.28	5708.50	6419.41	7138.80
Hoop-3	-2.78	737.67	1443.81	2161.88	2853.16	3565.70	4273.29	5004.59	5720.39	6418.22	7145.66
Hoop-4	33.64	737.92	1424.49	2174.11	2850.67	3556.69	4262.96	4981.61	5714.89	6428.90	7155.04
Hoop-5	-7.51	709.35	1405.91	2181.66	2822.03	3547.26	4262.95	4981.89	5717.52	6422.44	7146.50
Hoop-6	153.82	718.02	1411.80	2173.59	2839.89	3549.89	4278.28	4995.90	5707.12	6425.50	7141.73
Hoop-7	-17.15	724.94	1421.94	2226.08	2843.93	3551.99	4279.83	4988.15	5720.20	6428.94	7143.08
Hoop-8	166.89	423.06	1395.29	2183.61	2839.61	3553.67	4262.10	5006.40	5715.15	6438.14	7149.73
Hoop-9	68.82	620.46	1460.75	2170.24	2862.38	3555.00	4298.75	4988.87	5729.00	6440.99	7161.27
Hoop-10	-6.25	708.39	1412.64	2165.15	2834.73	3563.32	4269.80	4980.35	5731.03	6422.52	7141.15
Hoop-11	121.60	690.20	1435.02	2168.44	2782.03	3561.77	4279.15	4997.36	5701.43	6420.82	7150.89
Hoop-12	205.56	398.15	1438.61	2198.01	2853.66	3549.82	4266.14	4987.09	5734.82	6426.47	7160.84
Hoop-13	112.22	627.07	1402.03	2159.30	2880.14	3496.60	4262.66	4995.10	5701.63	6392.69	7150.95
Hoop-14	31.10	708.27	1392.66	2152.26	2852.52	3563.71	4273.11	5005.51	5730.00	6432.44	7133.67
UBF1	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
UBF2	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
UBF3	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
UBF4	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11

Table E-22. Strain survey raw data 90,000 cycles (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
UBF5	63.38	393.68	633.93	875.55	1031.60	1210.50	1376.73	1516.64	1650.64	1764.84	1869.14
UBF6	58.45	375.93	610.67	840.71	997.76	1170.61	1339.96	1485.52	1626.21	1745.91	1862.91
UBF7											
UBF8	42.89	335.14	544.81	755.02	898.51	1056.62	1210.42	1344.02	1472.27	1581.82	1688.75
UBF9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UBF10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UBA1	0.42	-0.17	-0.73	0.04	-1.19	-0.45	-0.02	-0.03	-0.46	-0.35	-0.44
UBA2	42.89	323.88	552.82	769.92	917.98	1079.73	1237.94	1373.79	1502.89	1613.07	1720.66
UBA3	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09
UBA4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UBA5	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
UBA6	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UBA7	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UBA8	-0.98	-0.24	-0.54	-1.03	-1.11	-0.97	-0.91	-1.39	-1.53	-1.38	-1.39
UBA9	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
UBA10	0.82	-1.27	2.98	0.64	0.53	-1.63	1.85	1.23	-0.01	-1.84	0.07
IS13	-78.22	-205.28	-239.70	-258.29	-256.54	-247.44	-234.09	-203.31	-172.21	-129.46	-80.88
IS14	22.10	41.91	101.39	145.99	180.42	216.04	246.43	283.82	315.02	351.63	388.66
IS15	-24.11	-167.40	-214.77	-248.18	-256.05	-257.90	-255.13	-234.12	-211.80	-176.69	-135.84
S13	0.19	0.95	3.10	3.89	3.78	3.35	2.33	1.77	0.70	-0.26	-0.43
S14	-10.16	-149.80	-231.72	-299.70	-355.54	-409.14	-462.36	-499.87	-534.47	-554.78	-571.51
S15	79.74	234.19	397.57	514.74	600.31	685.01	761.25	836.91	907.84	977.85	1047.98
RBF1	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09
RBF2	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
RBF3	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
RBF4	43.40	233.95	358.69	493.76	585.44	690.45	794.40	885.64	975.83	1053.99	1131.96
RBF5	45.33	229.37	350.84	480.33	569.33	670.30	771.01	859.31	945.79	1020.76	1094.80
RBF6	29.56	209.20	327.60	453.44	540.07	637.89	735.16	821.33	904.67	977.76	1050.31
RBF7	34.04	208.48	324.29	447.47	531.66	627.36	721.80	805.07	886.28	957.63	1028.07
RBF8	27.92	198.00	310.53	429.91	512.97	606.35	698.23	779.29	857.95	927.74	995.88
RBF9	25.46	191.70	302.87	419.99	500.19	591.46	681.30	761.20	837.91	905.22	972.31
RBF10	-2272.35	-2325.64	-2507.09	-2585.27	-2632.15	-2677.06	-2683.94	-2665.31	-2694.62	-2659.56	-2612.88
RBA2	74.59	213.32	316.12	420.46	493.16	574.12	653.81	724.89	793.48	854.37	914.66
RBA1	14.41	152.04	250.77	351.05	420.53	497.94	574.18	642.63	706.98	764.91	822.09
RBA3	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
RBA4	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
RBA5	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
RBA6	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Table E-22. Strain survey raw data 90,000 cycles (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
RBA7	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
RBA8	-4.76	-2.24	-3.07	-3.57	-3.50	-3.01	-0.07	-4.44	0.21	1.17	-2.20
RBA9	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
RBA10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IS16	8.74	-60.91	-69.00	-80.16	-77.09	-70.68	-63.70	-37.99	-13.62	23.98	66.70
IS17	23.38	84.79	151.56	211.21	254.26	299.62	339.79	381.76	416.59	452.43	487.23
IS18	0.10	-101.44	-120.33	-135.09	-131.04	-121.61	-108.11	-76.84	-45.03	-2.16	46.85
S16	51.37	177.47	332.59	455.54	553.65	655.42	751.91	843.70	932.99	1016.82	1101.02
S17	-25.75	-293.29	-413.35	-543.99	-652.08	-772.46	-894.98	-989.55	-1089.78	-1168.27	-1244.68
S18	79.90	236.74	393.33	517.35	612.16	708.87	798.99	884.39	966.49	1044.12	1121.57
UDBF1	33.70	269.51	480.99	669.15	798.98	937.72	1071.68	1186.70	1296.25	1390.43	1482.39
UDBF2	25.17	239.06	431.00	601.24	718.93	844.92	966.80	1072.25	1172.72	1259.52	1345.02
UDBF3	-3.15	-0.58	-2.00	-3.33	-3.48	-2.70	-3.22	-4.52	-4.97	-4.25	-4.45
UDBF4	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
UDBF5	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
UDBF6	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UDBF7	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
UDBF8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UDBF9	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11
UDBF10	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
UDBA1	7.20	6.59	7.82	12.62	11.61	14.87	13.48	9.80	11.56	8.05	6.23
UDBA2	5.11	4.45	5.79	9.20	9.40	10.87	10.03	7.36	6.40	4.25	4.08
UDBA3	5.36	5.36	8.36	10.71	11.42	11.41	10.71	8.67	4.88	4.12	4.07
UDBA4	-10.65	234.51	414.95	582.97	729.25	882.82	1038.07	1176.94	1314.66	1437.53	1558.79
UDBA5	3.93	241.14	415.58	577.89	718.24	865.69	1014.24	1147.12	1278.93	1396.84	1513.18
UDBA6	18.13	247.46	416.56	573.03	708.18	850.37	993.48	1121.09	1248.08	1361.34	1473.43
UDBA7	31.40	251.32	413.46	564.46	693.97	831.91	969.57	1092.60	1214.63	1324.13	1432.02
UDBA8	35.03	246.95	402.79	548.08	671.80	804.73	936.86	1054.47	1172.36	1276.11	1378.97
UDBA9	10.90	217.16	370.23	513.09	633.04	761.59	889.62	1002.54	1116.48	1216.91	1316.71
UDBA10	15.77	214.41	359.09	494.33	609.84	732.71	855.75	965.10	1074.53	1171.63	1267.91
IS22	-51.72	-146.07	-195.23	-220.54	-223.04	-218.01	-204.86	-176.07	-144.27	-102.67	-53.28
IS23	17.79	41.45	101.45	142.48	171.85	201.06	226.68	258.11	282.99	311.78	342.01
IS24	12.34	-109.89	-132.45	-155.05	-162.45	-167.22	-169.55	-157.94	-148.00	-128.91	-105.88
S22	87.12	225.25	400.30	515.54	597.94	682.91	762.63	838.57	911.37	980.96	1050.81
S23	-60.53	-400.64	-694.01	-939.61	-1096.76	-1264.25	-1425.47	-1551.43	-1669.22	-1757.03	-1834.17
S24	22.57	213.10	359.64	472.74	546.74	625.42	697.04	769.26	835.14	900.73	967.61
UDAF1	31.09	174.21	323.69	466.75	573.54	691.37	809.31	918.52	1025.29	1121.61	1218.60
UDAF2	20.61	140.67	269.58	393.87	487.13	589.64	691.73	787.22	879.97	964.23	1049.64

Table E-22. Strain survey raw data 90,000 cycles (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
UDAF3	-1.29	-1.15	-1.18	-1.39	-1.03	-1.19	-1.58	-1.98	-1.70	-1.55	-2.15
UDAF4	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
UDAF5	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11
UDAF6	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
UDAF7	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
UDAF8	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
UDAF9	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
UDAF10	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
UDAA1	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12
UDAA2	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
UDAA3	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
UDAA4	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
UDAA5	-94.86	197.17	476.65	725.36	895.49	1079.36	1258.05	1411.89	1555.81	1679.54	1800.37
UDAA6	30.27	305.99	569.11	801.94	960.53	1132.05	1298.89	1443.00	1576.51	1692.34	1805.43
UDAA7	36.50	297.91	548.58	769.87	920.65	1082.94	1241.14	1377.92	1505.27	1615.79	1723.54
UDAA8	28.27	277.14	515.52	725.41	868.72	1023.12	1173.45	1302.98	1424.55	1528.91	1632.31
UDAA9	29.29	267.31	494.40	694.97	831.17	978.10	1121.11	1245.81	1361.23	1462.49	1561.33
UDAA10	29.44	258.99	477.46	669.81	801.72	942.70	1080.55	1200.71	1312.40	1410.27	1506.10
IS28	-18.14	-140.80	-166.49	-173.01	-159.51	-138.46	-112.03	-67.88	-26.05	25.83	82.97
IS29	10.99	44.71	90.05	131.68	163.42	194.88	222.61	255.75	281.79	311.31	341.05
IS30	-12.29	-55.38	-0.22	38.25	73.44	113.21	154.50	207.09	256.19	311.59	370.63
S28	45.81	262.15	418.65	540.04	632.62	727.98	819.40	903.25	986.60	1063.84	1142.04
S29	-4.58	-200.31	-315.30	-415.61	-498.04	-576.78	-651.39	-703.68	-750.60	-781.51	-805.11
S30	23.58	173.13	252.58	339.43	412.59	492.07	572.21	648.18	725.43	798.09	872.57
UAF	7.41	143.44	242.87	367.96	458.66	560.92	664.71	765.39	859.28	948.64	1038.52
UAA	9.42	77.07	163.83	262.91	339.88	425.01	511.48	602.26	684.27	767.21	851.14
IS19	-18.09	-103.74	-105.64	-95.50	-76.16	-49.97	-21.21	24.00	65.87	117.74	174.05
IS20	4.55	36.50	90.54	145.92	186.76	229.22	267.10	316.27	352.85	397.66	441.90
IS21	-21.75	-10.05	24.00	61.14	95.22	133.87	171.94	222.34	267.76	321.22	377.46
S19	71.27	245.39	395.32	507.92	596.02	686.86	774.36	858.43	941.28	1020.31	1100.64
S20	-4.47	-260.11	-412.59	-585.47	-737.08	-903.86	-1083.55	-1230.26	-1385.85	-1513.67	-1641.09
S21	52.49	128.10	228.81	318.95	393.94	475.67	559.78	640.62	723.64	801.74	882.48
RAF	26.94	131.93	246.30	356.93	439.81	533.86	631.18	723.24	815.84	901.10	989.12
RAA	54.54	145.21	258.01	365.79	445.82	536.53	630.53	722.85	812.09	897.14	984.92
IS25	4.05	-37.85	-24.93	-5.29	21.44	56.12	95.00	145.88	196.08	252.55	314.86
IS26	20.37	87.65	174.81	255.10	314.52	380.30	445.70	510.69	571.17	629.33	688.46
IS27	8.51	-80.90	-48.05	-21.62	9.11	47.17	88.73	141.80	193.82	251.71	314.87
S25	26.88	174.55	319.00	426.37	507.79	592.22	673.79	749.54	823.02	892.18	961.69

Table E-22. Strain survey raw data 90,000 cycles (run 3) (continued)

Load Step	0	1	2	3	4	5	6	7	8	9	10
Pressure	0.01	0.79	1.41	2.12	2.65	3.30	4.01	4.66	5.39	6.04	6.73
S26	-8.85	-171.27	-289.12	-401.52	-501.48	-610.43	-729.64	-828.16	-934.41	-1023.56	-1114.35
S27	-17.89	188.51	302.95	399.25	469.64	547.91	622.93	695.11	763.06	829.35	896.56
HSF1	583.66	749.46	899.61	1045.33	1154.72	1264.52	1366.46	1458.96	1551.80	1640.32	1722.90
HSF2	1173.57	1372.29	1531.89	1634.26	1702.86	1775.65	1846.10	1924.57	1986.80	2054.06	2119.31
HSA	11.35	187.90	293.90	424.14	517.13	622.20	728.43	829.05	925.46	1014.75	1103.81
IS43	-5.72	-117.61	-131.73	-118.12	-94.41	-63.42	-29.43	24.25	69.70	127.95	188.73
IS44	19.80	99.47	161.98	228.42	275.87	327.79	377.38	430.07	476.04	523.52	570.61
IS45	-34.97	32.97	72.88	122.03	159.38	203.76	249.55	306.02	355.08	412.39	471.99
S43	46.06	308.95	478.63	604.24	701.00	799.74	896.39	982.92	1068.75	1147.86	1227.05
S44	31.17	-308.48	-467.26	-639.69	-792.27	-951.01	-1117.33	-1253.52	-1393.62	-1509.15	-1622.11
S45	35.70	95.75	189.21	275.64	349.16	429.17	512.26	590.77	671.81	747.91	825.40

APPENDIX F—STRAIN DATA REDUCTION PROCEDURE

The raw strain gauge data in appendix E were reduced to remove the strain gauge offset due to preloading after the panel was installed in the fixture. In the strain gauge data reduction, the first data point was removed to minimize the effects of preloading. A second-order regression using a least-squares method was used to curve-fit the remaining dataset to a second-order polynomial:

$$\varepsilon = Ax^2 + Bx + C \quad (\text{F} - 1)$$

where ε is the dependent strain value, x is the independent load increment variable, A is the quadratic coefficient, B is the linear coefficient, and C is the constant term or ordinate intercept. Parameter C was used to define the zero load offset, which was used to shift all data in the set and finally obtain the shifted values. Following the procedures defined above, the raw strain data in appendix E were reduced.

The crack-tip strain data of RB patch were selected as an example of the data-reduction procedure.

1. The raw strain data of three runs of strain survey are provided in figure F-1a.
2. After the first reading of each strain survey was removed (see figure F-1b), strain data were curve-fitted using equation F-1 and plotted as functions of applied pressure (see figure F-2a).
3. The hoop strains were shifted using the constant C obtained by following the data-reduction procedure. Finally, the reduced hoop strain data are shown in table F-2c and figure F-2b.

	(a) Raw Strain Data	(b) Altered Strain Data	(c) Offset Strain Data	
Run 1	Pressure (psi)	Strain ($\mu\epsilon$), RBA	Strain ($\mu\epsilon$), RBA	
	0.018031	-179.256		
	0.68723	-48.4517	-48.4517	121.1283
	1.379265	91.84048	91.84048	261.42048
	2.022922	201.2704	201.2704	370.8504
	2.670486	296.753	296.753	466.333
	3.33716	396.3081	396.3081	565.8881
	4.029282	485.8574	485.8574	655.4374
	4.651328	563.1438	563.1438	732.7238
	5.314384	644.3953	644.3953	813.9753
5.98502	713.4576	713.4576	883.0376	
6.682351	788.8536	788.8536	958.4336	
Run 2	Pressure (psi)	Strain ($\mu\epsilon$), RBA	Strain ($\mu\epsilon$), RBA	
	0.018771	-176.083		
	0.634368	-42.1384	-42.1384	113.4316
	1.337517	89.91351	89.91351	245.48351
	2.022185	197.3588	197.3588	352.9288
	2.676892	301.0824	301.0824	456.6524
	3.351	405.6105	405.6105	561.1805
	4.01765	485.8257	485.8257	641.3957
	4.668247	562.7662	562.7662	718.3362
	5.328668	646.3684	646.3684	801.9384
5.944288	707.558	707.558	863.128	
6.694103	787.1965	787.1965	942.7665	
Run 3	Pressure (psi)	Strain ($\mu\epsilon$), RBA	Strain ($\mu\epsilon$), RBA	
	-0.00333	-176.898		
	0.708737	-30.9289	-30.9289	124.4511
	1.308179	85.9678	85.9678	241.3478
	2.029754	207.1333	207.1333	362.5133
	2.691849	305.9637	305.9637	461.3437
	3.393086	403.1218	403.1218	558.5018
	3.961706	475.3555	475.3555	630.7355
	4.669229	567.4226	567.4226	722.8026
	5.258393	637.5668	637.5668	792.9468
6.060314	724.1891	724.1891	879.5691	
6.678808	780.0905	780.0905	935.4705	

Figure F-1. Strain data for gauge RBA at 20,000 cycles: (a) raw strain data, (b) strain data after first reading removed, and (c) strain data after 0 load offset

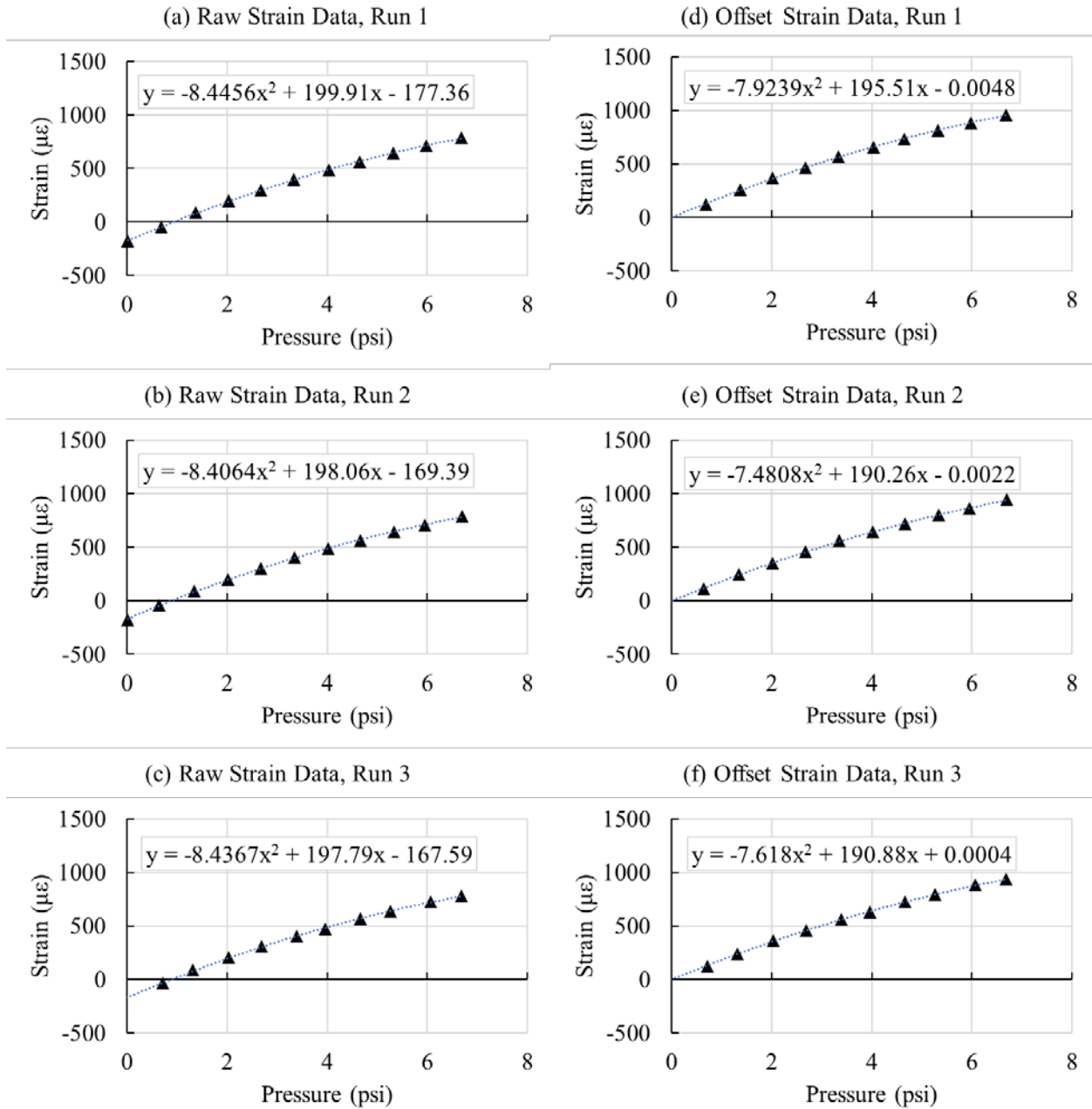


Figure F-2. Strain gauge reading as a function of pressure: (a) raw strain reading, run 1; (b) raw strain reading, run 2; (c) raw strain reading, run 3; (d) offset strain data, run 1; (e) offset strain data, run 2; and (f) offset strain data, run 3

APPENDIX G—COMPARISON OF STRAIN SURVEYS AT THREE ENVIRONMENTAL CONDITIONS

Comparisons of strain surveys at different environmental conditions are provided in this appendix. These strain surveys were conducted at 80,000 cycles, and the repair patches that were installed in the conditioned region (dark blue box in figure G-1) will be compared. Repair patches include: reference repairs, under-designed repairs, under-designed with partial disbond repairs, and a hand-sanded repair.

In this study, four repair patches were selected to use the strain gauge chains (see appendix C) to obtain higher resolution of strain distributions. These repairs included the reference B/Ep repair, RB; the under-designed B/Ep repair, UB; the under-designed with partial disbond B/Ep repair, UDB; and the under-designed with partial disbond aluminum repair, UDA.

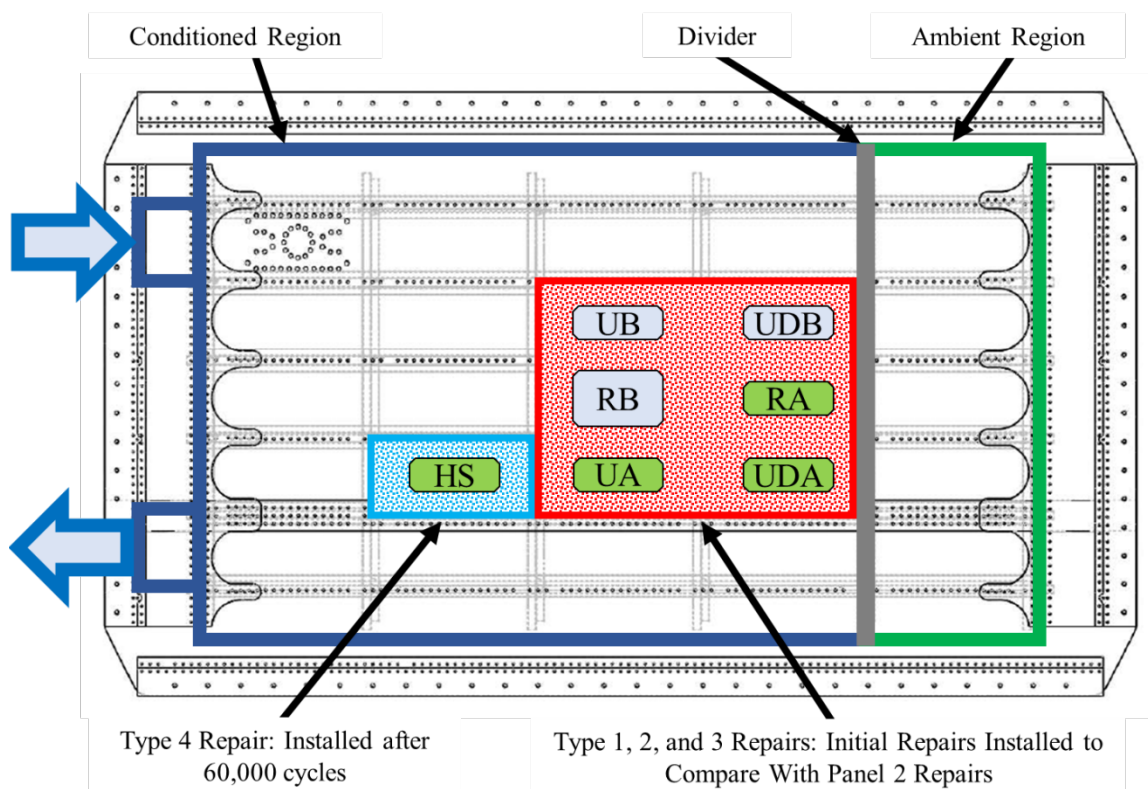


Figure G-1. Repair patches in the conditioned region are shown in the dark blue box

Type-1 Aluminum Repair Patch, RA

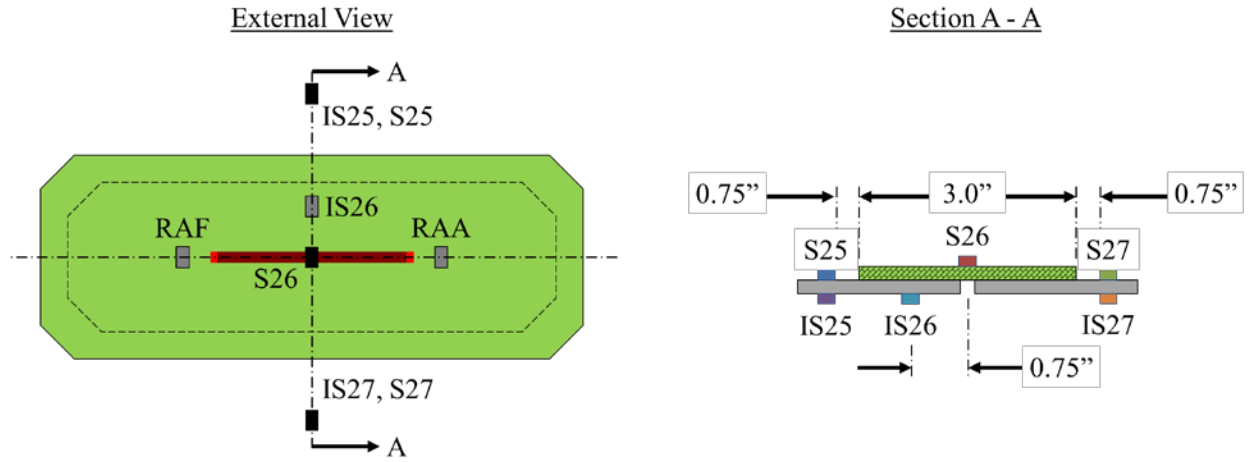


Figure G-2. Location of strain gauges in the vicinity of the type-1 aluminum repair patch, RA

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0	0.66	1.33	2.03	2.60	3.32	3.99	4.67	5.37	6.02	6.65
RAF	Ambient	16.67	106.34	218.19	322.78	422.61	522.76	610.25	700.60	788.72	874.15	964.02
	Hot/Wet	-85.24	21.52	131.49	236.41	343.99	443.12	538.61	633.04	727.22	821.33	910.70
	Cold	6.69	103.17	212.68	317.77	400.81	501.69	591.04	676.10	766.97	844.20	925.50
RAA	Ambient	18.48	94.78	197.11	297.72	393.76	492.31	576.99	666.48	751.69	836.01	925.39
	Hot/Wet	-121.81	-31.30	71.12	171.51	272.20	367.32	458.73	550.91	642.77	734.37	819.52
	Cold	24.50	110.42	214.63	315.66	398.23	491.74	579.88	661.67	751.74	825.72	905.50
IS25	Ambient	34.14	-0.78	-3.77	14.51	41.36	80.11	119.87	169.45	220.90	275.92	337.73
	Hot/Wet	-146.44	-146.42	-139.48	-115.35	-85.00	-48.27	-4.69	46.05	95.17	151.41	212.37
	Cold	-3.49	-49.75	-32.52	-10.33	24.89	64.12	110.45	157.89	216.86	271.44	328.48
IS26	Ambient	-0.13	58.40	137.30	212.91	283.64	354.80	415.02	478.52	537.36	595.21	655.68
	Hot/Wet	-125.86	-48.10	30.55	106.35	179.64	246.49	308.51	372.41	431.50	492.15	547.80
	Cold	50.37	109.66	188.87	262.19	322.76	390.04	452.08	508.71	571.41	622.38	677.11
IS27	Ambient	9.84	-47.91	-37.53	-12.60	18.97	60.86	103.14	155.14	207.61	264.26	327.28
	Hot/Wet	-175.44	-206.66	-184.46	-151.60	-114.97	-71.21	-25.35	29.46	80.50	139.79	199.09
	Cold	-20.38	-81.93	-65.20	-40.50	-2.08	36.13	85.20	132.05	193.22	247.08	306.08
S25	Ambient	-153.11	-19.12	108.74	212.14	302.23	387.12	456.45	527.85	596.63	662.65	729.90
	Hot/Wet	-237.93	-147.96	-49.94	28.70	90.86	154.90	220.69	283.01	340.79	403.33	468.57
	Cold	5.38	151.61	291.44	408.02	495.43	593.11	676.13	752.60	831.71	899.70	966.81
S26	Ambient	-17.22	-128.02	-263.95	-391.50	-515.50	-635.42	-741.33	-844.20	-945.34	-1039.78	-1137.09
	Hot/Wet	-220.13	-358.17	-490.47	-621.60	-755.58	-872.23	-987.49	-1092.99	-1203.58	-1303.22	-1396.95
	Cold	-74.31	-217.94	-346.43	-474.41	-566.76	-692.67	-792.20	-891.28	-990.50	-1076.58	-1158.77
S27	Ambient	-49.97	112.03	222.42	312.57	395.24	465.57	510.74	568.50	612.30	658.21	696.10
	Hot/Wet	-157.75	-83.19	-15.39	34.68	85.82	135.64	180.07	225.22	268.46	307.72	350.91
	Cold	49.51	168.40	263.66	348.66	409.02	477.93	540.71	597.90	664.57	712.70	764.57

Figure G-3. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10	
Pressure	0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7	
RAF	Ambient	21.27	118.20	218.64	321.04	420.34	516.90	610.71	702.94	786.98	874.04	958.83
	Hot/Wet	-84.24	25.56	128.07	240.98	345.56	447.66	541.46	631.45	723.43	816.47	905.50
	Cold	2.58	109.71	213.29	308.27	410.73	505.59	594.32	682.12	763.69	848.12	926.85
RAA	Ambient	26.76	103.81	196.86	294.52	390.31	484.32	575.06	665.50	748.45	836.56	919.62
	Hot/Wet	-121.39	-26.97	66.08	173.10	272.44	372.00	460.46	546.79	637.10	727.67	812.58
	Cold	25.61	115.83	215.93	309.53	404.48	498.36	584.06	668.74	747.75	829.37	907.47
IS25	Ambient	49.29	-0.13	-1.99	15.70	41.03	76.41	119.61	167.94	218.22	274.97	334.16
	Hot/Wet	-133.58	-137.71	-138.26	-116.91	-89.14	-50.65	-6.34	40.70	89.26	148.49	206.75
	Cold	42.90	-38.28	-28.97	-2.36	23.98	60.11	111.78	155.38	218.07	276.69	328.74
IS26	Ambient	6.12	63.86	136.44	210.11	280.26	348.18	413.46	477.13	534.80	595.22	651.93
	Hot/Wet	-129.92	-48.87	23.57	103.61	175.49	245.21	306.78	366.35	425.14	485.62	540.48
	Cold	59.52	117.02	190.98	260.01	327.43	394.53	455.01	513.94	569.99	626.81	678.84
IS27	Ambient	24.81	-47.18	-36.70	-11.63	17.74	56.31	101.83	152.39	204.75	263.94	323.70
	Hot/Wet	-191.11	-211.37	-190.11	-156.16	-119.89	-75.79	-28.94	21.40	74.61	135.13	194.09
	Cold	28.38	-74.07	-60.79	-30.78	-4.90	34.46	87.60	132.94	194.32	252.86	306.91
S25	Ambient	-159.60	-15.83	105.72	210.04	299.75	381.23	459.32	532.79	597.84	662.79	727.78
	Hot/Wet	-263.76	-157.61	-56.36	27.82	105.05	176.55	243.32	303.04	360.50	422.99	481.79
	Cold	-29.66	153.83	287.22	400.06	502.72	589.27	677.57	747.28	828.07	903.96	964.29
S26	Ambient	-12.44	-141.63	-260.11	-383.27	-509.18	-628.33	-739.86	-846.83	-942.23	-1036.98	-1128.58
	Hot/Wet	-198.75	-347.93	-472.38	-609.31	-740.36	-864.39	-976.23	-1077.70	-1182.95	-1282.61	-1379.74
	Cold	-50.13	-226.54	-344.25	-450.50	-584.70	-694.73	-798.53	-896.81	-987.26	-1077.63	-1155.19
S27	Ambient	-144.93	-36.46	160.59	239.10	354.07	413.84	482.90	549.19	624.38	670.19	721.33
	Hot/Wet	-138.27	-54.70	1.97	56.11	106.54	153.04	196.49	233.35	275.44	315.94	355.79
	Cold	5.51	160.50	253.30	333.38	404.89	465.64	535.32	588.79	652.13	709.08	754.68

Figure G-4. Raw strain gauge data at three environmental condition at 80,000 cycles (run 2)

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
RAF	Ambient	22.92	110.71	221.72	323.78	419.88	517.24	610.53	699.05	788.82	874.10	960.28
	Hot/Wet	-82.97	16.24	135.99	239.73	346.47	445.32	537.94	634.05	731.86	815.50	905.59
	Cold	5.22	107.60	213.52	303.21	410.63	503.95	601.22	683.04	765.21	847.67	933.48
RAA	Ambient	28.70	99.26	200.86	299.12	391.98	485.46	577.15	661.96	751.54	836.50	921.26
	Hot/Wet	-122.43	-36.42	72.96	171.65	274.44	369.13	457.98	549.80	644.28	726.88	813.14
	Cold	26.91	112.48	215.97	302.52	406.59	495.13	591.14	670.13	750.20	830.04	913.85
IS25	Ambient	49.76	5.37	0.85	15.18	41.86	77.27	121.74	167.00	220.34	276.21	335.24
	Hot/Wet	-129.89	-141.40	-139.67	-120.30	-87.80	-51.45	-4.52	37.31	91.71	146.98	208.11
	Cold	45.00	-42.83	-34.30	-8.23	21.26	57.80	114.90	163.73	214.27	269.84	333.52
IS26	Ambient	7.01	60.59	138.91	212.55	280.96	348.93	414.73	474.45	536.70	595.61	653.00
	Hot/Wet	-132.40	-58.16	26.38	99.94	174.53	241.61	303.56	365.21	427.99	483.09	539.41
	Cold	61.10	113.30	188.78	254.50	328.84	392.16	459.85	515.62	571.79	625.35	682.54
IS27	Ambient	24.99	-42.90	-33.58	-11.72	19.53	57.97	104.99	151.35	207.15	265.19	324.96
	Hot/Wet	-191.18	-215.64	-190.76	-160.52	-119.42	-76.26	-26.97	19.02	76.67	133.85	195.76
	Cold	29.39	-78.88	-66.15	-36.21	-6.54	30.83	87.82	139.12	191.16	248.95	311.04
S25	Ambient	-156.98	-22.13	109.27	211.27	299.63	379.12	456.04	526.29	594.98	659.32	723.26
	Hot/Wet	-241.69	-151.80	-42.02	39.73	112.94	181.88	248.28	307.93	375.22	430.74	491.43
	Cold	-21.33	161.69	293.53	392.49	500.19	586.70	680.58	753.40	825.64	897.94	973.43
S26	Ambient	-12.86	-126.62	-260.56	-388.04	-508.02	-625.97	-734.91	-840.75	-942.56	-1035.83	-1130.10
	Hot/Wet	-187.96	-316.35	-469.36	-599.05	-726.76	-847.24	-955.40	-1069.55	-1181.93	-1268.46	-1366.68
	Cold	-49.12	-217.22	-345.09	-439.97	-580.25	-691.98	-807.40	-897.27	-982.93	-1076.85	-1166.18
S27	Ambient	-3.14	133.63	236.79	322.58	397.17	464.79	523.53	583.09	641.79	708.10	776.26
	Hot/Wet	-136.90	-59.07	4.24	57.69	106.18	151.47	194.50	233.43	279.81	316.01	357.79
	Cold	7.52	164.33	251.94	322.83	397.10	459.94	537.42	588.94	640.88	699.14	761.52

Figure G-5. Raw strain gauge data at three environmental condition at 80,000 cycles (run 3)

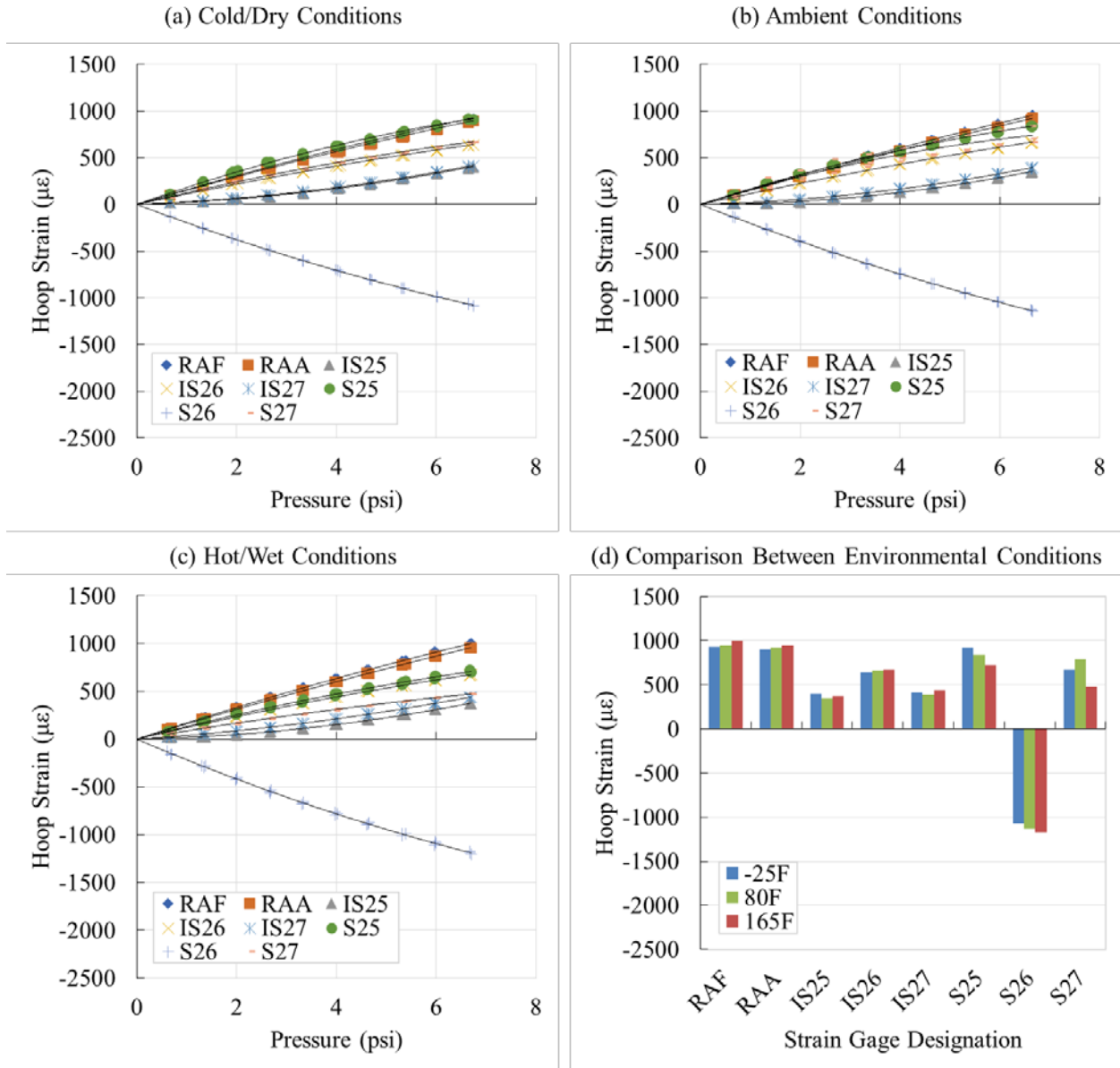


Figure G-6. Strain gauge measurements at 80,000 cycles at (a) cold-dry (-25°F) environmental conditions, (b) ambient environmental conditions, (c) hot-wet (165°F and 85% RH) environmental conditions, and (d) comparison of three environmental conditions at maximum strain survey loads

Type-1 B/Ep Repair Patch, RB

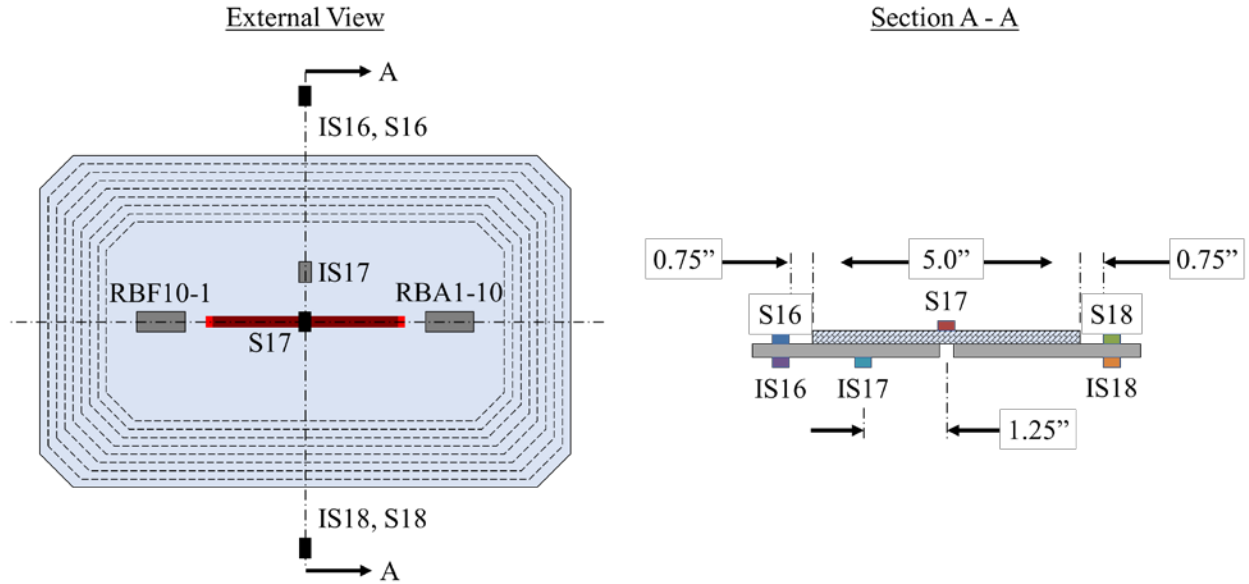


Figure G-7. Location of strain gauges in the vicinity of the type-1 B/Ep repair patch, RB

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
IS16	Ambient	7.04	-33.22	-58.53	-68.47	-70.45	-60.06	-43.43	-16.73	12.20	48.81	92.65
	Hot/Wet	-268.16	-282.52	-277.76	-260.35	-237.08	-205.22	-170.19	-122.84	-75.12	-18.86	41.39
	Cold	121.34	45.77	17.08	-5.30	-4.56	-14.71	-4.90	4.15	28.58	54.27	87.47
IS17	Ambient	23.12	82.08	140.91	194.60	243.60	289.62	328.35	368.40	404.47	438.79	473.45
	Hot/Wet	-35.97	1.71	39.94	77.21	111.77	143.46	170.87	200.65	225.50	251.41	275.16
	Cold	4.23	68.12	142.04	209.59	263.63	318.81	369.60	414.51	462.79	500.48	540.17
IS18	Ambient	0.02	-65.22	-102.57	-119.06	-123.49	-114.45	-96.40	-66.66	-32.47	7.88	56.67
	Hot/Wet	-321.72	-350.74	-351.41	-340.07	-315.94	-280.51	-241.06	-189.43	-135.72	-73.91	-7.72
	Cold	153.61	52.29	3.95	-29.90	-38.80	-56.10	-47.90	-36.58	-12.70	13.39	49.94
S16	Ambient	43.85	173.03	321.18	445.11	555.77	658.66	745.79	833.68	917.44	996.87	1077.91
	Hot/Wet	-160.82	-88.23	-8.18	89.24	181.04	265.89	345.97	422.89	501.08	571.30	634.99
	Cold	30.38	177.12	346.50	491.57	606.35	725.90	829.19	929.21	1030.02	1114.58	1202.16
S17	Ambient	5.45	-132.23	-240.71	-347.01	-447.75	-541.26	-620.26	-693.24	-763.36	-825.94	-888.43
	Hot/Wet	-1549.67	-1638.89	-1711.08	-1778.92	-1848.98	-1911.09	-1968.66	-2014.09	-2065.80	-2105.61	-2146.49
	Cold	430.07	235.00	102.98	-32.01	-124.21	-251.68	-346.77	-435.60	-518.72	-591.55	-658.65
S18	Ambient	66.41	202.63	341.83	459.10	561.92	657.81	734.15	816.09	893.84	967.50	1045.12
	Hot/Wet	-98.79	-54.69	21.80	112.12	200.75	277.96	352.38	430.49	509.58	583.34	662.81
	Cold	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure G-8. Raw strain gauge data at three environmental condition at 80,000 cycles (run 1)

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
IS16	Ambient	19.46	-37.83	-55.29	-66.69	-69.67	-61.95	-44.73	-20.18	9.73	48.23	90.22
	Hot/Wet	-249.70	-272.46	-266.30	-256.60	-236.56	-205.64	-167.83	-123.73	-75.75	-19.01	36.86
	Cold	144.55	40.71	15.42	5.73	-17.67	-19.63	-8.82	2.54	28.84	57.98	90.43
IS17	Ambient	22.09	86.06	138.94	191.86	239.41	283.71	326.06	365.80	401.25	437.23	470.95
	Hot/Wet	-43.84	-3.18	36.86	75.56	108.61	141.05	169.75	197.92	223.60	249.86	272.52
	Cold	-1.01	70.43	140.77	207.01	265.32	319.42	370.79	416.55	461.43	502.96	541.84
IS18	Ambient	16.25	-67.57	-100.43	-116.91	-124.47	-116.84	-97.75	-69.60	-35.57	6.72	53.49
	Hot/Wet	-332.30	-357.28	-354.93	-342.01	-317.45	-281.61	-239.07	-189.83	-135.09	-73.63	-10.71
	Cold	185.81	46.45	-1.70	-26.21	-59.29	-66.41	-59.10	-43.00	-17.42	12.13	52.83
S16	Ambient	51.33	186.20	325.68	445.48	554.50	655.04	747.64	836.55	915.37	994.93	1073.57
	Hot/Wet	-240.82	-158.95	-16.40	98.76	196.31	249.14	370.14	449.31	527.21	606.48	685.14
	Cold	29.24	198.46	352.87	496.30	623.24	733.61	842.76	937.22	1034.08	1123.98	1207.66
S17	Ambient	17.49	-153.90	-247.36	-348.60	-451.21	-544.31	-627.29	-703.23	-767.12	-828.99	-886.00
	Hot/Wet	-1547.18	-1636.55	-1698.71	-1771.82	-1841.18	-1907.63	-1957.70	-2003.25	-2046.80	-2088.68	-2125.35
	Cold	474.87	228.41	103.14	-9.32	-149.64	-257.98	-355.94	-442.86	-518.76	-594.53	-657.16
S18	Ambient	68.84	211.54	348.97	462.44	562.53	656.38	743.64	826.60	900.74	973.44	1047.91
	Hot/Wet	-168.90	-34.93	86.03	191.04	283.46	370.66	453.32	526.71	603.49	675.61	749.04
	Cold	0	0	0	0	0	0	0	0	0	0	0

Figure G-9. Raw strain gauge data at three environmental condition at 80,000 cycles (run 2)

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
IS16	Ambient	18.65	-28.37	-53.82	-67.09	-67.19	-59.48	-40.08	-19.54	12.37	50.37	91.93
	Hot/Wet	-248.87	-264.33	-271.58	-259.41	-236.20	-205.38	-167.36	-124.90	-73.68	-21.17	37.14
	Cold	142.50	39.11	11.89	2.77	-19.34	-22.26	-10.60	4.02	29.12	53.35	90.37
IS17	Ambient	21.72	82.48	140.04	191.87	239.22	284.31	327.91	365.02	402.93	438.87	472.31
	Hot/Wet	-43.21	-3.45	37.89	73.06	109.13	139.53	169.73	197.11	223.69	249.15	273.20
	Cold	-0.81	67.72	140.45	203.40	263.81	317.25	372.98	417.25	461.52	501.20	542.47
IS18	Ambient	16.28	-59.07	-99.44	-118.23	-121.94	-114.78	-94.04	-68.88	-33.29	8.73	54.96
	Hot/Wet	-326.63	-350.98	-355.92	-342.64	-315.68	-281.60	-239.08	-189.59	-132.22	-74.06	-9.03
	Cold	187.86	36.20	-9.82	-26.12	-60.57	-67.48	-62.33	-44.95	-17.56	10.55	49.93
S16	Ambient	52.91	180.63	326.15	447.77	555.45	651.76	747.34	833.12	917.26	996.35	1074.72
	Hot/Wet	-129.48	-7.61	134.82	233.98	326.08	409.78	480.53	560.27	641.83	715.47	791.73
	Cold	34.47	195.43	360.98	491.54	625.26	738.84	854.50	945.92	1039.26	1126.78	1218.65
S17	Ambient	14.95	-138.26	-247.87	-354.41	-450.82	-542.49	-622.09	-697.56	-766.90	-826.64	-885.73
	Hot/Wet	-1544.72	-1634.99	-1729.18	-1796.68	-1860.49	-1920.16	-1975.04	-2028.78	-2079.99	-2111.47	-2150.87
	Cold	478.15	222.93	92.00	-3.58	-147.91	-256.53	-364.12	-444.22	-519.80	-597.55	-667.13
S18	Ambient	74.00	208.23	349.69	464.95	565.83	657.35	745.40	825.97	903.95	978.60	1051.40
	Hot/Wet	-88.45	32.09	166.09	263.77	355.64	436.55	515.50	594.13	675.67	739.15	803.66
	Cold	0	0	0	0	0	0	0	0	0	0	0

Figure G-10. Raw strain gauge data at three environmental condition at 80,000 cycles (run 3)

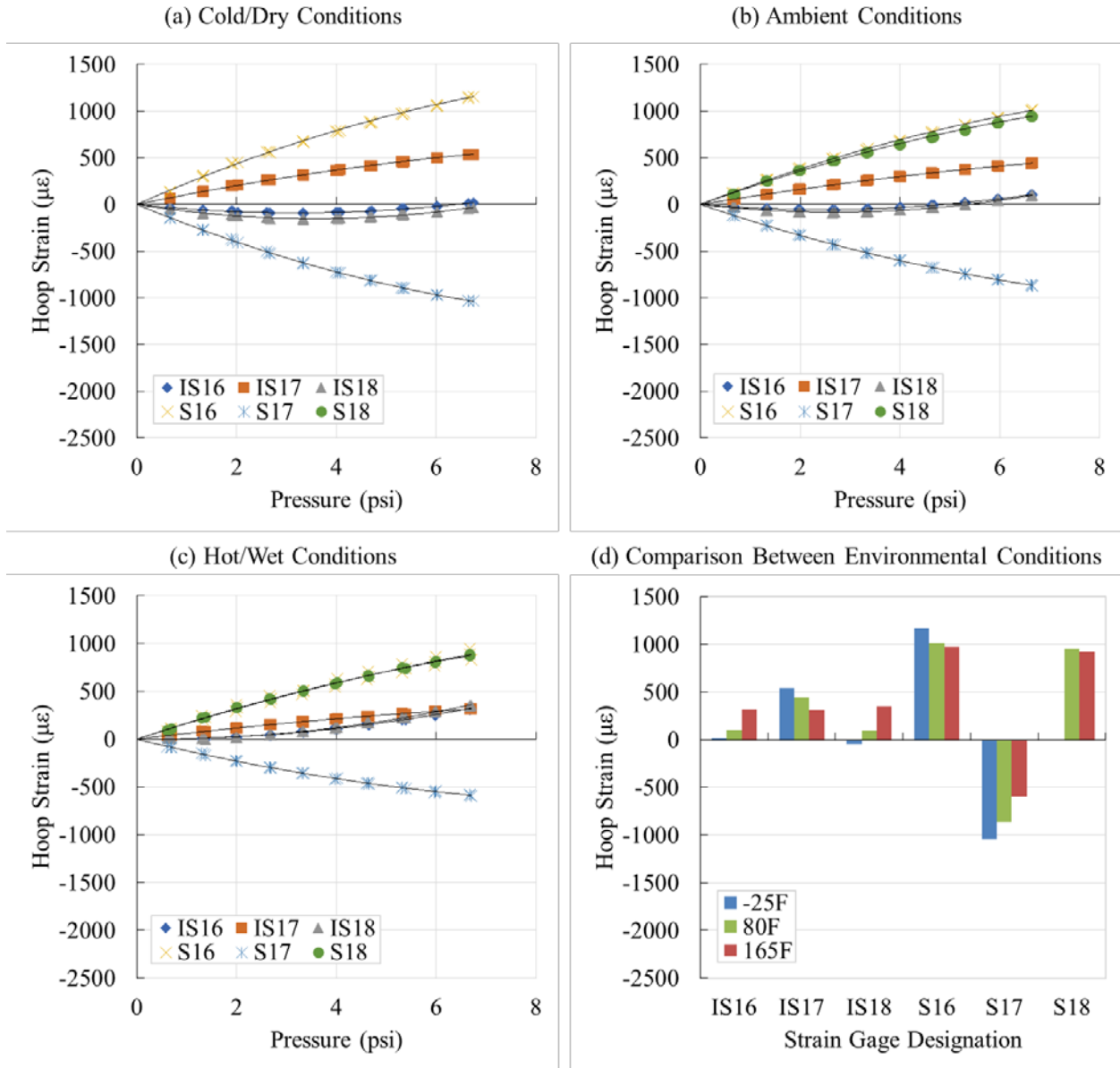


Figure G-11. Strain gauge measurements at 80,000 cycles at (a) cold-dry (-25°F) environmental conditions, (b) ambient environmental conditions, (c) hot-wet (165°F and 85% RH) environmental conditions, and (d) comparison of three environmental conditions at maximum strain survey loads

The notch-tip strain data are shown in the tables and figure below. Strain was measured at the maximum loading conditions at three different environmental conditions.

Table G-1. Strain measured at maximum loading conditions using strain gauge chain at the forward side

Strain Gauge	X Position	165°F	80°F	-25°F
RBF1	1.72	962.8	1156.8	1378.6
RBF2	1.76	891.0	1081.8	1292.6
RBF3	1.80	838.0	1025.4	1228.8
RBF4	1.84	797.0	981.2	1178.9
RBF5	1.88	767.4	950.2	1144.0
RBF6	1.92	746.5	927.2	1121.1
RBF7	1.95	729.7	908.2	1098.3
RBF8	1.99	712.0	886.6	1074.1
RBF9	2.03	698.2	870.5	1055.6
RBF10	2.07	684.2	854.4	1034.5

Table G-2. Strain measured at maximum loading conditions using strain gauge chain at the aft side

Strain Gauge	X Position	165°F	80°F	-25°F
RBA1	1.69	742.5	910.2	1093.7
RBA2	1.73	727.2	885.3	1066.9
RBA3	1.77	721.9	877.3	1055.4
RBA4	1.81	705.6	862.6	1055.8
RBA5	1.84	683.5	844.2	1021.7
RBA6	1.88	657.4	832.2	1009.3
RBA7	1.92	646.8	822.2	1002.5
RBA8	1.96	637.7	814.3	998.1
RBA9	2.00	630.4	805.3	981.2
RBA10	2.04	627.0	794.3	959.5

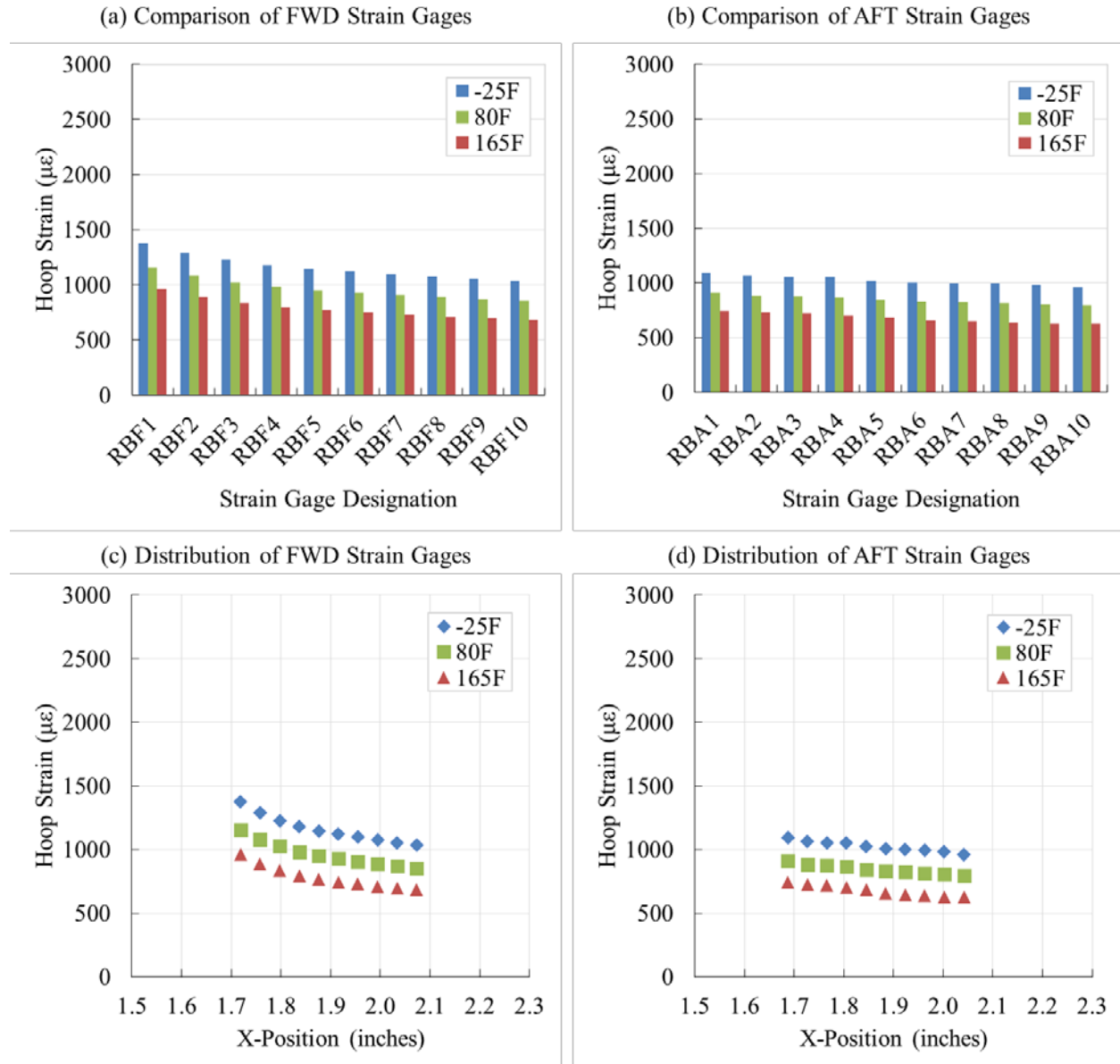


Figure G-12. Comparison of notch-tip strain at maximum loading conditions under three different environmental conditions: (a) comparison of fwd strain gauge chain, (b) comparison of aft strain gauge chain, (c) comparison of fwd strain gauge chain with respect to x-position, and (d) comparison of aft strain gauge chain with respect to x-position

Type-2 Aluminum Repair Patch, UA

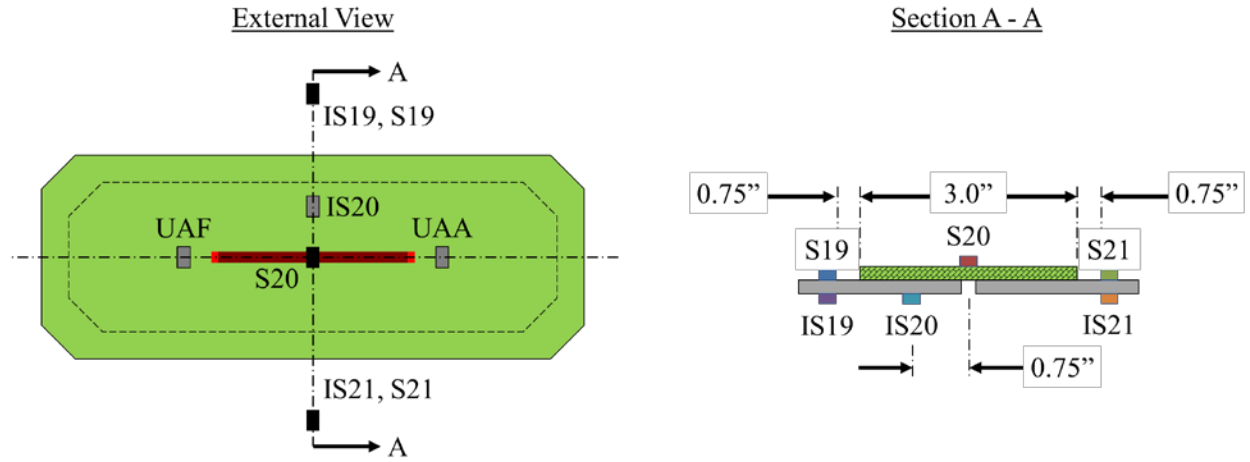


Figure G-13. Location of strain gauges in the vicinity of the type-2 aluminum repair patch, UA

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
UAF	Ambient	-73.47	46.17	149.95	261.87	370.94	478.98	569.06	664.07	749.56	836.38	928.25
	Hot/Wet	-100.12	9.74	114.51	228.95	344.19	446.49	540.01	639.48	732.04	825.39	914.10
	Cold	-8.35	104.04	212.33	322.19	414.42	514.01	609.84	693.60	787.10	862.91	940.91
UAA	Ambient	6.16	79.48	161.58	252.71	341.46	434.66	513.22	599.80	676.82	757.78	846.21
	Hot/Wet	9.52	72.62	156.63	251.50	349.55	441.55	526.57	623.10	711.27	804.90	893.79
	Cold	-71.22	-13.12	78.64	170.26	253.65	337.10	425.47	500.33	587.72	660.49	734.57
IS19	Ambient	7.99	-44.97	-62.77	-55.23	-38.48	-8.35	22.60	65.46	107.90	157.22	215.28
	Hot/Wet	-56.78	-110.46	-122.26	-110.46	-86.50	-53.16	-18.24	31.79	80.02	138.98	199.84
	Cold	-64.45	-124.83	-123.98	-111.43	-84.34	-63.39	-25.39	12.26	61.68	108.26	160.34
IS20	Ambient	-145.91	-108.42	-65.24	-15.25	30.66	80.90	119.54	166.60	204.14	247.57	296.83
	Hot/Wet	-104.41	-86.15	-61.92	-24.55	6.30	35.06	54.31	89.11	111.64	143.24	169.10
	Cold	-82.30	-62.14	-10.38	37.64	86.97	124.79	175.04	212.48	262.60	301.86	344.25
IS21	Ambient	-1.36	21.93	52.52	88.06	124.26	166.85	206.34	255.50	302.10	354.19	413.52
	Hot/Wet	23.94	23.50	45.80	79.87	117.80	160.33	200.84	255.19	305.50	364.91	424.53
	Cold	-108.56	-97.77	-55.02	-12.84	26.65	64.49	111.13	156.60	211.50	261.59	316.59
S19	Ambient	12.64	167.02	306.90	418.43	515.61	607.07	686.36	763.43	842.11	917.91	986.56
	Hot/Wet	47.46	190.86	314.23	416.99	511.28	597.88	679.06	759.35	837.51	915.25	996.35
	Cold	-32.17	96.70	227.26	336.44	422.20	514.91	597.95	678.82	762.49	837.26	914.29
S20	Ambient	-62.48	-275.34	-467.18	-664.21	-856.54	-1042.13	-1201.38	-1355.51	-1506.15	-1644.28	-1785.85
	Hot/Wet	-209.90	-399.18	-581.35	-770.13	-961.00	-1123.51	-1282.29	-1425.23	-1573.58	-1704.69	-1836.02
	Cold	-138.04	-373.61	-573.44	-778.70	-931.87	-1134.73	-1298.14	-1455.88	-1609.01	-1742.81	-1867.15
S21	Ambient	23.18	100.06	192.31	278.97	363.54	448.04	524.25	604.05	683.50	760.97	844.16
	Hot/Wet	17.78	105.54	196.08	281.73	367.60	448.64	528.65	608.06	689.66	770.00	853.60
	Cold	-50.16	24.24	115.51	203.46	274.79	361.38	438.55	517.77	599.85	674.01	750.64

Figure G-14. Raw strain gauge data at three environmental condition at 80,000 cycles (run 1)

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
UAF	Ambient	-75.57	53.96	150.68	258.19	366.44	468.83	566.63	662.32	747.25	840.24	923.50
	Hot/Wet	-123.02	-2.33	99.41	220.93	334.47	445.37	540.32	634.37	729.48	822.62	905.65
	Cold	-21.65	107.11	215.11	316.76	422.36	522.74	615.95	701.35	783.63	865.68	942.55
UAA	Ambient	15.25	85.00	163.84	250.05	337.90	424.67	510.56	596.52	674.49	763.02	841.72
	Hot/Wet	-3.87	70.68	152.51	252.25	349.11	447.49	534.14	622.96	714.20	805.64	886.85
	Cold	-62.52	-6.15	85.14	173.39	257.34	346.21	430.95	507.30	586.07	665.21	737.58
IS19	Ambient	22.51	-48.91	-61.09	-54.73	-39.39	-14.31	20.28	61.09	104.46	158.19	211.46
	Hot/Wet	-65.25	-118.02	-124.64	-113.28	-90.72	-56.29	-18.28	29.31	79.83	137.75	193.98
	Cold	-26.79	-123.60	-121.81	-101.95	-90.92	-62.32	-23.81	15.14	61.50	110.25	162.34
IS20	Ambient	-141.66	-111.36	-66.84	-20.64	24.56	68.81	112.89	157.96	199.41	251.15	293.73
	Hot/Wet	-132.08	-99.91	-76.33	-38.60	-5.64	26.97	50.12	80.21	108.06	138.85	159.52
	Cold	-71.97	-58.40	-5.96	44.04	82.46	131.40	177.91	217.66	260.45	304.35	346.35
IS21	Ambient	3.12	25.24	54.90	87.96	122.49	161.64	204.91	252.18	299.60	356.10	410.38
	Hot/Wet	-0.45	14.41	39.21	74.57	113.64	158.18	202.01	253.09	305.58	363.39	418.73
	Cold	-103.93	-92.37	-51.90	-6.31	24.81	66.10	113.06	159.59	210.97	264.50	317.16
S19	Ambient	2.71	174.26	305.58	411.31	506.91	598.12	679.75	764.29	842.55	918.34	994.66
	Hot/Wet	14.39	174.75	297.83	403.54	499.08	587.79	672.96	750.39	829.22	901.45	983.92
	Cold	-57.69	110.33	230.15	337.44	434.02	517.87	605.60	685.01	765.16	843.65	918.36
S20	Ambient	-49.92	-288.68	-456.42	-646.84	-842.87	-1027.46	-1197.81	-1359.73	-1501.29	-1641.30	-1773.95
	Hot/Wet	-189.47	-392.55	-562.31	-761.67	-951.23	-1128.07	-1284.78	-1423.77	-1569.73	-1703.55	-1830.52
	Cold	-95.02	-373.62	-563.72	-742.88	-958.31	-1138.60	-1307.08	-1460.71	-1600.92	-1741.53	-1861.28
S21	Ambient	32.58	103.68	191.26	275.10	358.67	442.26	523.75	605.35	680.24	758.78	837.92
	Hot/Wet	5.01	98.00	187.85	276.48	363.25	447.58	529.00	606.61	687.83	768.07	849.71
	Cold	-44.4509	27.7705	114.736	196.778	280.982	359.475	442.427	520.431	599.293	677.69	751.004

Figure G-15. Raw strain gauge data at three environmental condition at 80,000 cycles (run 2)

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
UAF	Ambient	-75.34	49.18	152.16	266.14	369.45	473.39	570.94	657.54	751.75	840.20	925.83
	Hot/Wet	-135.73	-20.70	103.04	214.09	330.77	435.86	535.02	632.40	733.51	818.77	906.52
	Cold	-21.16	113.95	217.33	308.61	424.59	515.27	620.82	704.75	788.31	868.92	949.43
UAA	Ambient	16.60	87.39	166.45	257.71	342.29	430.54	516.59	592.63	679.97	763.45	844.11
	Hot/Wet	-6.37	65.69	159.28	249.63	350.92	443.59	533.98	623.30	718.39	802.56	887.80
	Cold	-61.57	-2.58	86.35	166.38	261.48	339.99	435.96	513.50	591.96	667.65	745.01
IS19	Ambient	20.86	-40.31	-60.00	-53.32	-36.55	-10.71	25.07	60.21	108.01	159.72	212.92
	Hot/Wet	-65.69	-112.64	-128.11	-117.28	-90.34	-58.26	-17.67	26.90	80.16	135.12	194.73
	Cold	-28.67	-127.65	-126.27	-105.88	-90.59	-65.66	-24.34	15.88	64.70	109.29	164.46
IS20	Ambient	-141.52	-106.19	-65.30	-14.56	29.55	74.30	120.24	155.63	204.09	251.67	295.51
	Hot/Wet	-146.46	-111.53	-82.36	-49.03	-12.24	19.25	49.09	73.60	104.07	133.87	158.82
	Cold	-72.41	-55.61	-6.64	38.13	87.29	124.48	178.63	221.56	266.24	305.82	350.10
IS21	Ambient	4.82	29.34	56.80	91.37	126.22	164.77	209.47	250.90	302.93	357.13	411.81
	Hot/Wet	-0.86	12.04	38.83	71.70	113.99	155.92	202.52	250.70	306.12	361.16	419.59
	Cold	-104.48	-96.34	-54.57	-11.36	23.68	62.77	114.39	160.83	215.76	265.06	323.11
S19	Ambient	8.84	171.51	310.91	416.78	512.16	599.06	684.81	764.41	844.52	920.98	998.18
	Hot/Wet	17.58	166.84	304.20	409.24	503.22	591.13	673.82	755.48	841.02	912.09	992.25
	Cold	-56.75	103.33	233.98	333.75	434.62	521.91	612.73	688.30	768.00	843.96	927.52
S20	Ambient	-48.56	-263.93	-455.48	-652.99	-838.46	-1019.43	-1185.99	-1345.79	-1498.17	-1635.42	-1772.30
	Hot/Wet	-187.69	-368.22	-585.53	-773.37	-957.00	-1126.66	-1279.21	-1436.09	-1593.43	-1708.26	-1836.82
	Cold	-95.94	-382.20	-576.37	-733.71	-955.07	-1136.41	-1320.92	-1462.38	-1597.58	-1744.54	-1879.61
S21	Ambient	31.79	100.58	191.91	276.95	359.15	439.77	522.08	601.20	681.52	759.15	838.87
	Hot/Wet	11.35	94.61	191.50	278.08	363.70	445.28	525.34	608.07	695.24	768.29	851.51
	Cold	-43.8315	25.5829	115.953	193.132	279.254	361.736	449.083	522.771	601.815	679.098	761.569

Figure G-16. Raw strain gauge data at three environmental condition at 80,000 cycles (run 3)

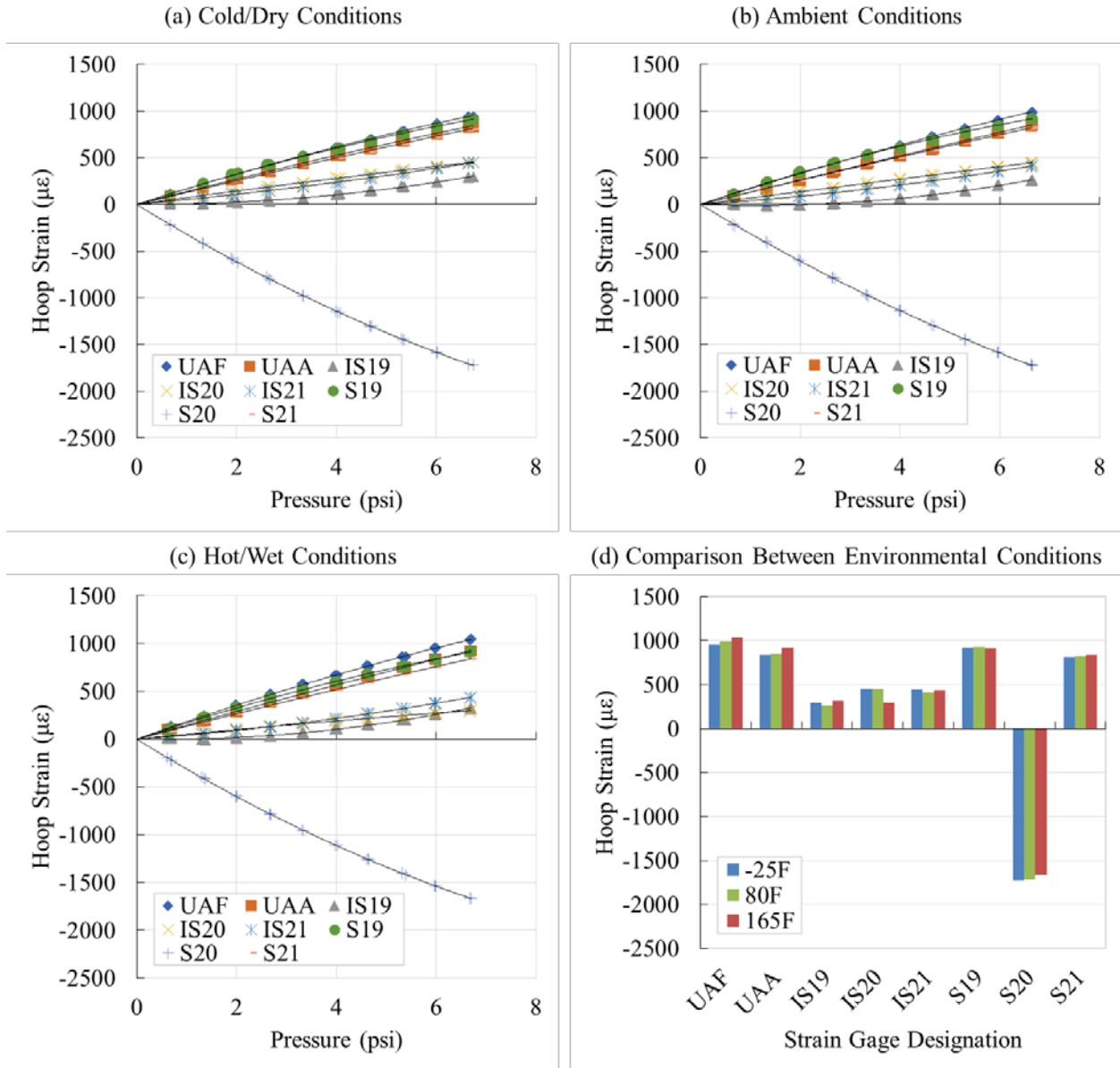


Figure G-17. Strain gauge measurements at 80,000 cycles at (a) cold-dry (-25°F) environmental conditions, (b) ambient environmental conditions, (c) hot-wet (165°F and 85% RH) environmental conditions, and (d) comparison of three environmental conditions at maximum strain survey loads

Type-2 B/Ep Repair Patch, UB

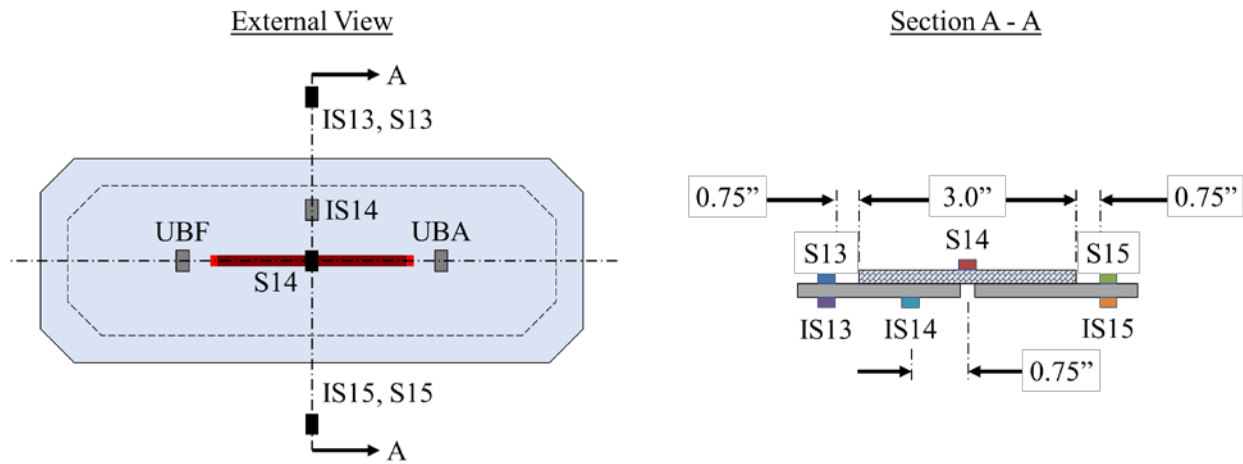


Figure G-18. Location of strain gauges in the vicinity of the type-2 B/Ep repair patch, UB

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
IS13	Ambient	-4.17	-86.05	-132.86	-149.84	-153.30	-143.76	-127.08	-99.08	-67.18	-28.57	17.30
	Hot/Wet	-210.15	-265.27	-280.95	-275.71	-259.06	-231.41	-199.91	-156.55	-110.83	-56.83	2.23
	Cold	79.60	-57.80	-128.32	-168.71	-179.81	-192.24	-184.22	-172.13	-144.02	-114.00	-76.62
IS14	Ambient	-17.85	15.94	62.01	104.74	141.84	179.01	211.24	247.69	282.11	317.26	354.29
	Hot/Wet	237.74	239.92	270.75	300.87	328.60	356.28	382.42	411.97	439.26	469.74	501.01
	Cold	-324.77	-289.52	-227.38	-175.18	-130.77	-87.38	-45.38	-5.98	41.12	81.76	125.56
IS15	Ambient	0.07	-97.15	-156.86	-187.04	-202.37	-204.28	-196.51	-177.46	-153.36	-122.09	-83.52
	Hot/Wet	-213.54	-279.16	-306.76	-315.05	-310.73	-293.77	-270.58	-236.14	-197.88	-151.08	-98.78
	Cold	82.49	-52.31	-128.09	-177.83	-198.48	-222.29	-224.14	-220.23	-202.54	-181.02	-152.45
S13	Ambient	-147.89	-20.77	103.45	198.53	278.28	352.35	414.50	478.85	540.48	599.82	662.04
	Hot/Wet	182.18	246.59	337.74	416.39	486.34	547.28	606.54	660.77	710.97	765.29	823.86
	Cold	-385.91	-217.92	-57.58	67.90	157.90	250.70	332.33	405.45	485.89	549.69	616.99
S14	Ambient	-123.88	-378.11	-611.25	-817.93	-1000.81	-1162.92	-1294.70	-1416.09	-1522.91	-1613.29	-1697.64
	Hot/Wet	-1702.06	-1812.37	-1956.58	-2116.04	-2265.16	-2374.99	-2482.33	-2571.32	-2656.69	-2723.51	-2785.86
	Cold	517.89	186.13	-88.33	-335.16	-499.75	-704.98	-859.63	-997.30	-1124.27	-1225.81	-1312.78
S15	Ambient	10.02	150.43	290.28	397.95	489.61	574.26	644.80	718.21	787.90	855.18	925.60
	Hot/Wet	273.58	357.58	463.81	551.33	629.86	701.33	768.04	834.59	899.60	965.01	1032.45
	Cold	-302.27	-146.75	16.83	146.17	246.90	344.70	430.76	509.68	594.78	666.11	741.77

Figure G-19. Raw strain gauge data at three environmental condition at 80,000 cycles (run 1)

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
IS13	Ambient	-0.01	-90.59	-131.05	-147.40	-152.84	-145.42	-127.35	-100.64	-68.86	-29.04	15.69
	Hot/Wet	-217.39	-269.72	-281.83	-276.20	-261.47	-233.06	-199.17	-157.62	-111.12	-56.81	-1.88
	Cold	122.80	-61.05	-129.03	-159.74	-189.45	-195.10	-187.04	-172.43	-144.55	-110.84	-74.41
IS14	Ambient	-17.03	13.48	60.03	101.41	137.70	173.51	208.77	244.82	278.74	314.99	351.97
	Hot/Wet	217.70	229.75	263.84	294.43	320.61	349.65	377.71	406.52	435.18	466.33	496.32
	Cold	-318.40	-288.59	-229.79	-173.60	-133.07	-89.17	-44.84	-4.38	40.37	87.39	128.91
IS15	Ambient	7.56	-104.01	-156.53	-185.17	-202.79	-205.83	-197.21	-179.64	-155.46	-123.23	-85.64
	Hot/Wet	-214.72	-281.84	-306.25	-315.41	-312.98	-296.05	-270.65	-237.58	-199.22	-151.71	-102.43
	Cold	124.73	-57.37	-129.32	-168.56	-210.28	-226.54	-227.41	-221.55	-204.13	-178.44	-149.34
S13	Ambient	-136.95	-12.65	108.92	200.09	278.15	350.48	416.96	481.16	539.43	599.45	659.11
	Hot/Wet	116.83	205.29	297.01	374.32	441.88	506.12	566.89	624.23	682.88	741.86	800.40
	Cold	-420.34	-223.19	-70.52	54.95	156.67	245.46	330.13	404.26	478.40	552.84	618.14
S14	Ambient	-98.14	-382.78	-589.99	-786.10	-970.67	-1131.45	-1273.98	-1401.34	-1503.70	-1598.38	-1682.11
	Hot/Wet	-1583.03	-1734.53	-1899.81	-2062.49	-2209.70	-2338.36	-2441.42	-2530.61	-2619.82	-2717.64	-2792.69
	Cold	608.21	185.98	-72.20	-291.13	-523.06	-702.40	-863.72	-998.03	-1117.13	-1224.50	-1305.46
S15	Ambient	21.53	159.31	296.84	400.18	489.17	571.49	647.11	720.07	786.59	854.41	922.39
	Hot/Wet	244.12	349.92	458.14	545.62	623.06	696.53	765.55	830.26	895.06	960.81	1025.41
	Cold	-315.25	-133.733	21.0375	151.375	255.119	348.103	436.428	515.852	595.246	675.035	747.307

Figure G-20. Raw strain gauge data at three environmental condition at 80,000 cycles (run 2)

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
IS13	Ambient	-1.50	-83.12	-130.11	-149.02	-151.07	-144.09	-123.74	-100.82	-67.23	-27.01	16.73
	Hot/Wet	-218.45	-265.15	-283.77	-280.36	-260.68	-234.80	-199.45	-158.66	-111.12	-59.48	-1.20
	Cold	118.89	-65.01	-134.14	-161.45	-190.91	-198.03	-189.74	-172.09	-145.08	-115.36	-74.79
IS14	Ambient	-16.14	13.43	60.84	100.34	138.12	172.56	210.56	243.30	279.45	316.24	352.06
	Hot/Wet	215.51	228.90	259.63	288.46	319.09	345.64	374.12	402.05	431.18	462.12	494.19
	Cold	-313.81	-289.61	-230.22	-179.27	-133.88	-90.87	-43.48	-2.91	41.94	82.95	130.06
IS15	Ambient	6.26	-96.79	-156.04	-187.35	-201.04	-204.23	-193.80	-178.86	-153.60	-121.11	-84.26
	Hot/Wet	-211.39	-275.50	-308.79	-318.45	-311.94	-296.58	-271.15	-238.43	-198.65	-153.79	-101.88
	Cold	124.51	-61.59	-134.75	-168.96	-210.92	-227.82	-228.62	-220.90	-202.39	-182.67	-149.40
S13	Ambient	-132.28	-16.18	110.44	202.11	279.77	348.44	416.81	478.10	540.15	599.75	659.28
	Hot/Wet	111.45	191.28	283.38	357.51	424.76	485.15	543.85	601.97	662.49	715.37	773.10
	Cold	-412.98	-223.54	-68.53	45.96	153.38	243.93	333.95	404.91	476.95	547.99	624.10
S14	Ambient	-98.66	-360.68	-589.33	-792.70	-967.62	-1125.31	-1264.71	-1389.80	-1501.21	-1594.34	-1679.19
	Hot/Wet	-1526.73	-1679.02	-1881.94	-2047.12	-2187.76	-2303.17	-2408.54	-2507.32	-2603.47	-2670.90	-2738.12
	Cold	602.09	179.35	-85.69	-275.43	-516.27	-697.83	-874.66	-1000.55	-1113.39	-1224.76	-1319.89
S15	Ambient	25.80	157.56	298.20	401.17	490.45	569.06	647.21	717.45	787.68	855.46	922.83
	Hot/Wet	246.67	346.38	456.78	544.38	622.77	693.53	760.51	827.31	896.20	957.65	1024.58
	Cold	-307.021	-134.632	24.3148	145.943	256.203	349.863	443.666	520.733	599.221	672.138	754.436

Figure G-21. Raw strain gauge data at three environmental condition at 80,000 cycles (run 3)

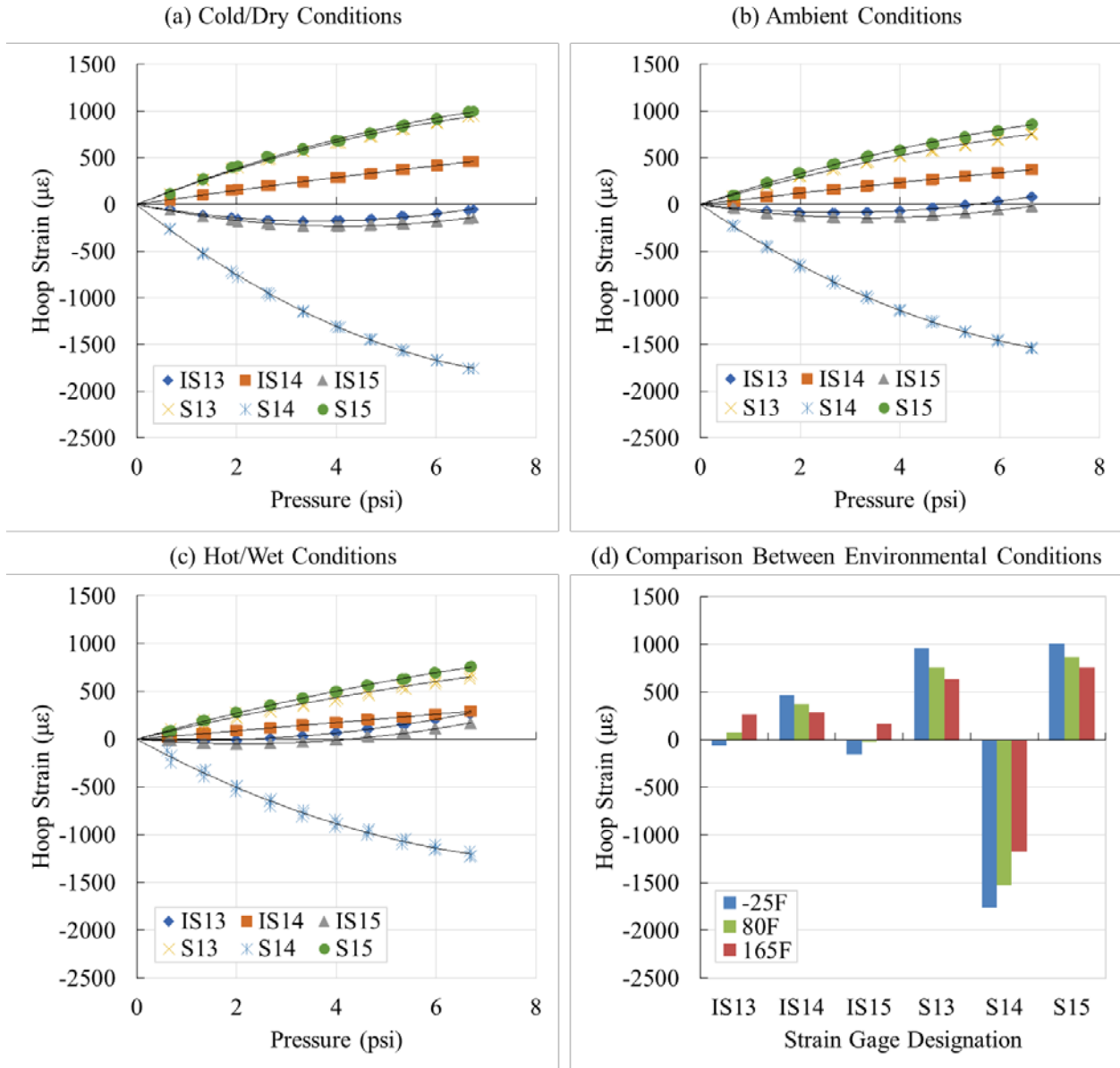


Figure G-22. Strain gauge measurements at 80,000 cycles at (a) cold-dry (-25°F) environmental conditions, (b) ambient environmental conditions, (c) hot-wet (165°F and 85% RH) environmental conditions, and (d) comparison of three environmental conditions at maximum strain survey loads

The notch-tip strain data are shown in tables G-15 and G1-16, and in figure G-11. Strain was measured at the maximum loading conditions at three different environmental conditions.

Table G-3. Strain measured at maximum loading conditions using strain gauge chain at the forward side

Strain Gauge	X Position	165°F	80°F	-25°F
UBF1	2.59	1788.7	1975.6	2193.2
UBF2	2.63	1656.2	1838.3	2045.7
UBF3	2.67	1558.0	1735.7	1938.3
UBF4	2.71	1468.0	1647.7	1844.3
UBF5	2.75	1404.5	1583.6	1773.8
UBF6	2.79	1348.8	1524.1	1715.4
UBF7	2.83	1306.0	1470.7	1654.0
UBF8	2.87	1284.4	1440.3	1624.5
UBF9	2.91			
UBF10	2.95			

Table G-4. Strain measured at maximum loading conditions using strain gauge chain at the aft side

Strain Gauge	X Position	165°F	80°F	-25°F
UBA1	2.63	1430.7	1594.7	1804.8
UBA2	2.66	1402.2	1553.4	1772.7
UBA3	2.70		1395.6	1686.4
UBA4	2.74	1311.2	1467.9	1668.8
UBA5	2.78	1274.4	1434.0	1650.6
UBA6	2.82	1244.3	1403.4	1595.3
UBA7	2.86	1214.4	1367.4	1582.6
UBA8	2.90	1181.5	1339.7	1555.7
UBA9	2.94	1149.3	1300.1	1489.2
UBA10	2.98	74.7	1.9	9.6

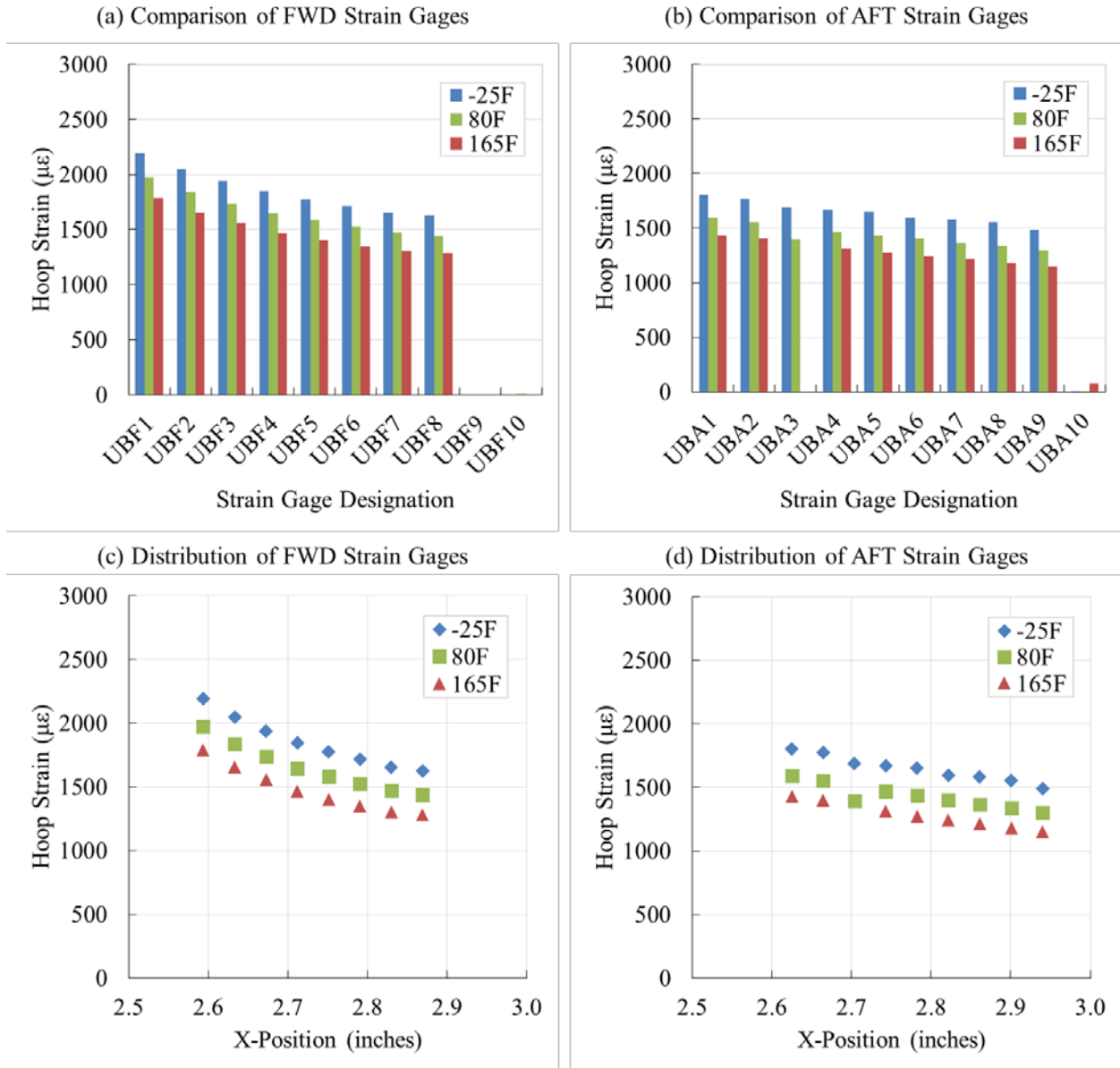


Figure G-23. Comparison of notch-tip strain at maximum loading conditions under three different environmental conditions: (a) comparison of fwd strain gauge chain, (b) comparison of aft strain gauge chain, (c) comparison of fwd strain gauge chain with respect to x -position, and (d) comparison of aft strain gauge chain with respect to x -position

Type-3 Aluminum Repair Patch, UDA

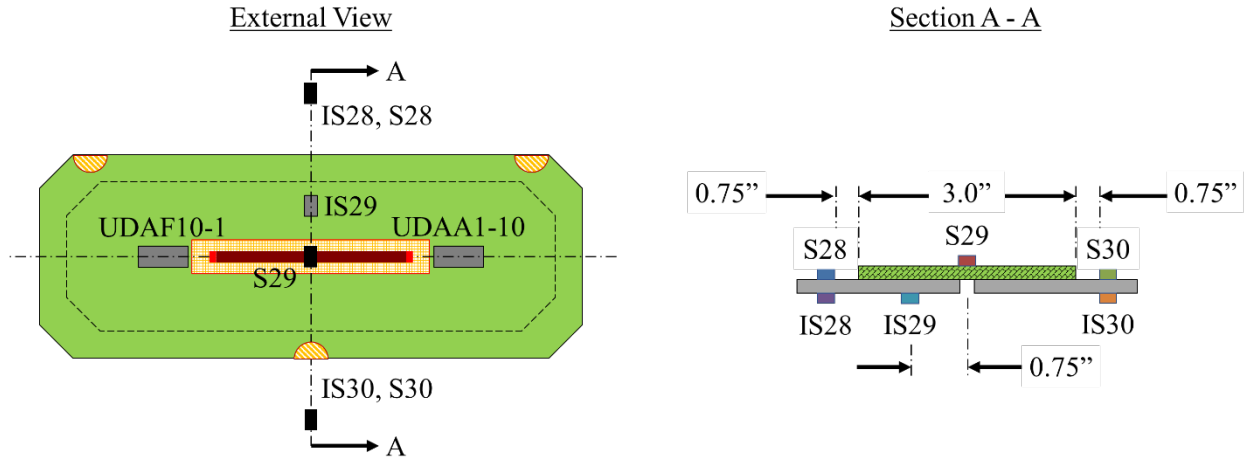


Figure G-24. Location of strain gauges in the vicinity of the type-3 aluminum repair patch, UDA

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
IS28	Ambient	11.86	-78.17	-123.53	-131.58	-123.83	-99.37	-70.41	-29.12	13.73	62.79	119.79
	Hot/Wet	-128.06	-192.59	-224.66	-225.46	-214.54	-189.72	-160.00	-116.01	-75.13	-23.21	28.37
	Cold	-41.87	-151.10	-172.22	-176.82	-156.26	-136.48	-100.51	-64.96	-12.77	33.71	85.32
IS29	Ambient	5.98	39.91	79.10	116.79	149.82	183.76	210.68	241.59	267.77	295.45	325.28
	Hot/Wet	-51.36	-15.11	24.07	63.02	98.80	131.61	160.56	194.30	222.46	254.25	281.94
	Cold	-11.38	13.18	51.67	86.86	119.37	146.31	176.30	200.06	229.01	253.54	279.50
IS30	Ambient	-112.69	-133.45	-93.13	-54.62	-15.09	32.01	76.49	130.47	183.76	241.13	305.65
	Hot/Wet	-37.05	-87.42	-79.41	-56.89	-28.90	5.90	43.38	93.16	138.61	191.38	243.67
	Cold	-46.20	-65.97	-30.83	8.22	49.91	93.05	145.75	195.62	259.25	312.77	370.82
S28	Ambient	-40.39	136.33	293.79	416.13	520.78	617.51	698.71	780.81	860.38	936.40	1015.76
	Hot/Wet	77.56	204.93	326.80	429.67	520.20	601.15	677.69	752.30	823.81	894.32	967.03
	Cold	3.87	183.58	337.49	464.68	557.98	664.03	752.65	835.57	923.95	998.70	1072.75
S29	Ambient	-55.49	-202.23	-338.47	-454.04	-555.19	-641.18	-708.17	-763.12	-808.96	-843.45	-870.02
	Hot/Wet	79.00	-70.26	-211.99	-337.28	-451.96	-541.91	-622.35	-684.22	-742.09	-785.53	-817.87
	Cold	-156.95	-318.38	-441.77	-550.38	-623.19	-705.80	-761.58	-807.94	-843.62	-867.79	-884.47
S30	Ambient	31.04	145.75	228.88	312.32	393.62	473.92	545.25	619.13	692.53	763.93	840.14
	Hot/Wet	32.20	148.19	232.11	314.67	394.56	467.45	538.91	610.39	680.09	749.19	821.69
	Cold	-55.24	55.45	161.25	254.86	331.70	419.96	497.59	572.96	655.13	723.43	793.67

Figure G-25. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10	
Pressure	0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7	
IS28	Ambient	32.21	-83.73	-121.58	-130.11	-124.18	-103.55	-71.86	-32.49	11.24	63.64	116.90
	Hot/Wet	-121.35	-187.26	-222.35	-228.24	-217.55	-194.41	-162.51	-123.28	-79.11	-28.27	23.36
	Cold	26.25	-140.10	-163.98	-160.36	-159.73	-135.30	-97.89	-61.85	-10.79	37.96	88.52
IS29	Ambient	10.46	41.91	80.17	115.99	149.11	179.75	209.69	238.97	266.33	297.41	324.41
	Hot/Wet	-57.52	-17.05	19.83	60.73	96.39	130.68	159.88	190.75	219.78	250.40	277.14
	Cold	-3.91	16.59	55.66	93.05	119.31	151.22	178.98	204.55	230.55	256.93	282.73
IS30	Ambient	-112.23	-129.73	-90.98	-54.44	-16.39	27.44	75.42	128.36	181.42	242.18	302.28
	Hot/Wet	-92.98	-124.73	-101.54	-77.23	-46.13	-9.56	30.77	75.98	124.94	177.12	231.56
	Cold	-40.06	-63.58	-28.43	15.25	49.62	97.04	150.20	199.92	259.30	318.45	373.72
S28	Ambient	-46.61	149.38	295.03	413.37	517.72	613.62	700.40	784.34	859.20	935.45	1011.33
	Hot/Wet	39.75	185.21	311.18	418.03	511.10	595.09	673.66	743.83	817.64	888.33	959.56
	Cold	-46.45	190.39	335.12	456.43	569.82	664.41	757.78	837.87	923.02	1001.22	1073.57
S29	Ambient	-43.04	-216.64	-335.90	-448.54	-551.90	-637.97	-707.77	-764.98	-808.16	-842.72	-867.98
	Hot/Wet	66.23	-89.81	-216.22	-347.51	-459.80	-555.60	-632.37	-691.95	-745.69	-789.34	-823.68
	Cold	-117.17	-323.89	-440.64	-533.89	-635.14	-708.51	-765.17	-810.95	-842.98	-869.28	-883.21
S30	Ambient	38.27	149.13	227.93	309.16	389.71	469.21	545.50	621.26	690.59	762.46	834.93
	Hot/Wet	41.93	156.87	232.93	314.44	393.70	468.79	541.56	608.67	678.56	746.54	817.27
	Cold	-56.6885	65.7243	163.198	252.377	340.764	422.883	503.978	577.666	654.114	727.889	794.849

Figure G-26. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 2)

Load Step	0	1	2	3	4	5	6	7	8	9	10	
Pressure	0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7	
IS28	Ambient	32.25	-71.32	-119.22	-129.43	-121.34	-100.75	-67.25	-32.37	14.15	65.23	118.54
	Hot/Wet	-118.63	-183.77	-226.73	-232.47	-217.34	-193.44	-160.52	-126.22	-79.45	-29.56	24.48
	Cold	27.41	-140.54	-169.88	-163.62	-159.22	-139.14	-96.98	-55.58	-11.99	37.00	92.42
IS29	Ambient	10.99	43.21	82.00	119.11	151.46	182.06	213.61	238.45	268.86	298.27	325.52
	Hot/Wet	-57.27	-19.76	21.42	59.09	95.99	129.70	160.17	188.97	219.63	249.05	277.13
	Cold	-1.04	19.06	57.21	90.04	122.18	148.82	179.76	207.00	234.92	257.46	284.53
IS30	Ambient	-110.96	-127.96	-88.36	-51.91	-13.36	29.41	79.12	127.10	184.13	243.17	303.93
	Hot/Wet	-105.35	-131.89	-109.27	-87.87	-55.23	-16.34	24.36	67.49	118.65	170.26	225.90
	Cold	-39.20	-65.17	-30.09	10.96	49.73	92.85	150.10	202.43	259.27	318.39	379.70
S28	Ambient	-44.93	137.78	296.56	417.05	519.01	610.97	699.17	780.48	860.38	936.32	1012.34
	Hot/Wet	33.32	172.70	314.46	415.52	506.39	590.12	666.73	740.50	819.75	884.81	958.12
	Cold	-45.59	193.06	339.18	448.94	567.62	663.85	764.22	843.44	921.21	1000.69	1082.96
S29	Ambient	-42.47	-200.56	-336.59	-452.98	-551.15	-636.72	-704.78	-762.09	-808.11	-841.88	-868.46
	Hot/Wet	58.85	-74.76	-231.78	-355.17	-465.12	-556.66	-629.94	-697.15	-754.42	-791.37	-824.81
	Cold	-115.64	-321.55	-444.01	-527.56	-633.45	-706.41	-768.37	-809.66	-840.55	-867.94	-883.43
S30	Ambient	38.37	145.35	227.42	310.27	389.12	465.99	542.92	617.03	691.16	762.67	835.55
	Hot/Wet	45.74	150.79	237.95	316.27	393.01	467.27	537.72	608.78	683.65	746.63	818.66
	Cold	-54.8153	69.1678	165.69	247.679	339.421	422.455	508.07	580.147	653.125	728.658	804.099

Figure G-27. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 3)

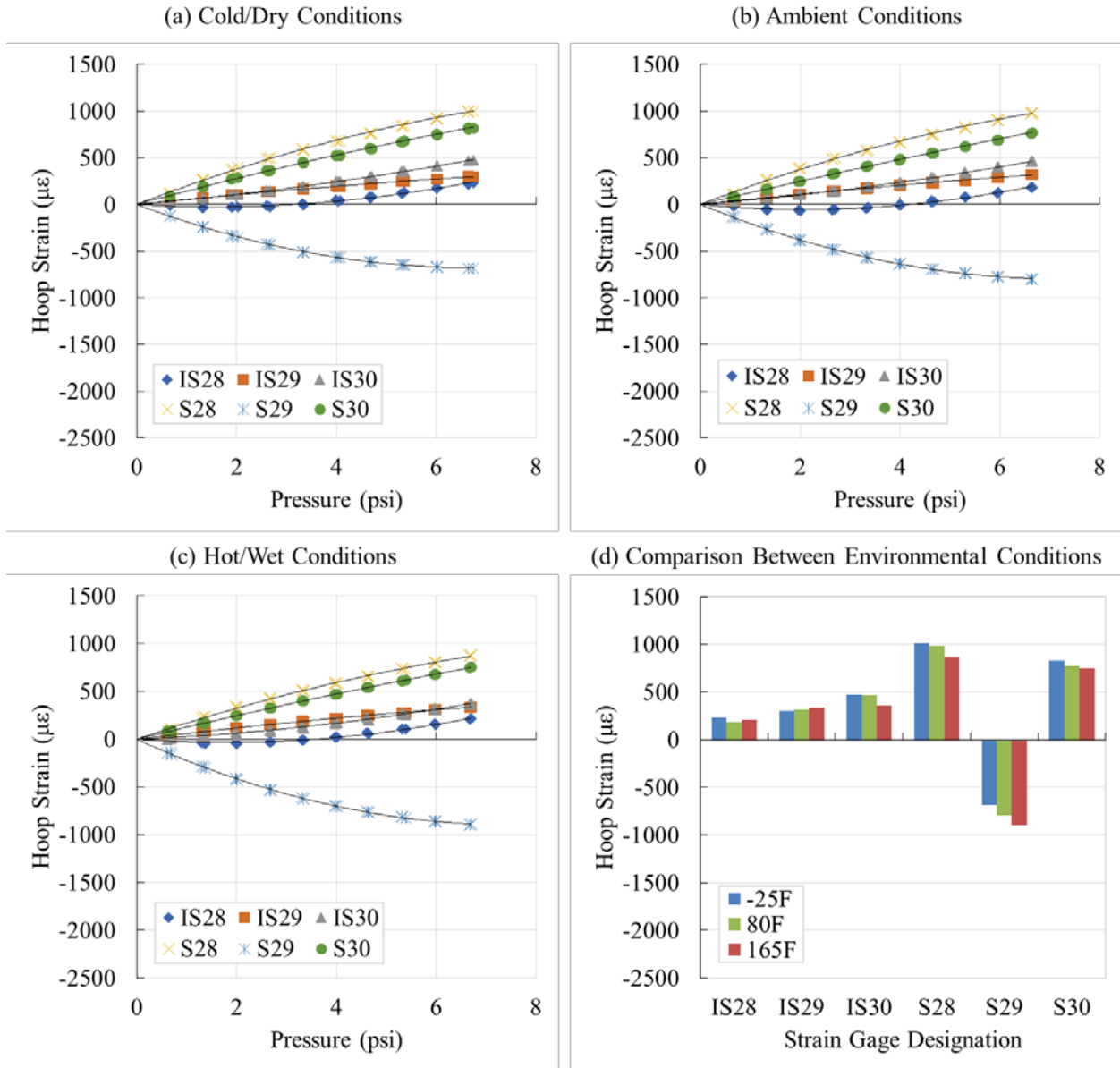


Figure G-28. Strain gauge measurements at 80,000 cycles at (a) cold-dry (-25°F) environmental conditions, (b) ambient environmental conditions, (c) hot-wet (165°F and 85% RH) environmental conditions, and (d) comparison of three environmental conditions at maximum strain survey loads

The notch-tip strain data are shown in tables G-20 and G-21, and in figure G-14. Strain was measured at the maximum loading conditions at three different environmental conditions.

Table G-5. Strain measured at maximum loading conditions using strain gauge chain at the forward side

Strain Gauge	X Position	165°F	80°F	-25°F
UDAF1	2.38	1724.4	1690.8	1646.0
UDAF2	2.41	1625.8	1593.1	1548.5
UDAF3	2.45	1542.1	1509.0	1465.4
UDAF4	2.49	1470.6	1437.3	1394.4
UDAF5	2.53	1405.3	1372.5	1329.1
UDAF6	2.57	1359.4	1325.8	1284.5
UDAF7	2.61	1312.4	1278.0	1238.5
UDAF8	2.65	1274.7	1239.0	1201.3
UDAF9	2.69	1240.3	1205.2	1168.4
UDAF10	2.73	1207.1	1169.8	1134.9

Table G-6. Strain measured at maximum loading conditions using strain gauge chain at the aft side

Strain Gauge	X Position	165°F	80°F	-25°F
UDAA1	2.41			
UDAA2	2.45	1598.8	1796.3	1811.7
UDAA3	2.48			
UDAA4	2.52	1453.4	1652.5	1666.6
UDAA5	2.56	1406.7	1595.2	1602.4
UDAA6	2.60	1338.4	1534.5	1546.0
UDAA7	2.64	1298.4	1480.5	1484.9
UDAA8	2.68	1253.9	1430.7	1435.8
UDAA9	2.72	1209.0	1382.3	1384.1
UDAA10	2.76	1174.0	1349.7	1354.1

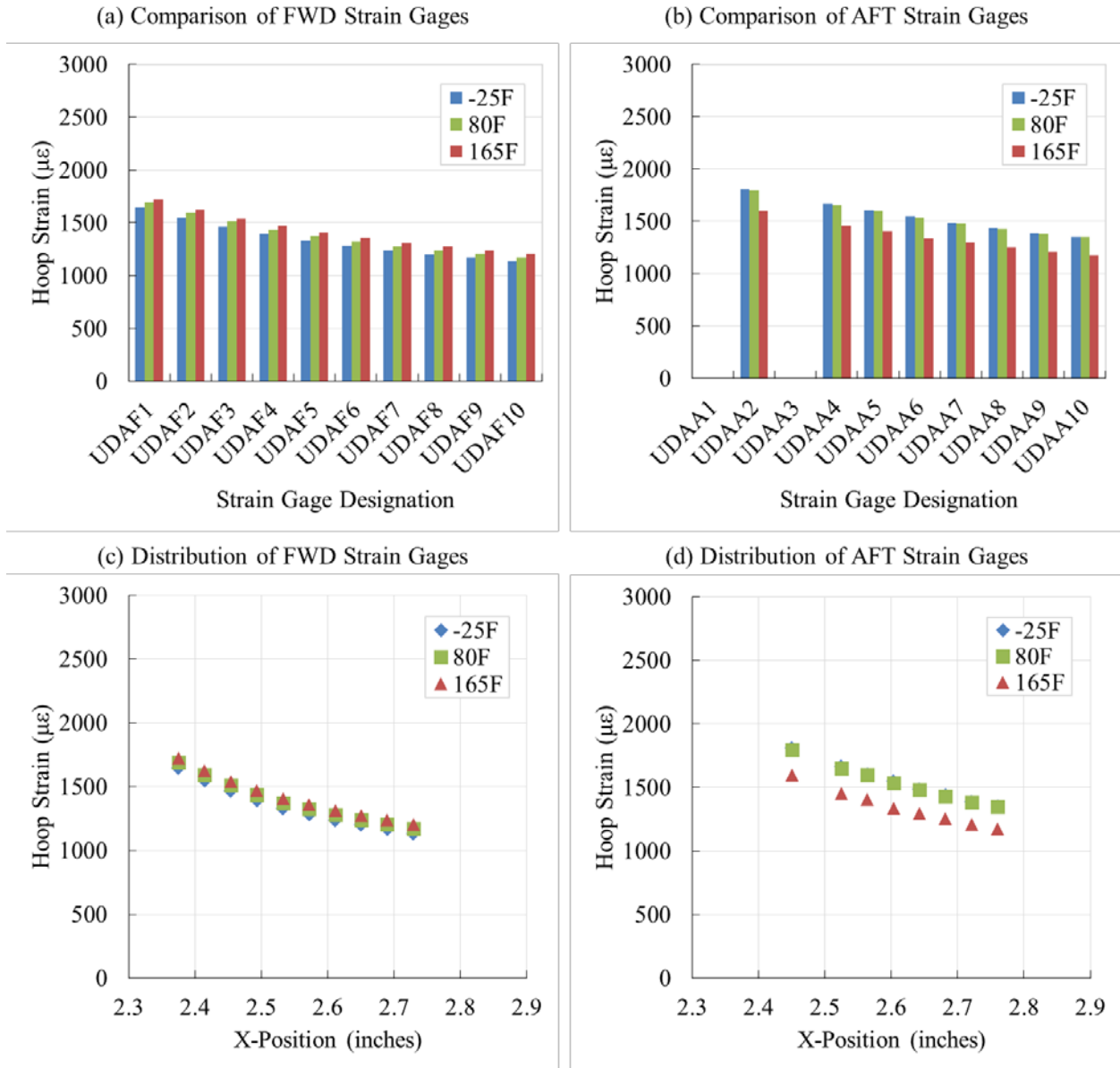


Figure G-29. Comparison of notch-tip strain at maximum loading conditions under three different environmental conditions: (a) comparison of fwd strain gauge chain, (b) comparison of aft strain gauge chain, (c) comparison of fwd strain gauge chain with respect to x -position, and (d) comparison of aft strain gauge chain with respect to x -position

Type-3 B/Ep Repair Patch, UDB

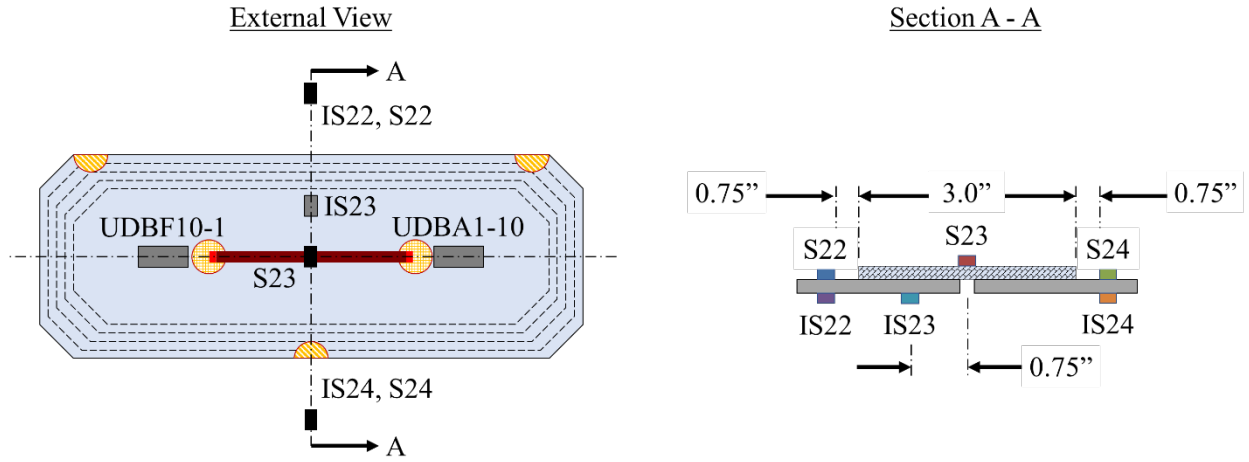


Figure G-30. Location of strain gauges in the vicinity of the type-3 B/Ep repair patch, UDB

Load Step		0	1	2	3	4	5	6	7	8	9	10
Pressure		0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
IS22	Ambient	24.45	-60.33	-121.94	-150.70	-162.51	-159.51	-146.80	-122.44	-92.28	-55.99	-11.13
	Hot/Wet	-259.40	-301.79	-328.88	-334.74	-331.39	-316.85	-292.67	-259.69	-224.46	-178.15	-128.27
	Cold	80.75	-30.10	-93.72	-132.13	-142.71	-150.46	-140.84	-123.62	-90.60	-60.46	-21.24
IS23	Ambient	-47.03	-13.90	28.78	67.47	99.96	132.60	159.38	190.54	218.90	247.17	277.16
	Hot/Wet	247.76	262.20	284.61	309.12	330.06	350.49	370.07	391.44	410.25	431.96	453.68
	Cold	-230.34	-193.02	-140.83	-97.45	-64.11	-26.35	8.09	38.18	74.17	104.77	136.19
IS24	Ambient	-153.16	-246.92	-291.65	-315.89	-329.83	-333.57	-330.12	-317.41	-300.90	-279.67	-252.76
	Hot/Wet	-357.31	-424.06	-444.34	-454.03	-457.60	-452.12	-440.64	-423.72	-404.51	-380.18	-350.51
	Cold	55.33	-61.26	-116.04	-151.19	-165.52	-177.52	-175.77	-167.98	-149.16	-131.11	-108.23
S22	Ambient	-30.16	115.80	266.67	384.15	483.22	573.75	648.88	725.74	799.31	869.00	942.06
	Hot/Wet	267.29	352.02	454.94	543.22	618.23	683.80	746.92	807.41	865.49	926.42	990.99
	Cold	-104.01	70.98	233.36	366.23	464.02	574.67	663.37	744.44	833.15	908.61	981.08
S23	Ambient	-44.69	-315.18	-598.45	-814.65	-1007.42	-1200.20	-1291.83	-1411.80	-1500.04	-1571.40	-1653.75
	Hot/Wet	-864.77	-1000.04	-1132.42	-1270.36	-1401.63	-1509.81	-1609.82	-1695.49	-1766.01	-1825.35	-1868.34
	Cold	1042.90	701.52	412.51	157.76	-8.52	-210.14	-360.73	-493.59	-609.63	-701.74	-778.24
S24	Ambient	-59.59	111.25	242.12	346.07	432.25	514.08	579.79	650.93	716.50	781.75	849.43
	Hot/Wet	-95.83	19.24	114.79	188.35	250.62	308.49	365.82	420.14	473.89	527.81	589.95
	Cold	-136.99	48.02	217.68	342.40	438.73	539.05	623.53	700.92	784.85	854.55	926.07

Figure G-31. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10	
Pressure	0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7	
IS22	Ambient	30.89	-66.32	-121.44	-147.87	-161.73	-160.06	-146.30	-123.59	-93.96	-56.19	-13.14
	Hot/Wet	-243.58	-293.70	-326.21	-335.22	-335.45	-316.91	-295.13	-264.96	-228.38	-182.60	-134.25
	Cold	120.49	-28.17	-92.89	-126.12	-151.39	-155.69	-142.84	-126.41	-94.58	-57.34	-20.45
IS23	Ambient	-49.84	-16.71	23.90	62.06	93.80	125.60	156.12	186.25	214.44	244.77	274.17
	Hot/Wet	231.34	253.29	277.86	303.47	321.68	342.33	364.12	384.69	404.33	427.54	447.01
	Cold	-234.47	-198.59	-149.81	-100.28	-67.77	-30.29	5.19	34.97	70.96	110.14	138.63
IS24	Ambient	-147.78	-251.13	-290.58	-313.42	-329.53	-334.05	-329.70	-318.88	-302.33	-279.90	-253.70
	Hot/Wet	-371.84	-435.62	-457.43	-467.67	-471.57	-466.09	-454.99	-438.16	-418.54	-391.48	-364.13
	Cold	99.72	-61.64	-116.63	-145.53	-173.67	-182.33	-178.04	-170.82	-150.76	-129.53	-105.93
S22	Ambient	-26.37	127.07	270.92	383.03	480.44	569.72	650.99	728.20	797.62	867.85	937.57
	Hot/Wet	232.15	346.19	451.66	539.21	610.01	682.77	749.40	809.44	867.84	929.75	987.58
	Cold	-139.84	72.47	227.86	359.75	474.48	572.06	668.40	745.66	831.88	917.06	983.18
S23	Ambient	-32.43	-333.56	-522.64	-748.88	-939.75	-1095.20	-1234.78	-1355.46	-1459.10	-1546.16	-1606.35
	Hot/Wet	-747.04	-903.16	-1044.00	-1196.62	-1325.40	-1439.07	-1538.44	-1620.54	-1693.88	-1762.03	-1816.43
	Cold	1139.33	706.67	434.61	208.48	-24.98	-204.63	-359.97	-491.17	-598.95	-698.71	-771.34
S24	Ambient	-50.37	122.55	244.46	342.11	428.29	507.74	580.44	651.22	713.86	779.99	844.54
	Hot/Wet	-93.74	34.79	121.09	195.73	258.67	320.61	379.25	433.57	486.89	543.52	597.54
	Cold	-177.55	56.9161	211.43	341.498	445.078	538.547	628.078	701.889	785.087	862.062	928.496

Figure G-32. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 2)

Load Step	0	1	2	3	4	5	6	7	8	9	10	
Pressure	0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7	
IS22	Ambient	29.26	-58.79	-119.88	-149.31	-160.25	-158.65	-143.79	-122.86	-91.91	-54.82	-12.38
	Hot/Wet	-241.56	-293.89	-330.98	-340.13	-332.71	-320.67	-294.14	-266.14	-228.34	-183.46	-132.88
	Cold	116.64	-35.52	-100.24	-127.68	-153.40	-157.44	-140.51	-122.33	-94.41	-63.06	-18.36
IS23	Ambient	-50.09	-18.17	25.99	61.69	93.87	124.64	156.79	184.49	214.90	244.88	273.61
	Hot/Wet	228.74	247.44	274.65	295.62	318.37	338.01	358.36	378.66	399.30	421.04	444.09
	Cold	-225.54	-192.55	-145.07	-105.37	-65.70	-31.19	6.62	39.56	77.01	106.44	142.77
IS24	Ambient	-148.13	-245.06	-288.88	-314.79	-328.10	-332.98	-327.03	-317.80	-300.66	-278.30	-252.66
	Hot/Wet	-379.84	-443.31	-469.23	-479.71	-480.01	-475.30	-461.35	-447.85	-427.35	-401.14	-370.27
	Cold	97.84	-66.76	-124.25	-147.93	-175.26	-183.51	-177.37	-168.08	-152.19	-134.39	-106.75
S22	Ambient	-20.76	120.81	273.63	386.45	482.23	567.02	649.55	724.59	798.51	868.48	938.09
	Hot/Wet	243.22	345.15	459.95	540.95	615.95	682.34	747.39	809.72	873.55	927.06	988.46
	Cold	-122.77	81.99	238.73	351.05	475.27	573.08	677.72	756.25	837.44	913.32	994.80
S23	Ambient	-23.07	-291.57	-595.60	-804.27	-1027.17	-1091.18	-1223.28	-1356.40	-1485.86	-1565.41	-1631.90
	Hot/Wet	-683.91	-827.36	-1003.42	-1140.68	-1273.41	-1384.52	-1482.53	-1576.46	-1699.11	-1743.79	-1801.54
	Cold	1127.48	707.56	425.11	222.94	-20.81	-202.39	-369.50	-491.22	-599.25	-698.39	-781.84
S24	Ambient	-49.25	117.68	247.12	344.78	427.78	504.12	579.74	646.35	714.78	779.43	844.38
	Hot/Wet	-77.18	45.12	132.01	203.44	269.10	327.39	385.30	436.81	491.84	539.62	594.93
	Cold	-161.451	65.8414	221.035	331.867	446.115	537.455	635.496	711.024	787.12	859.297	938.078

Figure G-33. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 3)

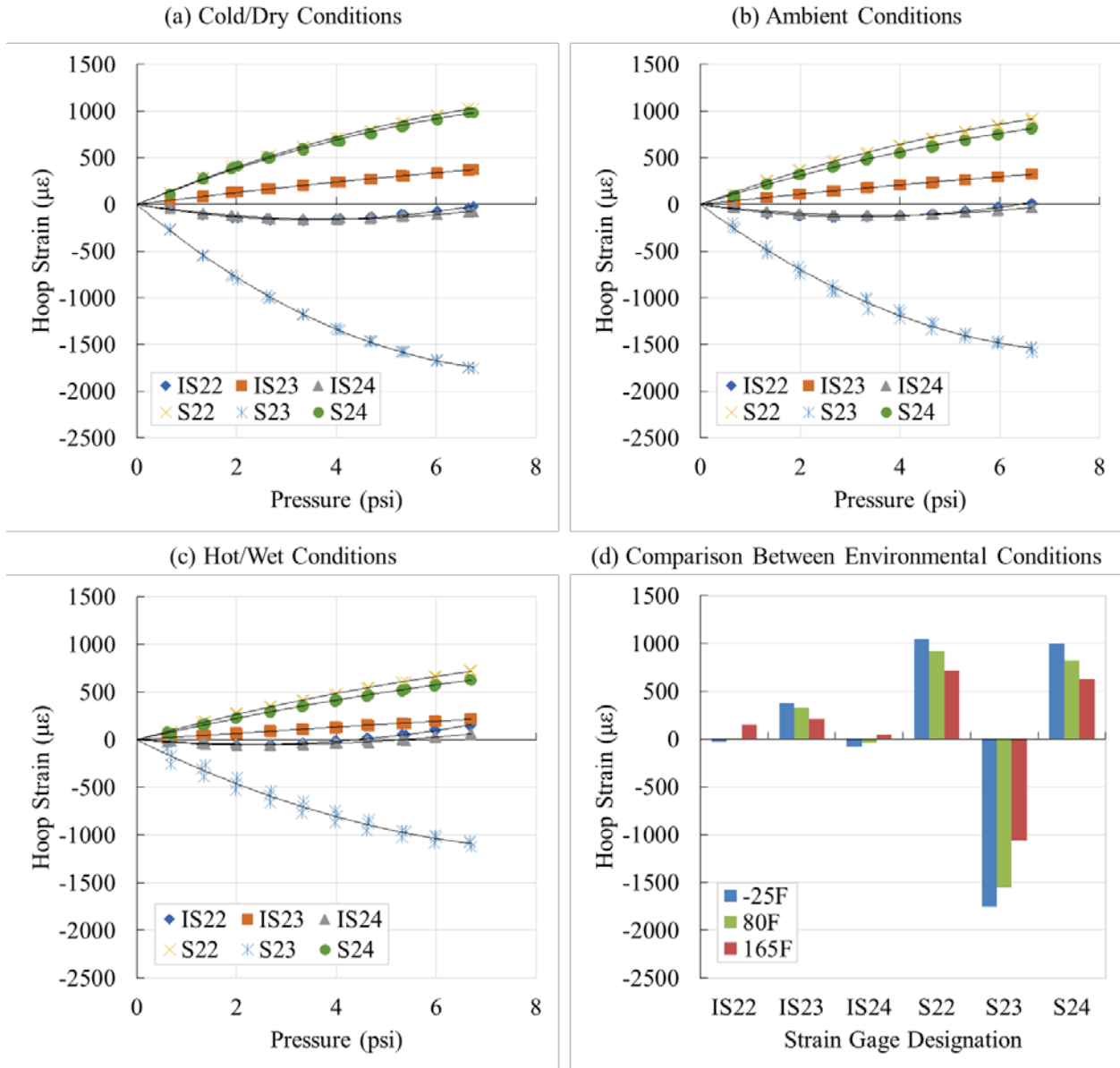


Figure G-34. Strain gauge measurements at 80,000 cycles at (a) cold-dry (-25°F) environmental conditions, (b) ambient environmental conditions, (c) hot-wet (165°F and 85% RH) environmental conditions, and (d) comparison of three environmental conditions at maximum strain survey loads

The notch-tip strain data are shown in tables G-25 and G-26, and in figure G-17. Strain was measured at the maximum loading conditions at three different environmental conditions.

Table G-7. Strain measured at maximum loading conditions using strain gauge chain at the forward side

Strain Gauge	X Position	165°F	80°F	-25°F
UDBF1	2.94			
UDBF2	2.98	1080.2	1619.3	2004.7
UDBF3	3.02	1292.5	2028.5	2458.8
UDBF4	3.06	1562.3	2401.0	2817.3
UDBF5	3.09	1549.2	2402.1	2799.4
UDBF6	3.13	1437.9	2162.4	2477.5
UDBF7	3.17	1531.6	1884.2	1995.6
UDBF8	3.21	1552.1	1627.3	1656.9
UDBF9	3.25	1468.6	1523.9	1572.3
UDBF10	3.29	1405.2	1444.1	1492.8

Table G-8. Strain measured at maximum loading conditions using strain gauge chain at the aft side

Strain Gauge	X Position	165°F	80°F	-25°F
UDBA1	2.88	1599.6	1616.6	1567.9
UDBA2	2.91	1536.3	1544.3	1498.6
UDBA3	2.95	1495.0	1501.2	1455.5
UDBA4	2.99	1447.8	1454.5	1409.7
UDBA5	3.03	1399.5	1404.0	1361.4
UDBA6	3.07	1360.0	1360.0	1318.3
UDBA7	3.11	1315.3	1318.4	1275.4
UDBA8	3.15	1268.7	1268.6	1228.8
UDBA9	3.19	1225.8	1222.4	1182.4
UDBA10	3.23	1190.1	1184.4	1141.2

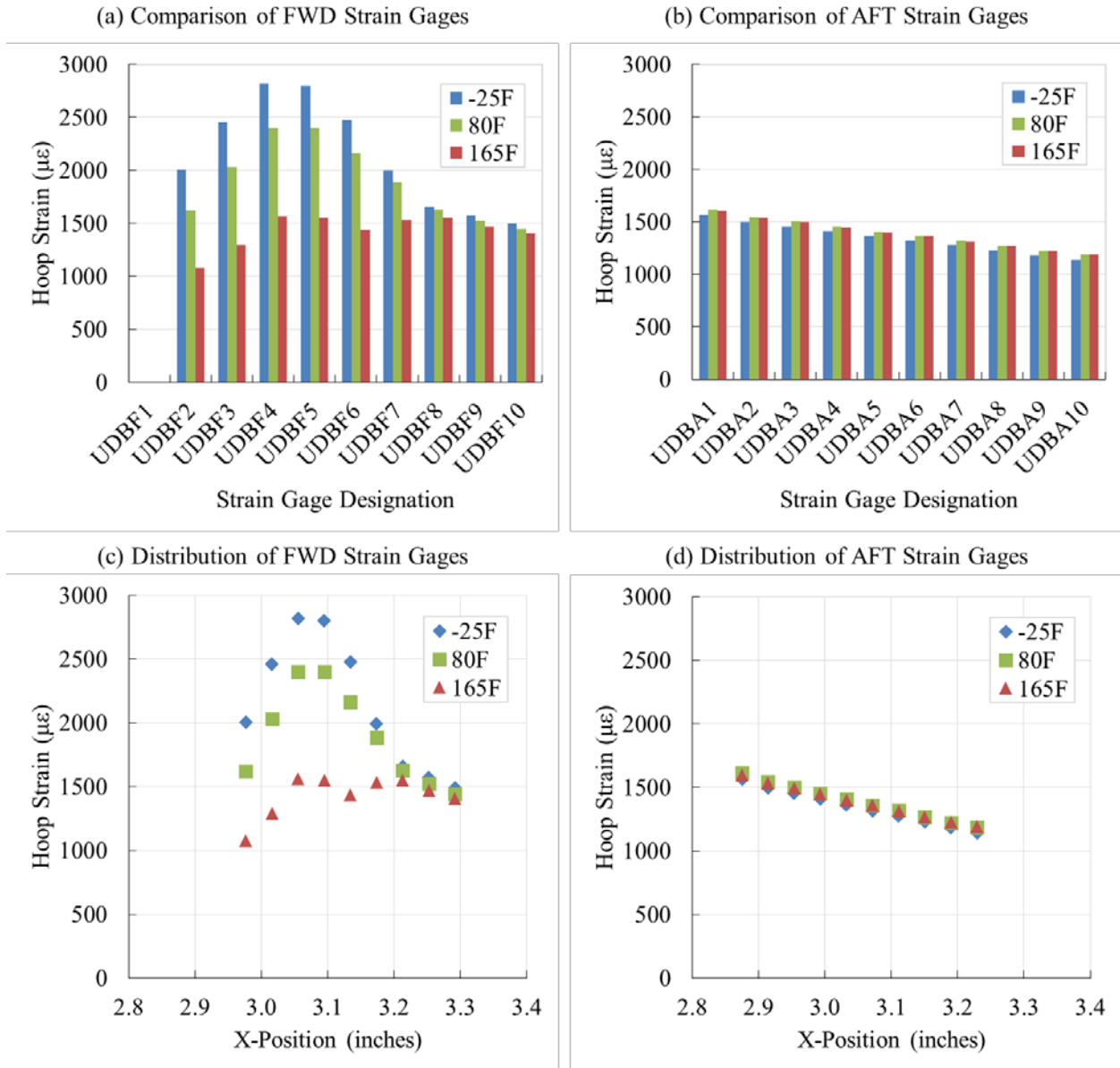


Figure G-35. Comparison of notch-tip strain at maximum loading conditions under three different environmental conditions: (a) comparison of fwd strain gauge chain, (b) comparison of aft strain gauge chain, (c) comparison of fwd strain gauge chain with respect to x-position, and (d) comparison of aft strain gauge chain with respect to x-position

Type-4 Aluminum Repair Patch, HS

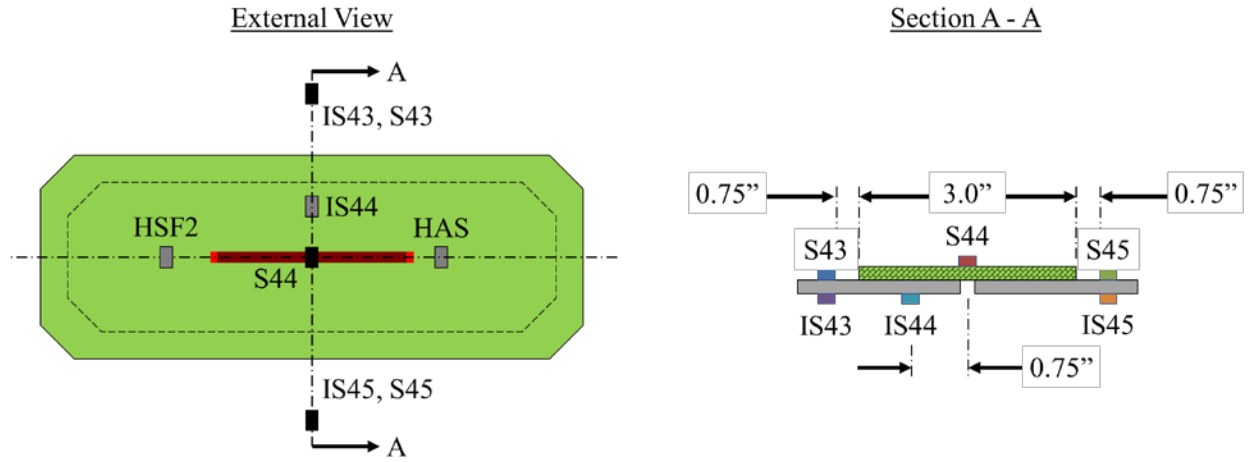


Figure G-36. Location of strain gauges in the vicinity of the type-4 aluminum repair patch, HS

Load Step	0	1	2	3	4	5	6	7	8	9	10	
Pressure	0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7	
HSF2	Ambient	0.26	130.74	235.57	343.00	443.22	543.58	625.55	712.04	788.63	866.14	948.61
	Hot/Wet	-32.50	95.12	206.33	319.39	426.55	524.07	610.73	707.49	793.93	881.93	964.86
	Cold	-69.37	61.30	167.70	271.13	360.09	450.90	538.66	615.78	701.54	768.87	839.50
HAS	Ambient	-17.24	134.36	251.33	371.18	484.07	594.99	688.07	784.24	872.07	959.27	1051.34
	Hot/Wet	-46.00	96.54	221.61	346.56	467.16	576.69	676.65	783.28	881.96	980.00	1074.21
	Cold	-64.94	86.61	205.47	321.44	418.71	521.69	619.41	706.23	798.75	877.47	956.84
IS43	Ambient	5.82	-74.81	-108.27	-100.80	-80.08	-43.24	-9.74	39.07	81.59	134.83	198.04
	Hot/Wet	-82.17	-147.59	-166.58	-150.01	-126.72	-92.15	-61.31	-3.76	43.10	104.63	163.71
	Cold	-137.10	-224.08	-238.99	-229.93	-199.37	-178.84	-131.13	-91.11	-30.98	15.43	75.13
IS44	Ambient	-16.97	59.31	123.60	187.62	246.43	305.13	353.65	405.80	452.81	500.45	551.51
	Hot/Wet	-22.04	50.50	113.57	176.85	235.64	289.90	337.98	392.10	440.67	490.57	538.63
	Cold	-95.01	-18.61	50.15	114.09	168.53	223.67	277.77	325.49	381.34	424.47	470.43
IS45	Ambient	-50.35	5.13	38.96	86.79	133.40	187.70	232.61	288.97	338.95	396.80	464.62
	Hot/Wet	-31.41	-3.24	27.48	73.74	119.21	166.84	208.84	271.11	323.97	387.77	449.57
	Cold	-119.98	-64.28	-20.21	27.77	76.92	122.81	180.39	229.53	295.99	348.34	410.72
S43	Ambient	8.72	233.14	409.14	539.57	656.93	754.27	841.90	932.94	1012.48	1093.54	1171.97
	Hot/Wet	46.51	243.82	391.95	513.74	622.63	716.69	803.41	887.63	969.93	1047.60	1127.92
	Cold	17.25	238.75	409.68	548.08	649.53	765.56	858.97	948.56	1041.05	1114.42	1193.02
S44	Ambient	55.68	-232.61	-449.27	-661.43	-855.92	-1038.63	-1196.84	-1345.27	-1489.25	-1620.50	-1752.54
	Hot/Wet	-286.47	-542.12	-740.98	-941.04	-1132.20	-1293.52	-1448.85	-1589.18	-1731.22	-1853.94	-1975.65
	Cold	-85.56	-387.33	-595.51	-807.82	-965.59	-1157.70	-1317.91	-1468.39	-1611.68	-1739.56	-1860.80
S45	Ambient	32.64	99.79	195.84	281.13	365.60	449.79	525.21	602.71	679.69	754.42	834.12
	Hot/Wet	6.43	99.09	190.55	277.30	363.33	443.30	521.91	598.91	677.67	754.14	833.60
	Cold	-53.39	10.53	101.56	187.87	260.14	348.19	425.25	502.48	583.59	653.88	728.10

Figure G-37. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 1)

Load Step	0	1	2	3	4	5	6	7	8	9	10	
Pressure	0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7	
HSF2	Ambient	-3.16	136.71	237.52	339.39	441.15	536.28	624.60	711.05	787.73	871.78	945.53
	Hot/Wet	-33.41	95.23	200.16	318.56	425.64	529.68	617.83	707.23	794.94	882.29	958.41
	Cold	-97.20	62.71	171.29	266.06	367.70	461.12	546.61	624.65	699.26	773.19	843.67
HAS	Ambient	-20.64	143.75	253.13	367.46	481.04	587.58	687.42	784.44	870.96	963.27	1046.98
	Hot/Wet	-50.49	94.24	213.95	345.70	465.36	581.85	682.70	782.70	881.51	979.29	1067.46
	Cold	-95.45	89.63	207.67	314.78	429.12	530.79	626.60	714.02	799.36	881.69	960.40
IS43	Ambient	25.46	-82.92	-105.38	-101.05	-81.64	-51.16	-13.13	32.55	79.71	141.63	196.24
	Hot/Wet	-79.30	-147.87	-167.28	-154.49	-131.11	-92.55	-58.25	-7.84	43.46	103.38	154.20
	Cold	-71.28	-229.52	-234.55	-222.32	-208.38	-168.80	-125.73	-81.21	-32.04	21.36	80.04
IS44	Ambient	-20.07	62.22	123.21	184.04	243.22	299.27	352.14	404.16	450.92	502.08	548.79
	Hot/Wet	-33.91	42.61	104.10	169.80	228.73	286.15	335.99	386.66	436.17	486.33	531.58
	Cold	-109.95	-17.97	50.91	111.14	171.51	227.56	281.56	330.55	379.66	426.94	474.62
IS45	Ambient	-53.05	0.40	39.16	82.30	128.97	178.00	228.52	283.32	335.97	401.85	460.97
	Hot/Wet	-48.30	-12.42	15.33	63.42	110.25	163.89	208.47	264.47	321.36	384.12	439.23
	Cold	-152.60	-62.11	-16.84	30.31	76.35	132.12	185.93	238.94	294.50	353.44	414.41
S43	Ambient	-6.39	247.26	408.28	536.46	650.37	751.50	846.25	932.96	1012.46	1087.61	1169.70
	Hot/Wet	21.46	233.38	377.39	504.15	613.22	711.85	800.51	880.57	962.49	1040.64	1118.29
	Cold	-72.19	249.87	414.25	541.54	664.47	767.25	863.29	953.53	1035.07	1116.64	1194.48
S44	Ambient	80.55	-236.99	-435.01	-642.82	-841.83	-1025.53	-1191.74	-1348.54	-1485.34	-1619.10	-1744.54
	Hot/Wet	-238.94	-499.18	-697.52	-911.56	-1103.71	-1279.15	-1432.84	-1569.38	-1709.63	-1839.75	-1959.48
	Cold	-11.48	-383.37	-590.25	-773.80	-989.66	-1163.15	-1326.58	-1474.79	-1608.79	-1740.86	-1857.63
S45	Ambient	36.24	109.39	195.27	278.37	362.57	445.65	525.71	605.01	677.90	753.61	828.92
	Hot/Wet	7.38	100.11	189.01	276.54	361.70	445.25	523.62	598.26	676.26	752.52	829.86
	Cold	-40.7078	20.1685	105.06	184.129	272.523	353.144	432.491	509.901	584.094	658.96	732.408

Figure G-38. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 2)

Load Step	0	1	2	3	4	5	6	7	8	9	10	
Pressure	0.0	0.7	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7	
HSF2	Ambient	-2.20	130.54	239.94	348.50	445.79	539.53	628.50	706.55	791.82	871.45	947.49
	Hot/Wet	-36.04	86.39	210.68	318.60	426.38	525.72	618.13	707.36	801.53	880.27	960.25
	Cold	-98.08	68.89	174.27	258.93	369.68	453.29	552.40	627.26	702.67	775.80	849.58
HAS	Ambient	-20.16	135.52	255.04	375.92	484.54	589.93	689.98	780.04	874.57	963.08	1048.93
	Hot/Wet	-53.03	84.11	223.98	345.69	465.62	576.94	681.04	782.58	888.50	976.86	1068.29
	Cold	-93.63	96.35	212.36	307.01	430.35	524.19	633.04	717.13	800.33	883.88	967.92
IS43	Ambient	25.49	-68.84	-103.31	-94.10	-73.73	-44.50	-3.97	31.14	85.66	142.78	199.11
	Hot/Wet	-82.30	-142.27	-169.00	-159.54	-131.35	-95.84	-53.91	-12.26	42.37	99.31	155.07
	Cold	-72.72	-227.18	-238.75	-224.72	-200.58	-176.21	-123.97	-79.28	-25.76	24.88	84.55
IS44	Ambient	-20.22	59.00	124.35	188.05	245.27	300.15	354.28	401.46	453.09	502.28	549.94
	Hot/Wet	-36.97	36.07	105.95	167.01	226.75	281.69	334.04	383.93	437.25	483.18	531.02
	Cold	-109.50	-16.75	50.68	106.96	172.03	223.80	284.59	331.44	381.29	427.93	477.87
IS45	Ambient	-51.78	2.49	41.34	90.61	135.17	182.70	235.12	280.47	340.95	402.38	463.47
	Hot/Wet	-56.81	-21.23	17.48	57.84	108.07	157.97	209.53	260.37	322.20	380.14	439.37
	Cold	-152.37	-60.16	-15.74	23.48	78.87	123.03	189.72	242.14	299.46	356.02	420.73
S43	Ambient	-7.07	231.83	409.85	538.28	649.08	748.30	844.27	926.41	1011.25	1091.66	1170.56
	Hot/Wet	18.89	214.57	381.22	502.26	609.10	704.12	790.61	876.92	964.56	1035.66	1115.05
	Cold	-72.39	247.73	416.18	534.78	664.60	766.75	871.17	952.25	1034.86	1116.48	1201.98
S44	Ambient	79.86	-211.68	-436.90	-650.33	-840.31	-1020.22	-1182.24	-1338.39	-1483.89	-1615.84	-1744.17
	Hot/Wet	-226.68	-457.82	-704.96	-906.64	-1094.40	-1263.50	-1415.00	-1567.52	-1719.37	-1826.73	-1947.36
	Cold	-12.13	-394.79	-600.54	-765.42	-985.73	-1159.58	-1337.01	-1472.65	-1604.42	-1742.48	-1870.05
S45	Ambient	35.50	105.84	195.33	280.03	362.49	443.27	523.29	600.86	678.61	753.07	829.43
	Hot/Wet	14.42	97.88	193.02	278.57	362.96	443.02	520.42	600.05	683.49	752.85	831.31
	Cold	-38.6414	17.9369	107.39	182.683	273.008	354.533	439.576	512.35	586.343	661.545	739.857

Figure G-39. Raw strain gauge data at three environmental conditions at 80,000 cycles (run 3)

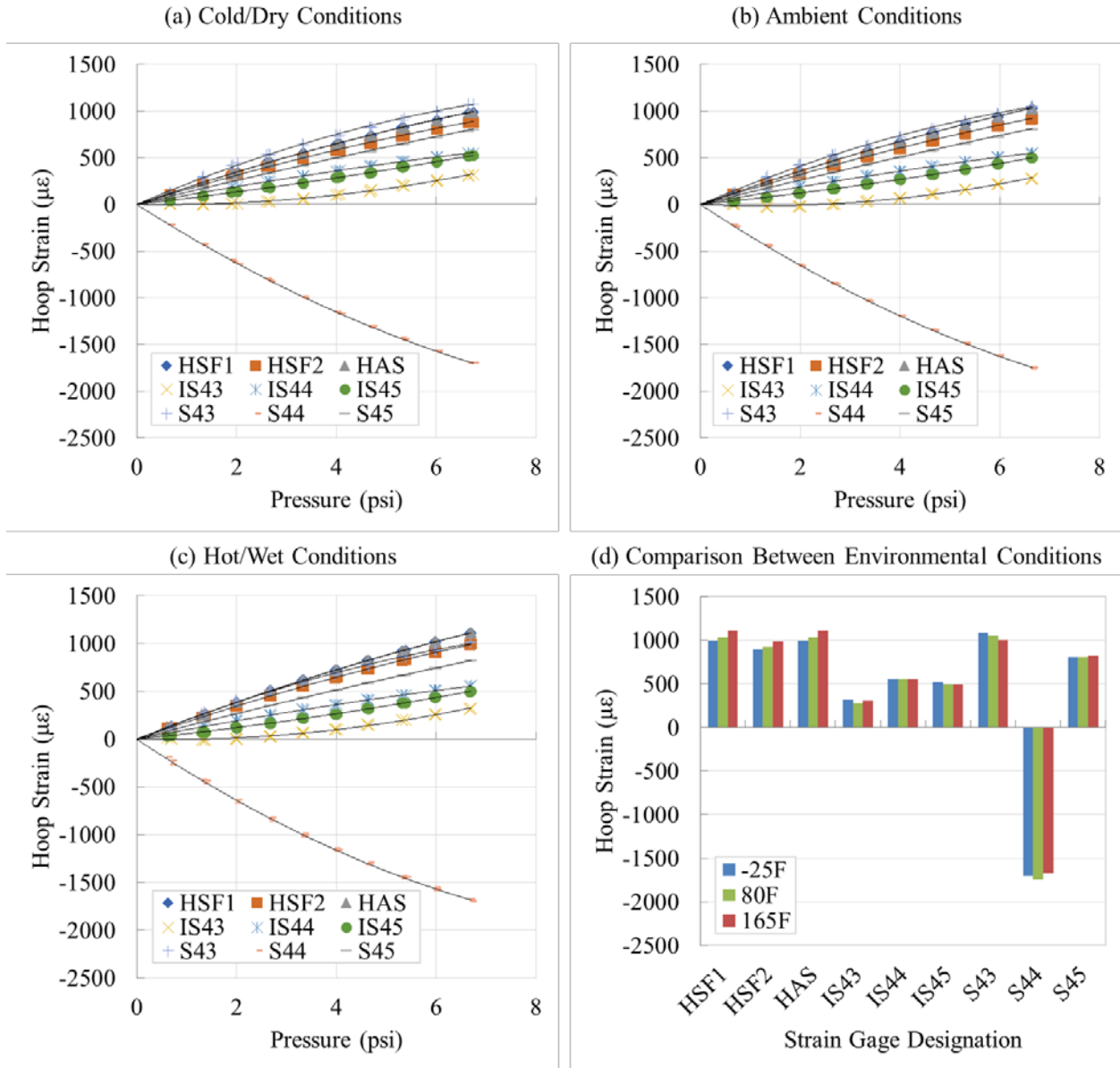


Figure G-40. Strain gauge measurements at 80,000 cycles at (a) cold-dry (-25°F) environmental conditions, (b) ambient environmental conditions, (c) hot-wet (165°F and 85% RH) environmental conditions, and (d) comparison of three environmental conditions at maximum strain survey loads

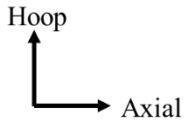
APPENDIX H—DIGITAL IMAGE CORRELATION RESULTS

During the strain survey, the digital image correlation (DIC) surveys were also conducted during all test phases. The color fringe pattern of each figure in this appendix shows the full-field hoop strain measurement around the patch area. The accompanying plots show the value of hoop strains along the vertical sections drawn in the figures. All the measurements were obtained at the maximum loading conditions (75% SL), as listed in table H-1.

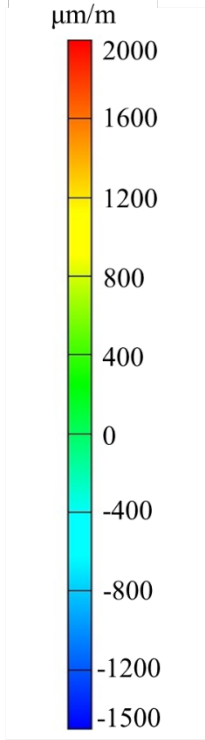
Table H-1. Loading conditions during DIC strain survey

Phases	Maximum Mechanical Load				Environmental Load	
	Pressure (psi)	Hoop (lb)	Axial (lb)	Frame (lb)	Temperature	Humidity
Baseline	6.7	7140	1133	6675	Ambient	
Hot–Wet	6.7	7140	1133	6675		
Cold–Dry	6.7	7140	1133	6675		

Type 1 Aluminum
Repair Patch, RA



Strain Survey Loads
Pressure: 6.675 psi
Hoop: 7140 lb
Axial 6675 lb
Frame 1132.5 lb



— Section 1
- - Section 2
⋯ Section 3

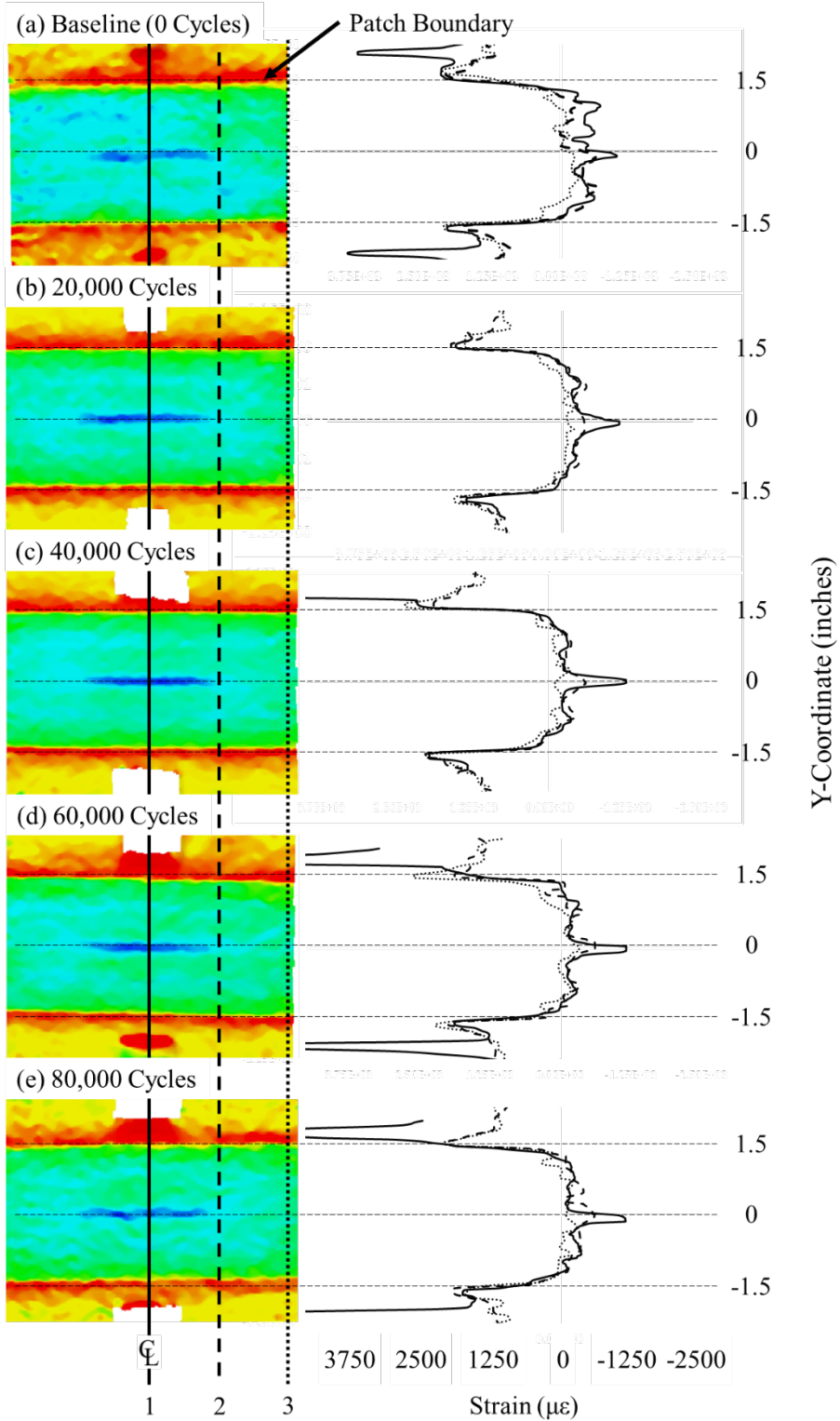


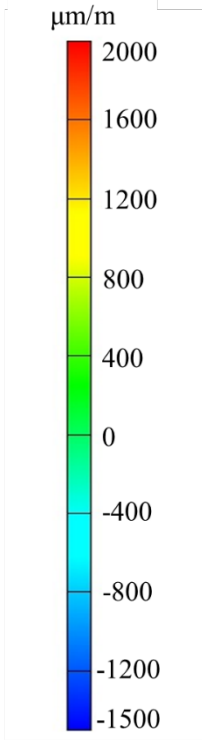
Figure H-1. The DIC results for the RA repair at (a) 0, (b) 20,000, (c) 40,000, (d) 60,000, and (e) 80,000 cycles

Type I B/Ep
Repair Patch, RB

Hoop
Axial

Strain Survey Loads

Pressure: 6.675 psi
Hoop: 7140 lb
Axial 6675 lb
Frame 1132.5 lb



— Section 1
- - Section 2
... Section 3

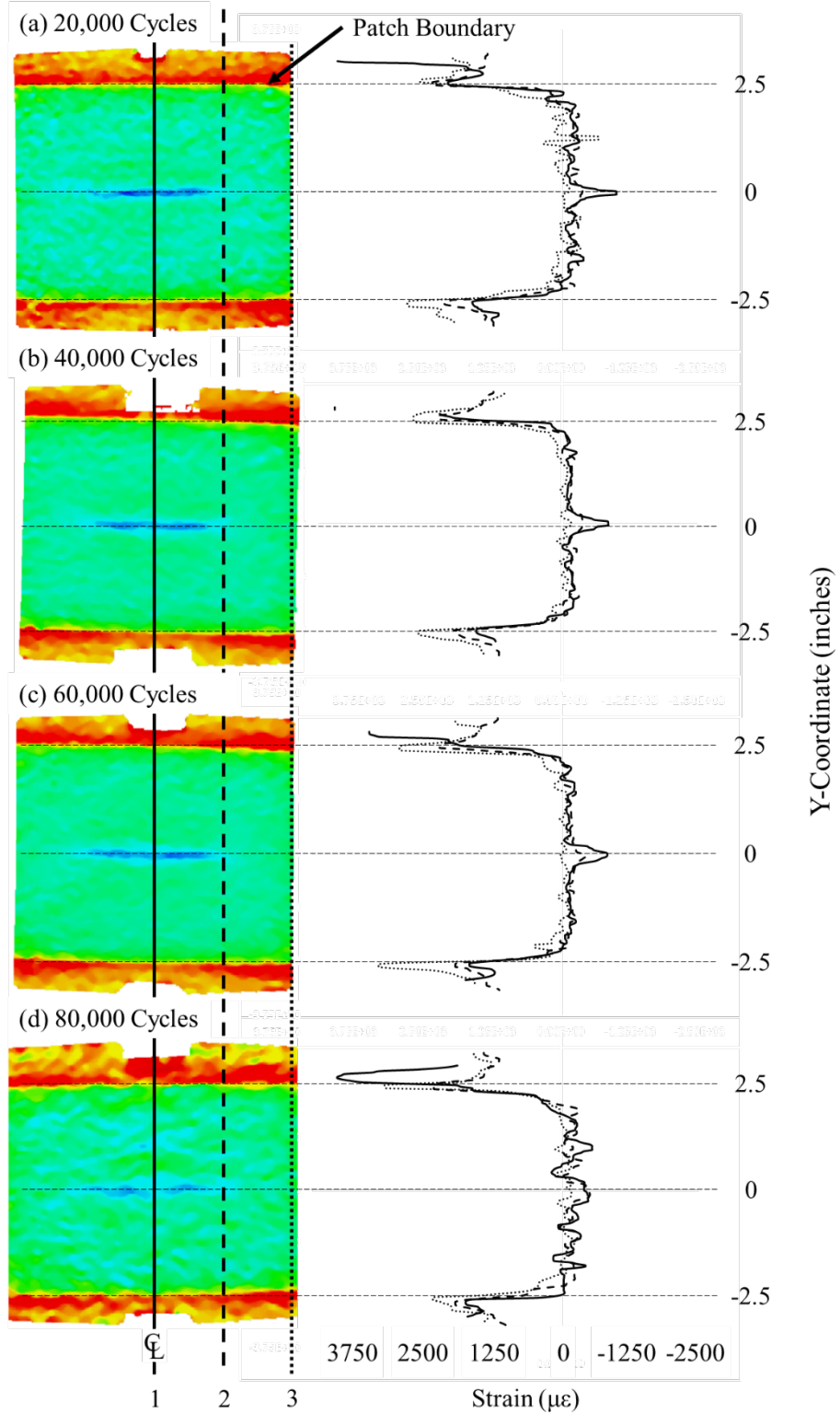
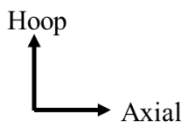
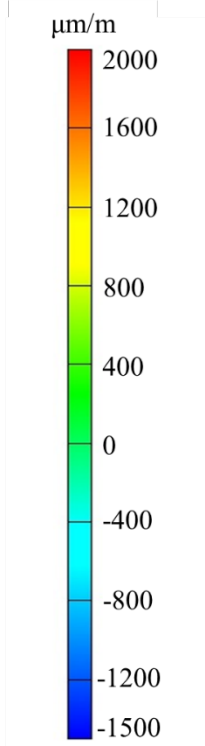


Figure H-2. The DIC results for the RB repair at (a) 20,000, (b) 40,000, (c) 60,000, and (d) 80,000 cycles (Note: the data at 0 cycles was unavailable because of a damaged file)

Type 2 Aluminum
Repair Patch, UA



Strain Survey Loads
 Pressure: 6.675 psi
 Hoop: 7140 lb
 Axial 6675 lb
 Frame 1132.5 lb



— Section 1
 - - Section 2
 ···· Section 3

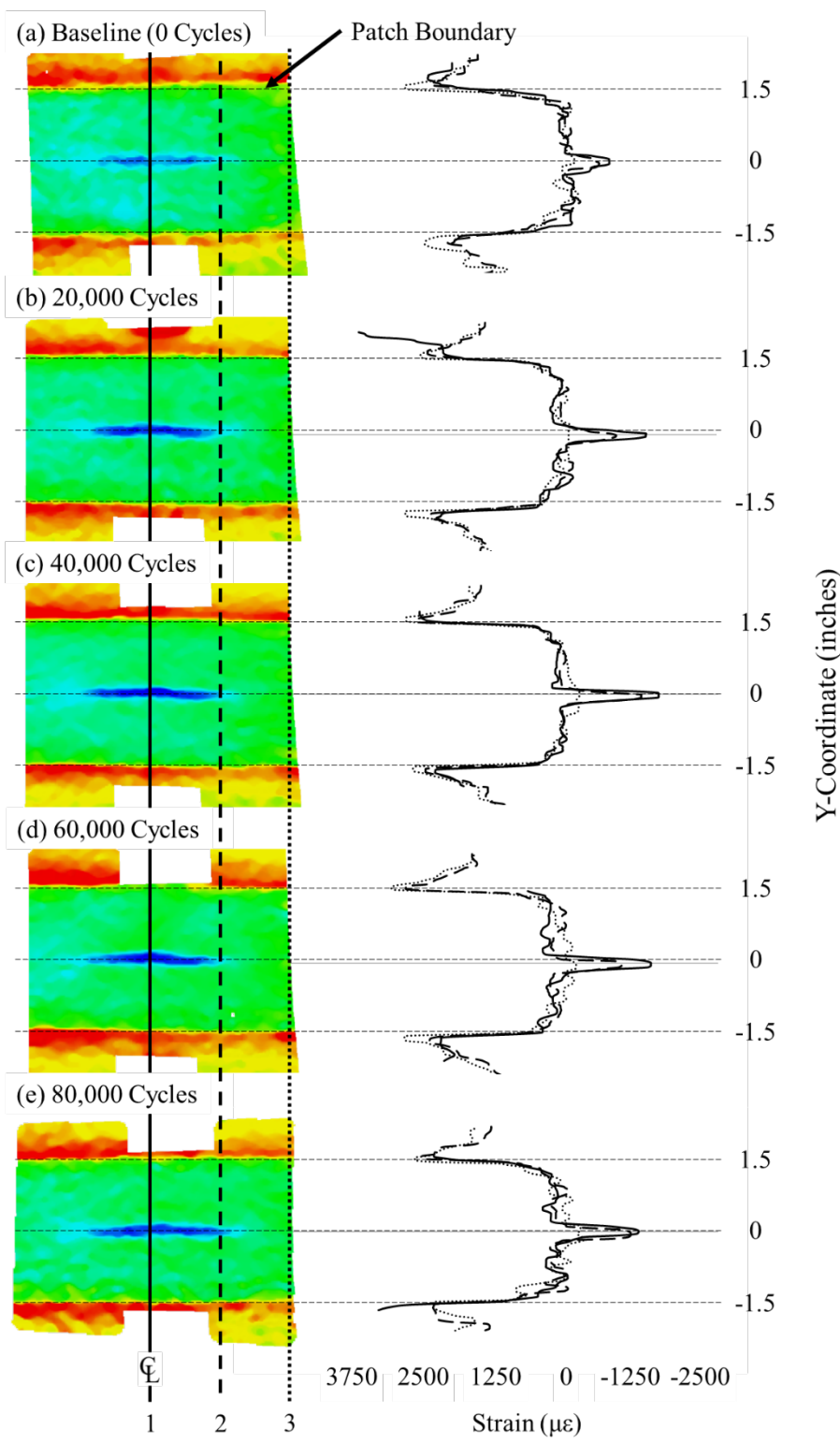


Figure H-3. The DIC results for the UA repair at (a) 0, (b) 20,000, (c) 40,000, (d) 60,000, and (e) 80,000 cycles

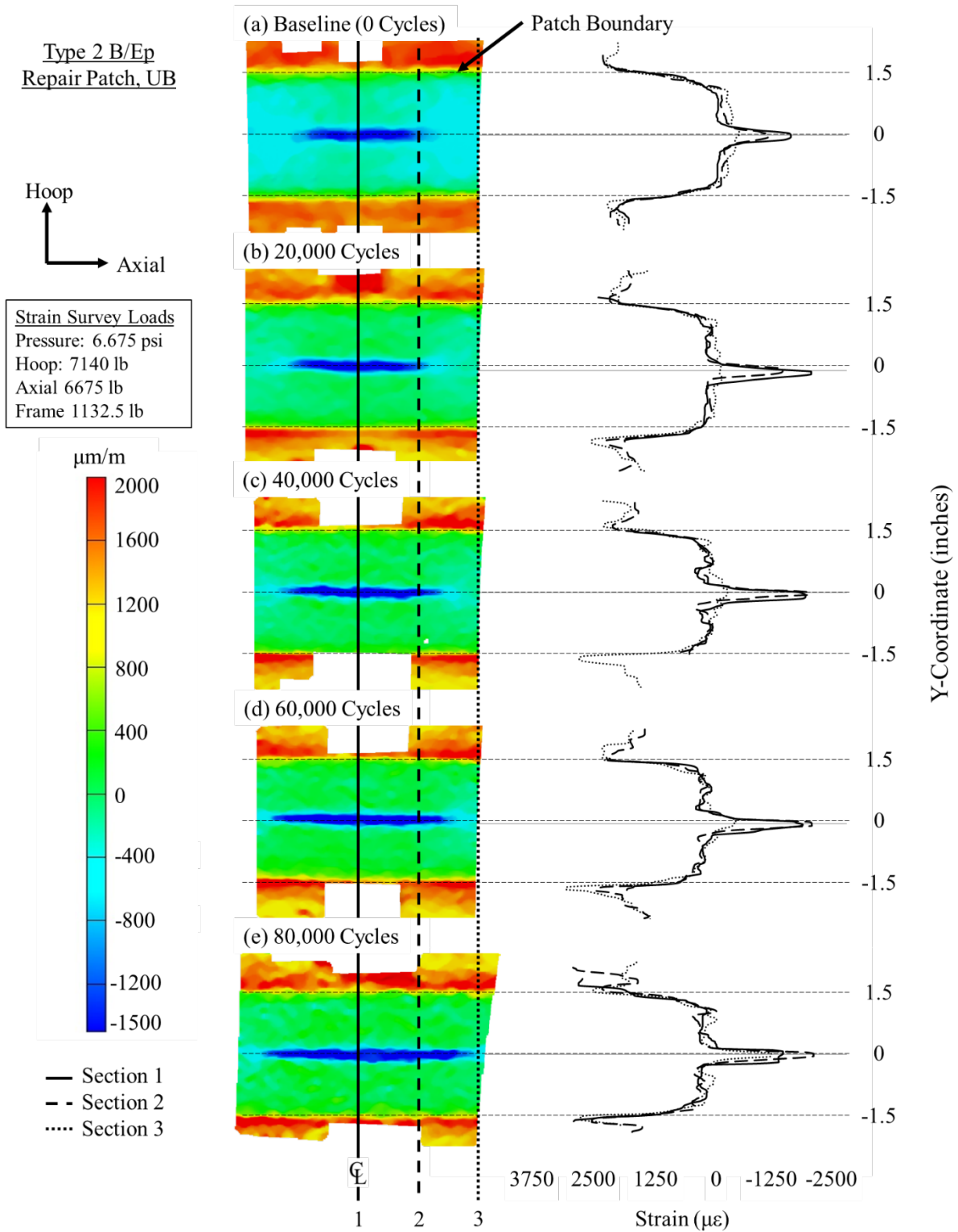


Figure H-4. The DIC results for the UB repair at (a) 0, (b) 20,000, (c) 40,000, (d) 60,000, and (e) 80,000 cycles

Type 3 Aluminum
Repair Patch, UDA

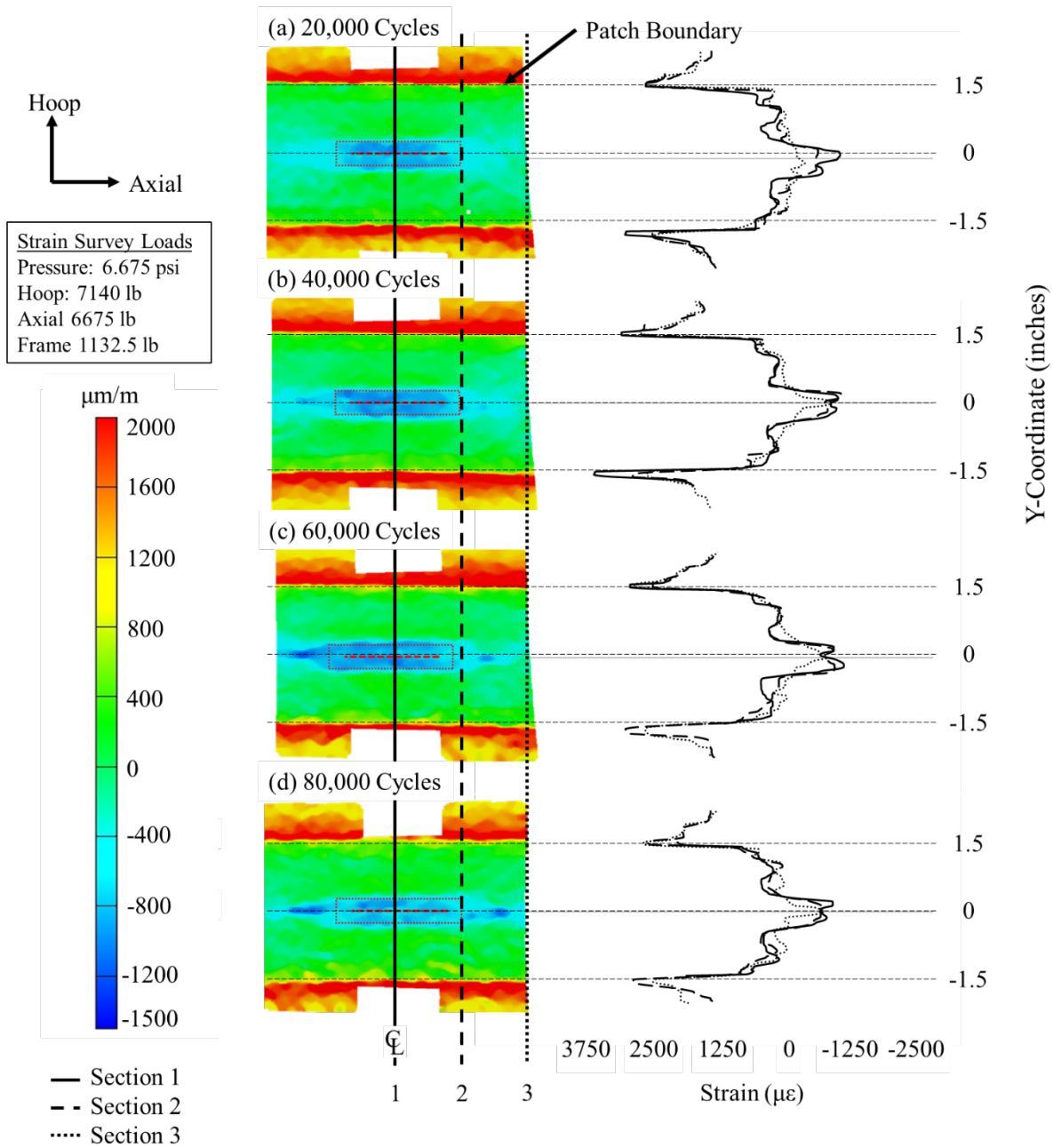


Figure H-5. The DIC results for the UDA repair at (a) 20,000, (b) 40,000, (c) 60,000, and (d) 80,000 cycles (Note: the data at 0 cycles was unavailable because of a damaged file)

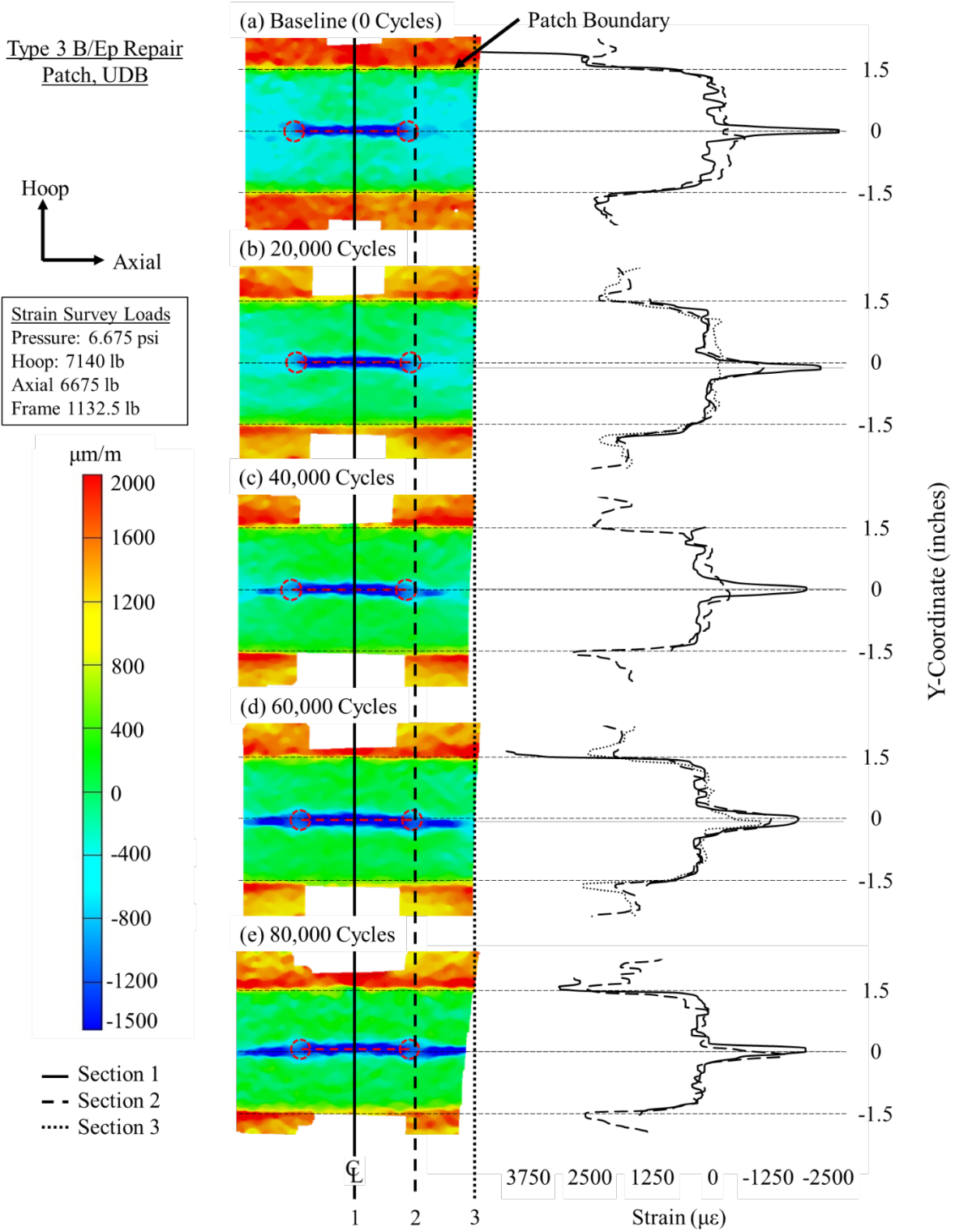
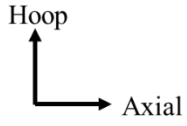


Figure H-6. The DIC results for the UDB repair at (a) 0, (b) 20,000, (c) 40,000, (d) 60,000, and (e) 80,000 cycles

Type 4 Aluminum
Repair Patch, HS



Strain Survey Loads
 Pressure: 6.675 psi
 Hoop: 7140 lb
 Axial 6675 lb
 Frame 1132.5 lb

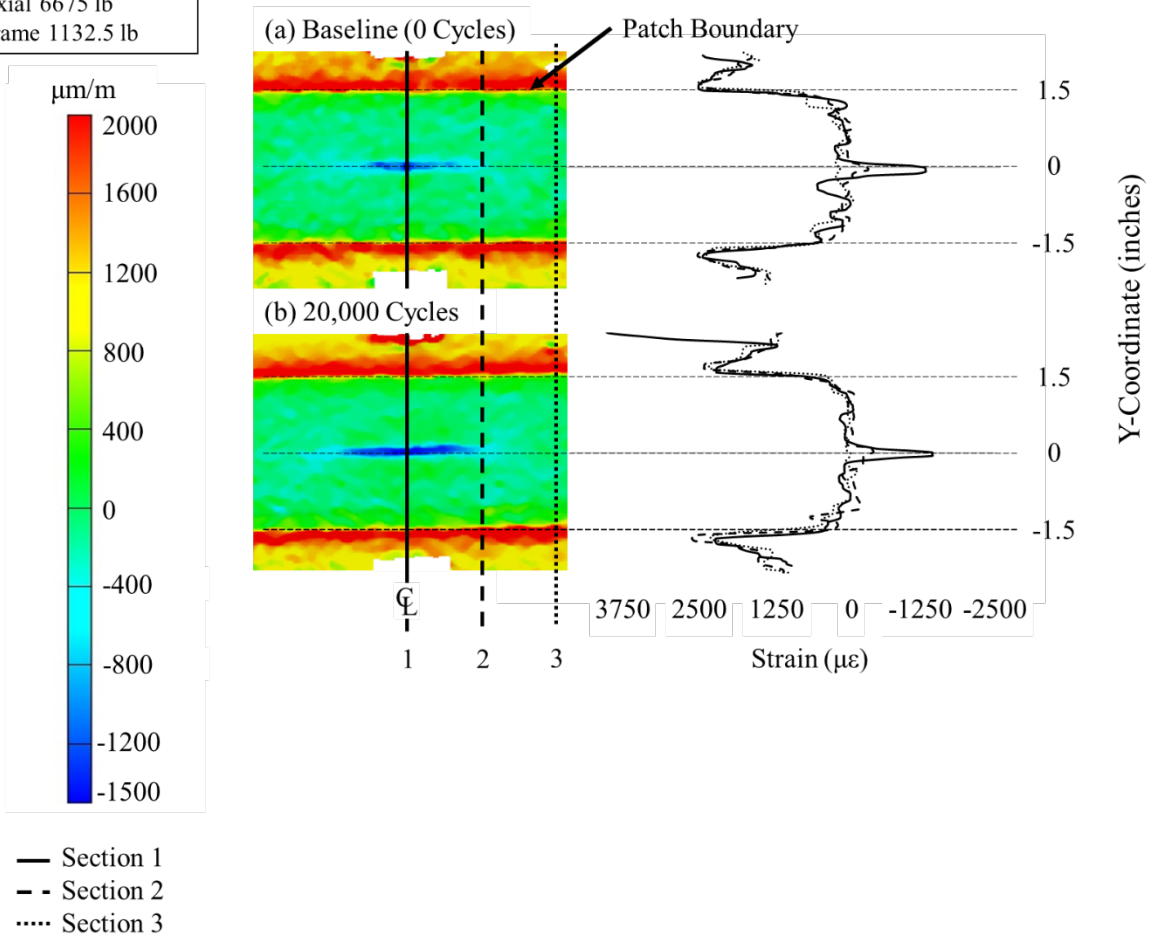


Figure H-7. The DIC results for the HS repair at (a) 0 and (b) 20,000 cycles

APPENDIX I—CRACK-GROWTH DATA

The initial notches introduced at various mid-bay locations of the panel were 2.8 inches in length ($2a = 2.8$ in). These notches were fatigue pre-sharpened using cyclic loads that were 75% of applied fatigue loads to extend the total crack length to approximately 3 inches. This appendix sums up the crack-growth data for all the notches during pre-cracking and during the fatigue tests after patch installations. The pre-cracking crack extension data were collected from the external surface of the panel using a remote-controlled crack monitoring system. During fatigue cycling, crack extension data were collected at intervals of 100, 200, or 500 cycles using the underwater camera system, which is reported as visual measurements in this appendix. The eddy current (EC) system was used every 5000 cycles to measure crack extension from the external surface of the patch and internal surface of the panel for composite repairs, and from the internal surface of the skin for the aluminum repairs. In this appendix, crack-growth data for all of the repairs during pre-cracking and fatigue tests are provided. These data are provided for forward (fwd) and aft half-crack lengths for pre-cracking, and for average half-crack length for fatigue stages.

In the figures representing pre-cracking crack-growth data, the closed and open circles represent visual measurements of the fwd and aft side of the notch, respectively. During fatigue, a solid line shows the visual measurements, the open circle shows the internal high-frequency EC results, and the open square shows the external low-frequency EC results.

REFERENCE REPAIRS

Reference aluminum and boron epoxy (B/Ep) repairs were subjected to hot-wet conditions to 80,000 cycles and to cold-dry conditions to 20,000 cycles.

REFERENCE ALUMINUM REPAIR (RA)

Table I-1 provides the half-crack length data of RA repair during pre-cracking. Figure I-1 shows the corresponding half-crack length as a function of fatigue cycles. Figure I-2 provides the half-crack length data during fatigue cycling. Figure I-3a shows the fwd and aft half-crack length, and figure I-3b shows averaged half-crack length as a function of fatigue cycles.

Table I-1. Half-crack length during pre-cracking for the RA repair (tabular)

Cycles	Visual	
	a _{AFT} (in.)	a _{FWD} (in.)
250	1.422	1.400
400	1.425	1.400
600	1.450	1.440
700	1.450	1.440
900	1.460	1.440
1000	1.460	1.440
1100	1.470	1.450
1200	1.490	1.450
1400	1.500	1.470

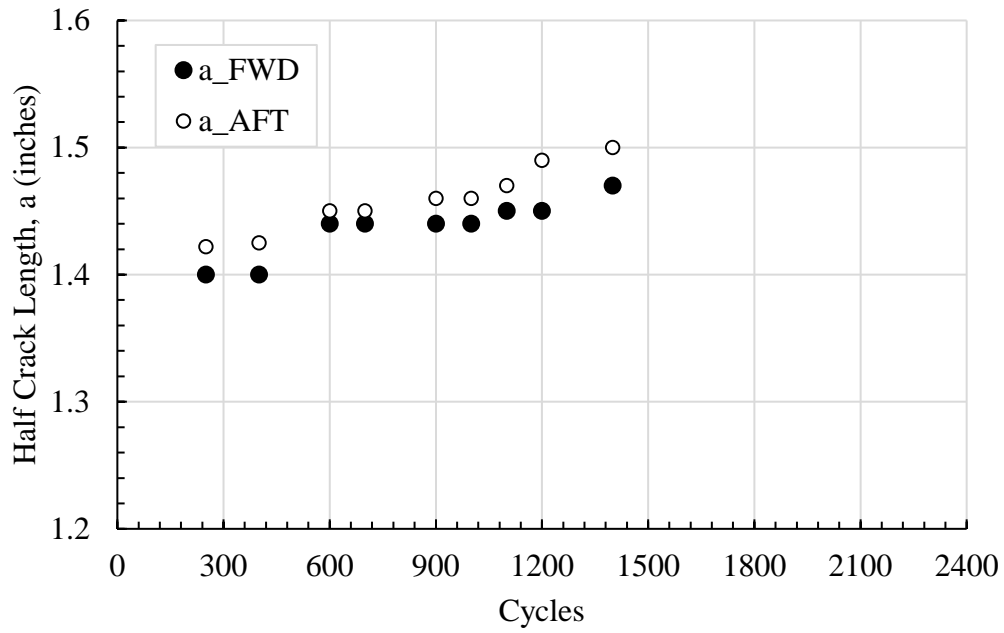


Figure I-1. Half-crack length during pre-cracking for the RA repair

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
0	1.525	1.475	1.5	1.5	1.55	1.525	1.48	1.52	1.5
1000	1.5	1.5	1.5						
2000	1.5	1.5	1.5						
3000	1.5	1.5	1.5						
4000	1.5	1.5	1.5						
5000	1.5	1.5	1.5	1.5	1.55	1.525	1.4	1.45	1.425
5001	1.5	1.5	1.5						
5200	1.5	1.5	1.5						
5400	1.5	1.5	1.5						
5600	1.5	1.5	1.5						
5600	1.5	1.5	1.5						
6000	1.5	1.5	1.5						
6200	1.5	1.5	1.5						
6400	1.5	1.5	1.5						
6600	1.5	1.5	1.5						
6800	1.5	1.5	1.5						
7000	1.5	1.5	1.5						
7600	1.5	1.5	1.5						
7800	1.5	1.5	1.5						
8000	1.5	1.5	1.5						
8200	1.5	1.5	1.5						
8400	1.5	1.5	1.5						
8800	1.5	1.5	1.5						
9200	1.5	1.5	1.5						
8600	1.5	1.5	1.5						
9400	1.5	1.5	1.5						
9600	1.5	1.5	1.5						
9800	1.5	1.5	1.5						
10000	1.5	1.5	1.5	1.5	1.55	1.525	1.4	1.45	1.425
10200	1.5	1.5	1.5						
10400	1.5	1.5	1.5						
10600	1.5	1.5	1.5						
10800	1.5	1.5	1.5						
11000	1.5	1.5	1.5						
11200	1.5	1.5	1.5						
11600	1.5	1.5	1.5						
11800	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
12000	1.5	1.5	1.5						
12200	1.5	1.5	1.5						
12400	1.5	1.5	1.5						
11400	1.5	1.5	1.5						
12600	1.5	1.5	1.5						
12800	1.5	1.5	1.5						
13400	1.5	1.5	1.5						
13600	1.5	1.5	1.5						
13800	1.5	1.5	1.5						
14000	1.5	1.5	1.5						
14200	1.5	1.5	1.5						
14400	1.5	1.5	1.5						
14600	1.5	1.5	1.5						
14800	1.5	1.5	1.5						
15000	1.5	1.5	1.5	1.5	1.55	1.525	1.54	1.5	1.52
15200	1.5	1.5	1.5						
15400	1.5	1.5	1.5						
15600	1.5	1.5	1.5						
15800	1.5	1.5	1.5						
16000	1.5	1.5	1.5						
16200	1.5	1.5	1.5						
16400	1.5	1.5	1.5						
16600	1.5	1.5	1.5						
16800	1.5	1.5	1.5						
17000	1.5	1.5	1.5						
17200	1.5	1.5	1.5						
17400	1.5	1.5	1.5						
17600	1.5	1.5	1.5						
17800	1.5	1.5	1.5						
18000	1.5	1.5	1.5						
18200	1.5	1.5	1.5						
18400	1.5	1.5	1.5						
18600	1.5	1.5	1.5						
18800	1.5	1.5	1.5						
19000	1.5	1.5	1.5						
19200	1.5	1.5	1.5						
19400	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
19600	1.5	1.5	1.5						
19800	1.5	1.5	1.5						
20000	1.5	1.5	1.5	1.5	1.55	1.525	1.4	1.45	1.425
20200	1.5	1.5	1.5						
20400	1.5	1.5	1.5						
20600	1.5	1.5	1.5						
20800	1.5	1.5	1.5						
21000	1.5	1.5	1.5						
21200	1.5	1.5	1.5						
21400	1.5	1.5	1.5						
21600	1.5	1.5	1.5						
21800	1.5	1.5	1.5						
22000	1.5	1.5	1.5						
22200	1.5	1.5	1.5						
22400	1.5	1.5	1.5						
22600	1.5	1.5	1.5						
22800	1.5	1.5	1.5						
23000	1.5	1.5	1.5						
23200	1.5	1.5	1.5						
23400	1.5	1.5	1.5						
23600	1.5	1.5	1.5						
23800	1.5	1.5	1.5						
24000	1.5	1.5	1.5						
24200	1.5	1.5	1.5						
24400	1.5	1.5	1.5						
24600	1.5	1.5	1.5						
24800	1.5	1.5	1.5						
25000	1.5	1.5	1.5	1.5	1.55	1.525	1.42	1.46	1.44
25200	1.5	1.5	1.5						
25400	1.5	1.5	1.5						
25600	1.5	1.5	1.5						
25800	1.5	1.5	1.5						
26000	1.5	1.5	1.5						
26200	1.5	1.5	1.5						
26400	1.5	1.5	1.5						
26600	1.5	1.5	1.5						
26800	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
27000	1.5	1.5	1.5						
27200	1.5	1.5	1.5						
27400	1.5	1.5	1.5						
27600	1.5	1.5	1.5						
27800	1.5	1.5	1.5						
28000	1.5	1.5	1.5						
28200	1.5	1.5	1.5						
28400	1.5	1.5	1.5						
28600	1.5	1.5	1.5						
28800	1.5	1.5	1.5						
29000	1.5	1.5	1.5						
29200	1.5	1.5	1.5						
29400	1.5	1.5	1.5						
29600	1.5	1.5	1.5						
29800	1.5	1.5	1.5						
30000	1.5	1.5	1.5	1.5	1.55	1.525	1.42	1.45	1.435
30200	1.5	1.5	1.5						
30400	1.5	1.5	1.5						
30600	1.5	1.5	1.5						
30800	1.5	1.5	1.5						
31000	1.5	1.5	1.5						
31200	1.5	1.5	1.5						
31400	1.5	1.5	1.5						
31600	1.5	1.5	1.5						
31800	1.5	1.5	1.5						
32000	1.5	1.5	1.5						
32200	1.5	1.5	1.5						
32400	1.5	1.5	1.5						
32600	1.5	1.5	1.5						
32800	1.5	1.5	1.5						
33000	1.5	1.5	1.5						
33200	1.5	1.5	1.5						
33400	1.5	1.5	1.5						
33600	1.5	1.5	1.5						
33800	1.5	1.5	1.5						
34000	1.5	1.5	1.5						
34200	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
34400	1.5	1.5	1.5						
34600	1.5	1.5	1.5						
34800	1.5	1.5	1.5						
35000	1.5	1.5	1.5						
35200	1.5	1.5	1.5						
35400	1.5	1.5	1.5						
35600	1.5	1.5	1.5						
35800	1.5	1.5	1.5						
36000	1.5	1.5	1.5						
36200	1.5	1.5	1.5						
36400	1.5	1.5	1.5						
36600	1.5	1.5	1.5						
36800	1.5	1.5	1.5						
37000	1.5	1.5	1.5						
37200	1.5	1.5	1.5						
37400	1.5	1.5	1.5						
37600	1.5	1.5	1.5						
37800	1.5	1.5	1.5						
38000	1.5	1.5	1.5						
38200	1.5	1.5	1.5						
38400	1.5	1.5	1.5						
38600	1.5	1.5	1.5						
38800	1.5	1.5	1.5						
39000	1.5	1.5	1.5						
39200	1.5	1.5	1.5						
39400	1.5	1.5	1.5						
39600	1.5	1.5	1.5						
39800	1.5	1.5	1.5						
40000	1.5	1.5	1.5	1.55	1.55	1.55	1.42	1.5	1.46
40200	1.5	1.5	1.5						
40400	1.5	1.5	1.5						
40600	1.5	1.5	1.5						
40800	1.5	1.5	1.5						
41000	1.5	1.5	1.5						
41200	1.5	1.5	1.5						
41400	1.5	1.5	1.5						
41600	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
41800	1.5	1.5	1.5						
42000	1.5	1.5	1.5						
42200	1.5	1.5	1.5						
42400	1.5	1.5	1.5						
42600	1.5	1.5	1.5						
42800	1.5	1.5	1.5						
43000	1.5	1.5	1.5						
43200	1.5	1.5	1.5						
43400	1.5	1.5	1.5						
43600	1.5	1.5	1.5						
43800	1.5	1.5	1.5						
44000	1.5	1.5	1.5						
44200	1.5	1.5	1.5						
44400	1.5	1.5	1.5						
44600	1.5	1.5	1.5						
44800	1.5	1.5	1.5						
45000	1.5	1.5	1.5						
45200	1.5	1.5	1.5						
45400	1.5	1.5	1.5						
45600	1.5	1.5	1.5						
45800	1.5	1.5	1.5						
46000	1.5	1.5	1.5						
46200	1.5	1.5	1.5						
46400	1.5	1.5	1.5						
46600	1.5	1.5	1.5						
46800	1.5	1.5	1.5						
47000	1.5	1.5	1.5						
47200	1.5	1.5	1.5						
47400	1.5	1.5	1.5						
47600	1.5	1.5	1.5						
47800	1.5	1.5	1.5						
48000	1.5	1.5	1.5						
48200	1.5	1.5	1.5						
48400	1.5	1.5	1.5						
48600	1.5	1.5	1.5						
48800	1.5	1.5	1.5						
49000	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
49200	1.5	1.5	1.5						
49400	1.5	1.5	1.5						
49600	1.5	1.5	1.5						
49800	1.5	1.5	1.5						
50000	1.5	1.5	1.5	1.55	1.55	1.55	1.43	1.44	1.435
50200	1.5	1.5	1.5						
50400	1.5	1.5	1.5						
50600	1.5	1.5	1.5						
50800	1.5	1.5	1.5						
51000	1.5	1.5	1.5						
51200	1.5	1.5	1.5						
51400	1.5	1.5	1.5						
51600	1.5	1.5	1.5						
51800	1.5	1.5	1.5						
52000	1.5	1.5	1.5						
52200	1.5	1.5	1.5						
52400	1.5	1.5	1.5						
52600	1.5	1.5	1.5						
52800	1.5	1.5	1.5						
53000	1.5	1.5	1.5						
53200	1.5	1.5	1.5						
53400	1.5	1.5	1.5						
53600	1.5	1.5	1.5						
53800	1.5	1.5	1.5						
54000	1.5	1.5	1.5						
54200	1.5	1.5	1.5						
54400	1.5	1.5	1.5						
54600	1.5	1.5	1.5						
54800	1.5	1.5	1.5						
55000	1.5	1.5	1.5						
55200	1.5	1.5	1.5						
55400	1.5	1.5	1.5						
55600	1.5	1.5	1.5						
55800	1.5	1.5	1.5						
56000	1.5	1.5	1.5						
56200	1.5	1.5	1.5						
56400	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
56600	1.5	1.5	1.5						
56800	1.5	1.5	1.5						
57000	1.5	1.5	1.5						
57200	1.5	1.5	1.5						
57400	1.5	1.5	1.5						
57600	1.5	1.5	1.5						
57800	1.5	1.5	1.5						
58000	1.5	1.5	1.5						
58200	1.5	1.5	1.5						
58400	1.5	1.5	1.5						
58600	1.5	1.5	1.5						
58800	1.5	1.5	1.5						
59000	1.5	1.5	1.5						
59200	1.5	1.5	1.5						
59400	1.5	1.5	1.5						
59600	1.5	1.5	1.5						
59800	1.5	1.5	1.5						
60000	1.5	1.5	1.5	1.55	1.55	1.55	1.43	1.43	1.43
60100	1.5	1.5	1.5						
60200	1.5	1.5	1.5						
60400	1.5	1.5	1.5						
60600	1.5	1.5	1.5						
61000	1.5	1.5	1.5						
61200	1.5	1.5	1.5						
61400	1.5	1.5	1.5						
61600	1.5	1.5	1.5						
61800	1.5	1.5	1.5						
62600	1.5	1.5	1.5						
63000	1.5	1.5	1.5						
63400	1.5	1.5	1.5						
63800	1.5	1.5	1.5						
64000	1.5	1.5	1.5						
64400	1.5	1.5	1.5						
64800	1.5	1.5	1.5						
65000	1.5	1.5	1.5						
65400	1.5	1.5	1.5						
65800	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
66000	1.5	1.5	1.5						
66400	1.5	1.5	1.5						
66800	1.5	1.5	1.5						
67000	1.5	1.5	1.5						
67400	1.5	1.5	1.5						
67800	1.5	1.5	1.5						
68000	1.5	1.5	1.5						
68400	1.5	1.5	1.5						
68800	1.5	1.5	1.5						
69200	1.5	1.5	1.5						
69600	1.5	1.5	1.5						
70000	1.5	1.5	1.5						
70400	1.5	1.5	1.5						
70800	1.5	1.5	1.5						
71400	1.5	1.5	1.5						
71800	1.5	1.5	1.5						
72400	1.5	1.5	1.5						
72800	1.5	1.5	1.5						
73400	1.5	1.5	1.5						
73800	1.5	1.5	1.5						
74400	1.5	1.5	1.5						
74800	1.5	1.5	1.5						
75400	1.5	1.5	1.5						
75800	1.5	1.5	1.5						
76400	1.5	1.5	1.5						
76800	1.5	1.5	1.5						
77200	1.5	1.5	1.5						
77600	1.5	1.5	1.5						
78000	1.5	1.5	1.5						
78400	1.5	1.5	1.5						
78800	1.5	1.5	1.5						
79200	1.5	1.5	1.5						
79600	1.5	1.5	1.5						
80000	1.5	1.5	1.5	1.575	1.55	1.5625	1.43	1.43	1.43
80100	1.5	1.5	1.5						
80400	1.5	1.5	1.5						
80600	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
80800	1.5	1.5	1.5						
81000	1.5	1.5	1.5						
81300	1.5	1.5	1.5						
81500	1.5	1.5	1.5						
81700	1.5	1.5	1.5						
82000	1.5	1.5	1.5						
82200	1.5	1.5	1.5						
82400	1.5	1.5	1.5						
82600	1.5	1.5	1.5						
82800	1.5	1.5	1.5						
83000	1.5	1.5	1.5						
83400	1.5	1.5	1.5						
83500	1.5	1.5	1.5						
83600	1.5	1.5	1.5						
83800	1.5	1.5	1.5						
84000	1.5	1.5	1.5						
84200	1.5	1.5	1.5						
84600	1.5	1.5	1.5						
84800	1.5	1.5	1.5						
84800	1.5	1.5	1.5						
85000	1.5	1.5	1.5						
85200	1.5	1.5	1.5						
85400	1.5	1.5	1.5						
85500	1.5	1.5	1.5						
85600	1.5	1.5	1.5						
85800	1.5	1.5	1.5						
86000	1.5	1.5	1.5						
86200	1.5	1.5	1.5						
86400	1.5	1.5	1.5						
86500	1.5	1.5	1.5						
86600	1.5	1.5	1.5						
86800	1.5	1.5	1.5						
87000	1.5	1.5	1.5						
87200	1.5	1.5	1.5						
87400	1.5	1.5	1.5						
87500	1.5	1.5	1.5						
87600	1.5	1.5	1.5						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
87800	1.5	1.5	1.5						
88000	1.5	1.5	1.5						
88200	1.5	1.5	1.5						
88400	1.5	1.5	1.5						
88500	1.5	1.5	1.5						
88600	1.5	1.5	1.5						
88800	1.5	1.5	1.5						
89000	1.5	1.5	1.5						
89200	1.5	1.5	1.5						
89400	1.5	1.5	1.5						
89600	1.5	1.5	1.5						
89800	1.5	1.5	1.5						
90000	1.5	1.5	1.5	1.5375	1.55	1.54375	1.45	1.45	1.45

Figure I-2. Half-crack length data during fatigue for the RA repair (tabular)

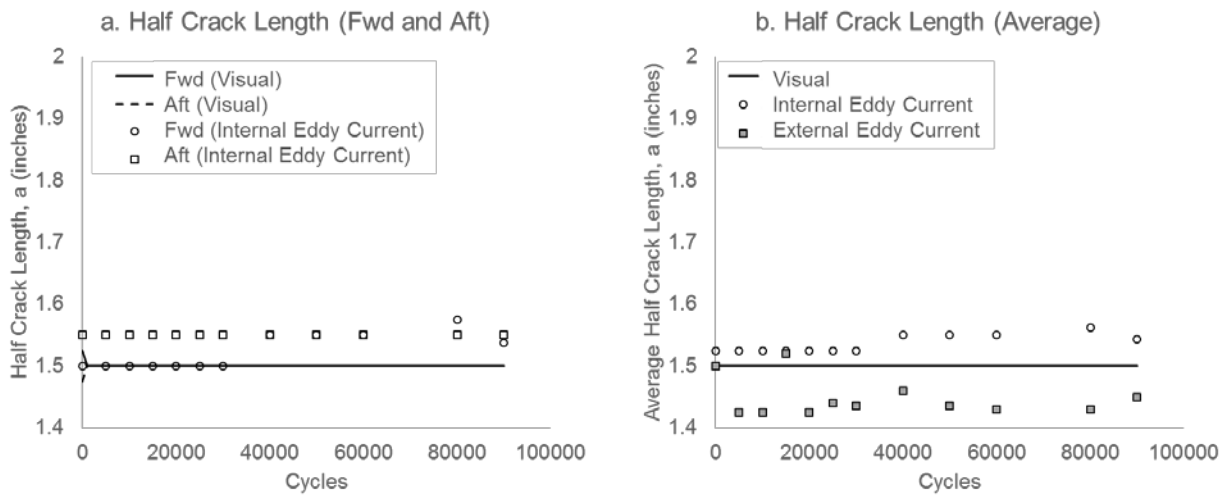


Figure I-3. The RA repair crack-growth data during fatigue (90,000 cycles): (a) forward and aft half-crack length and (b) average half-crack length

REFERENCE B/EP REPAIRS (RB)

Table I-2 provides the half-crack length data of RB repair during pre-cracking. Figure I-4 shows the corresponding half-crack length as a function of fatigue cycles. Figure I-5 provides the half-crack length data during fatigue cycling. Figure I-6a shows the fwd and aft half-crack length, and figure I-6b shows the averaged half-crack length as a function of fatigue cycles.

Table I-2. Half-crack length during pre-cracking for the RB repair (tabular)

Cycles	Visual	
	a _{AFT} (in.)	a _{FWD} (in.)
250	1.400	1.400
400	1.425	1.400
600	1.425	1.425
700	1.425	1.425
900	1.450	1.450
1000	1.450	1.450
1100	1.450	1.460
1200	1.450	1.470
1400	1.460	1.480

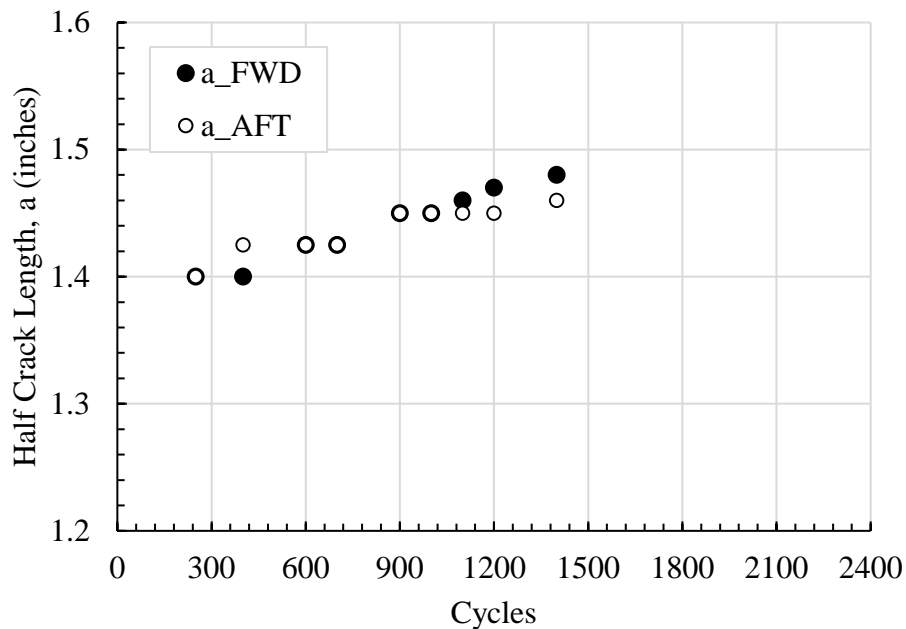


Figure I-4. Half-crack length during pre-cracking for the RB repair

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
0	1.5	1.525	1.5125	1.5	1.525	1.5125	1.5	1.4	1.45
1000	1.5	1.525	1.5125						
2000	1.5	1.525	1.5125						
3000	1.5	1.525	1.5125						
4000	1.5	1.525	1.5125						
5000	1.5	1.525	1.5125	1.55	1.525	1.5375	1.5	1.45	1.475
5001	1.5	1.525	1.5125						
5200	1.5	1.525	1.5125						
5400	1.5	1.525	1.5125						
5600	1.5	1.525	1.5125						
5600	1.5	1.525	1.5125						
6000	1.5	1.525	1.5125						
6200	1.5	1.525	1.5125						
6400	1.5	1.525	1.5125						
6600	1.5	1.525	1.5125						
6800	1.5	1.525	1.5125						
7000	1.5	1.525	1.5125						
7600	1.5	1.525	1.5125						
7800	1.5	1.525	1.5125						
8000	1.5	1.525	1.5125						
8200	1.5	1.525	1.5125						
8400	1.5	1.525	1.5125						
8800	1.5	1.525	1.5125						
9200	1.5	1.525	1.5125						
8600	1.5	1.525	1.5125						
9400	1.5	1.525	1.5125						
9600	1.5	1.525	1.5125						
9800	1.5	1.525	1.5125						
10000	1.5	1.525	1.5125	1.55	1.55	1.55	1.5	1.45	1.475
10200	1.5	1.525	1.5125						
10400	1.5	1.525	1.5125						
10600	1.5	1.525	1.5125						
10800	1.5	1.525	1.5125						
11000	1.5	1.525	1.5125						
11200	1.5	1.525	1.5125						
11600	1.5	1.525	1.5125						
11800	1.5	1.525	1.5125						
12000	1.5	1.525	1.5125						
12200	1.5	1.525	1.5125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
12400	1.5	1.525	1.5125						
11400	1.5	1.525	1.5125						
12600	1.5	1.525	1.5125						
12800	1.5	1.525	1.5125						
13400	1.5	1.525	1.5125						
13600	1.5	1.525	1.5125						
13800	1.5	1.525	1.5125						
14000	1.5	1.525	1.5125						
14200	1.5	1.525	1.5125						
14400	1.5	1.525	1.5125						
14600	1.5	1.525	1.5125						
14800	1.5	1.525	1.5125						
15000	1.5	1.525	1.5125	1.55	1.55	1.55	1.64	1.5	1.57
15200	1.5	1.525	1.5125						
15400	1.5	1.525	1.5125						
15600	1.5	1.525	1.5125						
15800	1.5	1.525	1.5125						
16000	1.5	1.525	1.5125						
16200	1.5	1.525	1.5125						
16400	1.5	1.525	1.5125						
16600	1.5	1.525	1.5125						
16800	1.5	1.525	1.5125						
17000	1.5	1.525	1.5125						
17200	1.5	1.525	1.5125						
17400	1.5	1.525	1.5125						
17600	1.5	1.525	1.5125						
17800	1.5	1.525	1.5125						
18000	1.5	1.525	1.5125						
18200	1.5	1.525	1.5125						
18400	1.5	1.525	1.5125						
18600	1.5	1.525	1.5125						
18800	1.5	1.525	1.5125						
19000	1.5	1.525	1.5125						
19200	1.5	1.525	1.5125						
19400	1.5	1.525	1.5125						
19600	1.5	1.525	1.5125						
19800	1.5	1.525	1.5125						
20000	1.5	1.525	1.5125	1.55	1.55	1.55	1.5	1.45	1.475
20200	1.5	1.525	1.5125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
20400	1.5	1.525	1.5125						
20600	1.5	1.525	1.5125						
20800	1.5	1.525	1.5125						
21000	1.5	1.525	1.5125						
21200	1.5	1.525	1.5125						
21400	1.5	1.525	1.5125						
21600	1.5	1.525	1.5125						
21800	1.5	1.525	1.5125						
22000	1.5	1.525	1.5125						
22200	1.5	1.525	1.5125						
22400	1.5	1.525	1.5125						
22600	1.5	1.525	1.5125						
22800	1.5	1.525	1.5125						
23000	1.5	1.525	1.5125						
23200	1.5	1.525	1.5125						
23400	1.5	1.525	1.5125						
23600	1.5	1.525	1.5125						
23800	1.5	1.525	1.5125						
24000	1.5	1.525	1.5125						
24200	1.5	1.525	1.5125						
24400	1.5	1.525	1.5125						
24600	1.5	1.525	1.5125						
24800	1.5	1.525	1.5125						
25000	1.5	1.525	1.5125	1.55	1.55	1.55	1.5	1.45	1.475
25200	1.5	1.525	1.5125						
25400	1.5	1.525	1.5125						
25600	1.5	1.525	1.5125						
25800	1.5	1.525	1.5125						
26000	1.5	1.525	1.5125						
26200	1.5	1.525	1.5125						
26400	1.5	1.525	1.5125						
26600	1.5	1.55	1.525						
26800	1.5	1.525	1.5125						
27000	1.5	1.55	1.525						
27200	1.5	1.55	1.525						
27400	1.5	1.55	1.525						
27600	1.5	1.55	1.525						
27800	1.5	1.55	1.525						
28000	1.5	1.55	1.525						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
28200	1.5	1.55	1.525						
28400	1.5	1.55	1.525						
28600	1.5	1.55	1.525						
28800	1.5	1.55	1.525						
29000	1.5	1.55	1.525						
29200	1.5	1.55	1.525						
29400	1.5	1.55	1.525						
29600	1.5	1.55	1.525						
29800	1.5	1.55	1.525						
30000	1.5	1.55	1.525	1.55	1.55	1.55	1.55	1.45	1.5
30200	1.5	1.55	1.525						
30400	1.5	1.55	1.525						
30600	1.5	1.55	1.525						
30800	1.5	1.55	1.525						
31000	1.5	1.55	1.525						
31200	1.5	1.55	1.525						
31400	1.5	1.55	1.525						
31600	1.5	1.55	1.525						
31800	1.5	1.55	1.525						
32000	1.5	1.55	1.525						
32200	1.5	1.55	1.525						
32400	1.5	1.5	1.5						
32600	1.5	1.5	1.5						
32800	1.5	1.5	1.5						
33000	1.5	1.55	1.525						
33200	1.5	1.55	1.525						
33400	1.5	1.5	1.5						
33600	1.5	1.5	1.5						
33800	1.5	1.55	1.525						
34000	1.5	1.55	1.525						
34200	1.5	1.55	1.525						
34400	1.5	1.55	1.525						
34600	1.5	1.55	1.525						
34800	1.55	1.575	1.5625						
35000	1.55	1.575	1.5625						
35200	1.55	1.575	1.5625						
35400	1.55	1.575	1.5625						
35600	1.55	1.575	1.5625						
35800	1.55	1.575	1.5625						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
36000	1.55	1.575	1.5625						
36200	1.55	1.575	1.5625						
36400	1.55	1.575	1.5625						
36600	1.55	1.575	1.5625						
36800	1.55	1.575	1.5625						
37000	1.55	1.575	1.5625						
37200	1.55	1.575	1.5625						
37400	1.55	1.575	1.5625						
37600	1.55	1.5875	1.56875						
37800	1.55	1.5875	1.56875						
38000	1.55	1.5875	1.56875						
38200	1.55	1.5875	1.56875						
38400	1.55	1.5875	1.56875						
38600	1.55	1.5875	1.56875						
38800	1.55	1.5875	1.56875						
39000	1.55	1.5875	1.56875						
39200	1.55	1.5875	1.56875						
39400	1.55	1.5875	1.56875						
39600	1.55	1.5875	1.56875						
39800	1.55	1.5875	1.56875						
40000	1.55	1.5875	1.56875	1.6	1.6	1.6	1.55	1.5	1.525
40200	1.55	1.5875	1.56875						
40400	1.55	1.5875	1.56875						
40600	1.55	1.6	1.575						
40800	1.55	1.6	1.575						
41000	1.55	1.6	1.575						
41200	1.55	1.6	1.575						
41400	1.55	1.6	1.575						
41600	1.55	1.6	1.575						
41800	1.55	1.6	1.575						
42000	1.55	1.6	1.575						
42200	1.55	1.6	1.575						
42400	1.55	1.6	1.575						
42600	1.55	1.6	1.575						
42800	1.55	1.6	1.575						
43000	1.55	1.6	1.575						
43200	1.55	1.6	1.575						
43400	1.55	1.6	1.575						
43600	1.55	1.6	1.575						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
43800	1.55	1.6	1.575						
44000	1.55	1.6	1.575						
44200	1.55	1.6	1.575						
44400	1.55	1.6	1.575						
44600	1.55	1.6	1.575						
44800	1.55	1.6	1.575						
45000	1.55	1.6	1.575						
45200	1.55	1.6	1.575						
45400	1.55	1.6	1.575						
45600	1.55	1.6	1.575						
45800	1.55	1.6	1.575						
46000	1.5625	1.6125	1.5875						
46200	1.5625	1.6125	1.5875						
46400	1.5625	1.6125	1.5875						
46600	1.5625	1.6125	1.5875						
46800	1.5625	1.6125	1.5875						
47000	1.5625	1.6125	1.5875						
47200	1.5625	1.6125	1.5875						
47400	1.575	1.6125	1.59375						
47600	1.575	1.6125	1.59375						
47800	1.575	1.6125	1.59375						
48000	1.575	1.6125	1.59375						
48200	1.575	1.6125	1.59375						
48400	1.575	1.6125	1.59375						
48600	1.575	1.6125	1.59375						
48800	1.575	1.6125	1.59375						
49000	1.575	1.6125	1.59375						
49200	1.575	1.6125	1.59375						
49400	1.575	1.625	1.6						
49600	1.575	1.625	1.6						
49800	1.575	1.625	1.6						
50000	1.575	1.625	1.6	1.6	1.65	1.625	1.69	1.4	1.545
50200	1.575	1.625	1.6						
50400	1.6	1.625	1.6125						
50600	1.6	1.625	1.6125						
50800	1.6	1.625	1.6125						
51000	1.6	1.625	1.6125						
51200	1.6	1.65	1.625						
51400	1.6	1.625	1.6125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
51600	1.6	1.625	1.6125						
51800	1.6	1.625	1.6125						
52000	1.6	1.65	1.625						
52200	1.6	1.65	1.625						
52400	1.6	1.65	1.625						
52600	1.6	1.65	1.625						
52800	1.6	1.65	1.625						
53000	1.6	1.65	1.625						
53200	1.6	1.65	1.625						
53400	1.6	1.65	1.625						
53600	1.6	1.65	1.625						
53800	1.6	1.65	1.625						
54000	1.6	1.65	1.625						
54200	1.6	1.65	1.625						
54400	1.6	1.65	1.625						
54600	1.6	1.65	1.625						
54800	1.6	1.65	1.625						
55000	1.6	1.65	1.625						
55200	1.6	1.65	1.625						
55400	1.6	1.65	1.625						
55600	1.6	1.65	1.625						
55800	1.6	1.65	1.625						
56000	1.6	1.65	1.625						
56200	1.6	1.65	1.625						
56400	1.6	1.65	1.625						
56600	1.6	1.65	1.625						
56800	1.6	1.65	1.625						
57000	1.6	1.65	1.625						
57200	1.6	1.65	1.625						
57400	1.6	1.65	1.625						
57600	1.6	1.65	1.625						
57800	1.6	1.65	1.625						
58000	1.6	1.65	1.625						
58200	1.6	1.65	1.625						
58400	1.6125	1.65	1.63125						
58600	1.6125	1.65	1.63125						
58800	1.6125	1.65	1.63125						
59000	1.6125	1.65	1.63125						
59200	1.6125	1.65	1.63125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
59400	1.6125	1.65	1.63125						
59600	1.6125	1.65	1.63125						
59800	1.6125	1.65	1.63125						
60000	1.6125	1.65	1.63125	1.65	1.65	1.65	1.73	1.43	1.58
60100	1.6125	1.65	1.63125						
60200	1.6125	1.65	1.63125						
60400	1.6125	1.65	1.63125						
60600	1.6125	1.65	1.63125						
61000	1.6125	1.65	1.63125						
61200	1.6125	1.65	1.63125						
61400	1.6125	1.65	1.63125						
61600	1.6125	1.65	1.63125						
61800	1.6125	1.65	1.63125						
62600	1.625	1.65	1.6375						
63000	1.625	1.65	1.6375						
63400	1.625	1.65	1.6375						
63800	1.625	1.65	1.6375						
64000	1.625	1.675	1.65						
64400	1.625	1.675	1.65						
64800	1.625	1.675	1.65						
65000	1.625	1.675	1.65						
65400	1.625	1.675	1.65						
65800	1.625	1.675	1.65						
66000	1.625	1.675	1.65						
66400	1.625	1.675	1.65						
66800	1.625	1.675	1.65						
67000	1.625	1.675	1.65						
67400	1.625	1.675	1.65						
67800	1.65	1.675	1.6625						
68000	1.65	1.675	1.6625						
68400	1.65	1.6875	1.66875						
68800	1.65	1.6875	1.66875						
69200	1.65	1.6875	1.66875						
69600	1.65	1.6875	1.66875						
70000	1.65	1.6875	1.66875						
70400	1.65	1.7	1.675						
70800	1.65	1.7	1.675						
71400	1.65	1.7	1.675						
71800	1.6625	1.7	1.68125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
72400	1.6625	1.7	1.68125						
72800	1.6625	1.7	1.68125						
73400	1.6625	1.7	1.68125						
73800	1.6625	1.7	1.68125						
74400	1.6625	1.7125	1.6875						
74800	1.6625	1.7125	1.6875						
75400	1.675	1.725	1.7						
75800	1.675	1.725	1.7						
76400	1.675	1.725	1.7						
76800	1.675	1.725	1.7						
77200	1.7	1.725	1.7125						
77600	1.7	1.725	1.7125						
78000	1.7	1.725	1.7125						
78400	1.7	1.725	1.7125						
78800	1.7	1.725	1.7125						
79200	1.7	1.725	1.7125						
79600	1.7	1.725	1.7125						
80000	1.7	1.725	1.7125	1.75	1.75	1.75	1.75	1.65	1.7
80100	1.7	1.725	1.7125						
80400	1.7	1.725	1.7125						
80600	1.7	1.725	1.7125						
80800	1.7	1.725	1.7125						
81000	1.7	1.725	1.7125						
81300	1.7	1.725	1.7125						
81500	1.7	1.75	1.725						
81700	1.7	1.75	1.725						
82000	1.7	1.75	1.725						
82200	1.7	1.75	1.725						
82400	1.7	1.75	1.725						
82600	1.7	1.75	1.725						
82800	1.7	1.75	1.725						
83000	1.7	1.75	1.725						
83400	1.725	1.75	1.7375						
83500	1.725	1.75	1.7375						
83600	1.725	1.75	1.7375						
83800	1.725	1.75	1.7375						
84000	1.725	1.75	1.7375						
84200	1.725	1.75	1.7375						
84600	1.725	1.75	1.7375						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
84800	1.725	1.75	1.7375						
84800	1.725	1.75	1.7375						
85000	1.725	1.75	1.7375						
85200	1.725	1.75	1.7375						
85400	1.725	1.75	1.7375						
85500	1.725	1.75	1.7375						
85600	1.725	1.75	1.7375						
85800	1.725	1.75	1.7375						
86000	1.725	1.75	1.7375						
86200	1.725	1.75	1.7375						
86400	1.725	1.75	1.7375						
86500	1.725	1.75	1.7375						
86600	1.725	1.75	1.7375						
86800	1.725	1.75	1.7375						
87000	1.725	1.775	1.75						
87200	1.725	1.775	1.75						
87400	1.725	1.775	1.75						
87500	1.725	1.775	1.75						
87600	1.725	1.8	1.7625						
87800	1.725	1.8	1.7625						
88000	1.725	1.8	1.7625						
88200	1.725	1.8	1.7625						
88400	1.725	1.8	1.7625						
88500	1.725	1.8	1.7625						
88600	1.725	1.825	1.775						
88800	1.725	1.825	1.775						
89000	1.725	1.825	1.775						
89200	1.7375	1.825	1.78125						
89400	1.7375	1.825	1.78125						
89600	1.7375	1.825	1.78125						
89800	1.7375	1.825	1.78125						
90000	1.7375	1.825	1.78125	1.775	1.8	1.7875	1.8	1.7	1.75

Figure I-5. Half-crack length data during fatigue for the RB repair (tabular)

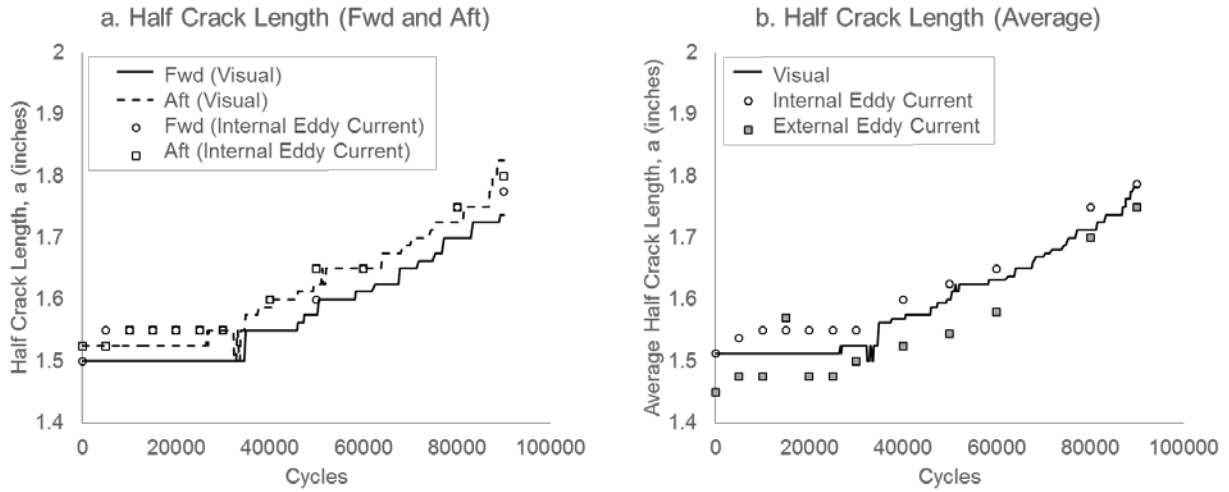


Figure I-6. The RB repair crack-growth data during fatigue (90,000 cycles): (a) forward and aft half-crack length and (b) average half-crack length

UNDER-DESIGNED REPAIRS

Under-designed aluminum and B/Ep repairs were subjected to hot-wet conditions to 80,000 cycles, and cold-dry conditions to 20,000 cycles.

UNDER-DESIGNED ALUMINUM REPAIRS (UA)

Table I-3 provides the half-crack length data of UA repair during pre-cracking. Figure I-7 shows the corresponding half-crack length as a function of fatigue cycles. Figure I-8 provides the half-crack length data during fatigue cycling. Figure I-9a shows the fwd and aft half-crack length, and figure I-9b shows averaged half-crack length as a function of fatigue cycles.

Table I-3. Half-crack length during pre-cracking for the UA repair (tabular)

Cycles	Visual	
	a _{AFT} (in.)	a _{FWD} (in.)
250	1.400	1.425
400	1.400	1.425
600	1.430	1.440
700	1.440	1.440
900	1.440	1.450
1000	1.440	1.460
1100	1.450	1.460
1200	1.475	1.465
1400	1.475	1.480

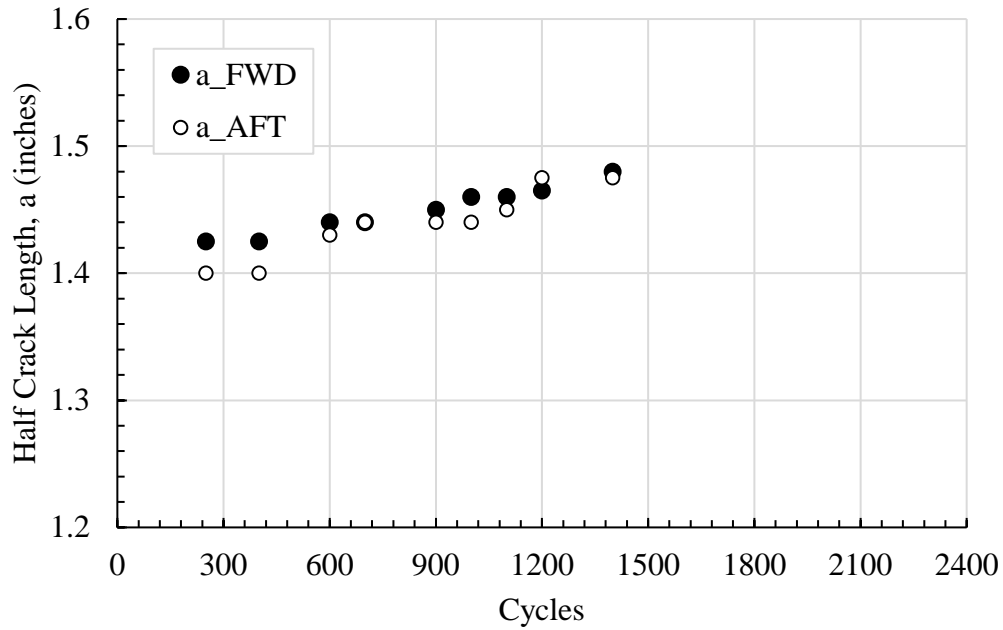


Figure I-7. Half-crack length during pre-cracking for the UA repair

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
0	1.5	1.525	1.5125	1.5	1.5	1.5	1.46	1.42	1.44
1000	1.5	1.525	1.5125						
2000	1.5	1.525	1.5125						
3000	1.5	1.525	1.5125						
4000	1.5	1.525	1.5125						
5000	1.5	1.525	1.5125	1.5	1.5	1.5	1.45	1.45	1.45
5001	1.5	1.525	1.5125						
5200	1.5	1.525	1.5125						
5400	1.5	1.525	1.5125						
5600	1.525	1.525	1.525						
5600	1.525	1.525	1.525						
6000	1.525	1.525	1.525						
6200	1.525	1.525	1.525						
6400	1.525	1.525	1.525						
6600	1.525	1.525	1.525						
6800	1.525	1.525	1.525						
7000	1.525	1.525	1.525						
7600	1.525	1.525	1.525						
7800	1.525	1.525	1.525						
8000	1.525	1.525	1.525						
8200	1.525	1.525	1.525						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
8400	1.525	1.5375	1.53125						
8800	1.525	1.5375	1.53125						
9200	1.525	1.5375	1.53125						
8600	1.525	1.5375	1.53125						
9400	1.55	1.5375	1.54375						
9600	1.55	1.5375	1.54375						
9800	1.55	1.5375	1.54375						
10000	1.55	1.5375	1.54375	1.55	1.55	1.55	1.5	1.5	1.5
10200	1.55	1.5375	1.54375						
10400	1.55	1.5375	1.54375						
10600	1.55	1.5375	1.54375						
10800	1.55	1.5375	1.54375						
11000	1.55	1.5375	1.54375						
11200	1.55	1.5375	1.54375						
11600	1.55	1.5375	1.54375						
11800	1.55	1.5375	1.54375						
12000	1.55	1.5375	1.54375						
12200	1.55	1.5375	1.54375						
12400	1.55	1.5375	1.54375						
11400	1.55	1.5375	1.54375						
12600	1.55	1.5375	1.54375						
12800	1.55	1.5375	1.54375						
13400	1.55	1.5375	1.54375						
13600	1.55	1.5375	1.54375						
13800	1.55	1.5375	1.54375						
14000	1.55	1.5375	1.54375						
14200	1.55	1.5375	1.54375						
14400	1.55	1.5375	1.54375						
14600	1.55	1.5375	1.54375						
14800	1.55	1.5375	1.54375						
15000	1.55	1.5375	1.54375	1.55	1.55	1.55	1.5	1.5	1.5
15200	1.55	1.5375	1.54375						
15400	1.55	1.5375	1.54375						
15600	1.55	1.5375	1.54375						
15800	1.55	1.5375	1.54375						
16000	1.55	1.5375	1.54375						
16200	1.55	1.5375	1.54375						
16400	1.55	1.5375	1.54375						
16600	1.55	1.5375	1.54375						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
16800	1.55	1.5375	1.54375						
17000	1.55	1.5375	1.54375						
17200	1.55	1.5375	1.54375						
17400	1.55	1.5375	1.54375						
17600	1.55	1.5375	1.54375						
17800	1.55	1.5375	1.54375						
18000	1.55	1.5375	1.54375						
18200	1.55	1.5375	1.54375						
18400	1.55	1.5375	1.54375						
18600	1.55	1.5375	1.54375						
18800	1.55	1.5375	1.54375						
19000	1.55	1.5375	1.54375						
19200	1.55	1.5375	1.54375						
19400	1.55	1.5375	1.54375						
19600	1.55	1.5375	1.54375						
19800	1.55	1.5375	1.54375						
20000	1.55	1.5375	1.54375	1.55	1.55	1.55	1.5	1.5	1.5
20200	1.55	1.55	1.55						
20400	1.55	1.55	1.55						
20600	1.55	1.55	1.55						
20800	1.55	1.55	1.55						
21000	1.55	1.55	1.55						
21200	1.55	1.55	1.55						
21400	1.55	1.55	1.55						
21600	1.55	1.55	1.55						
21800	1.55	1.55	1.55						
22000	1.55	1.55	1.55						
22200	1.55	1.55	1.55						
22400	1.55	1.55	1.55						
22600	1.55	1.55	1.55						
22800	1.55	1.55	1.55						
23000	1.55	1.55	1.55						
23200	1.55	1.55	1.55						
23400	1.55	1.55	1.55						
23600	1.55	1.55	1.55						
23800	1.55	1.55	1.55						
24000	1.55	1.55	1.55						
24200	1.55	1.55	1.55						
24400	1.55	1.55	1.55						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
24600	1.55	1.55	1.55						
24800	1.55	1.55	1.55						
25000	1.55	1.55	1.55	1.55	1.55	1.55	1.48	1.5	1.49
25200	1.55	1.55	1.55						
25400	1.55	1.55	1.55						
25600	1.55	1.55	1.55						
25800	1.55	1.55	1.55						
26000	1.55	1.55	1.55						
26200	1.55	1.55	1.55						
26400	1.55	1.55	1.55						
26600	1.55	1.55	1.55						
26800	1.55	1.55	1.55						
27000	1.55	1.55	1.55						
27200	1.55	1.55	1.55						
27400	1.55	1.55	1.55						
27600	1.55	1.55	1.55						
27800	1.55	1.55	1.55						
28000	1.55	1.55	1.55						
28200	1.55	1.55	1.55						
28400	1.55	1.55	1.55						
28600	1.55	1.55	1.55						
28800	1.55	1.55	1.55						
29000	1.55	1.55	1.55						
29200	1.55	1.55	1.55						
29400	1.55	1.55	1.55						
29600	1.55	1.55	1.55						
29800	1.55	1.55	1.55						
30000	1.55	1.55	1.55	1.5	1.575	1.5375	1.5	1.5	1.5
30200	1.55	1.55	1.55						
30400	1.55	1.55	1.55						
30600	1.55	1.55	1.55						
30800	1.55	1.55	1.55						
31000	1.55	1.55	1.55						
31200	1.55	1.55	1.55						
31400	1.55	1.55	1.55						
31600	1.55	1.55	1.55						
31800	1.55	1.55	1.55						
32000	1.55	1.55	1.55						
32200	1.55	1.55	1.55						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
32400	1.55	1.55	1.55						
32600	1.55	1.55	1.55						
32800	1.55	1.55	1.55						
33000	1.55	1.55	1.55						
33200	1.55	1.55	1.55						
33400	1.55	1.55	1.55						
33600	1.55	1.55	1.55						
33800	1.55	1.55	1.55						
34000	1.55	1.55	1.55						
34200	1.55	1.55	1.55						
34400	1.55	1.55	1.55						
34600	1.55	1.55	1.55						
34800	1.55	1.55	1.55						
35000	1.55	1.55	1.55						
35200	1.55	1.55	1.55						
35400	1.55	1.55	1.55						
35600	1.55	1.55	1.55						
35800	1.55	1.55	1.55						
36000	1.55	1.55	1.55						
36200	1.55	1.55	1.55						
36400	1.55	1.55	1.55						
36600	1.55	1.55	1.55						
36800	1.55	1.55	1.55						
37000	1.55	1.55	1.55						
37200	1.55	1.55	1.55						
37400	1.55	1.55	1.55						
37600	1.55	1.55	1.55						
37800	1.55	1.55	1.55						
38000	1.55	1.55	1.55						
38200	1.55	1.55	1.55						
38400	1.55	1.55	1.55						
38600	1.55	1.55	1.55						
38800	1.55	1.55	1.55						
39000	1.55	1.55	1.55						
39200	1.55	1.55	1.55						
39400	1.55	1.55	1.55						
39600	1.55	1.55	1.55						
39800	1.55	1.55	1.55						
40000	1.55	1.55	1.55	1.55	1.55	1.55	1.5	1.5	1.5

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
40200	1.55	1.55	1.55						
40400	1.55	1.55	1.55						
40600	1.55	1.55	1.55						
40800	1.55	1.55	1.55						
41000	1.55	1.55	1.55						
41200	1.55	1.55	1.55						
41400	1.55	1.55	1.55						
41600	1.55	1.55	1.55						
41800	1.55	1.55	1.55						
42000	1.55	1.55	1.55						
42200	1.55	1.55	1.55						
42400	1.55	1.55	1.55						
42600	1.55	1.55	1.55						
42800	1.55	1.55	1.55						
43000	1.55	1.55	1.55						
43200	1.55	1.55	1.55						
43400	1.55	1.55	1.55						
43600	1.55	1.55	1.55						
43800	1.55	1.55	1.55						
44000	1.55	1.55	1.55						
44200	1.55	1.55	1.55						
44400	1.55	1.55	1.55						
44600	1.55	1.55	1.55						
44800	1.55	1.55	1.55						
45000	1.55	1.55	1.55						
45200	1.55	1.55	1.55						
45400	1.55	1.55	1.55						
45600	1.55	1.55	1.55						
45800	1.55	1.55	1.55						
46000	1.55	1.55	1.55						
46200	1.55	1.55	1.55						
46400	1.55	1.55	1.55						
46600	1.55	1.55	1.55						
46800	1.55	1.55	1.55						
47000	1.55	1.55	1.55						
47200	1.55	1.55	1.55						
47400	1.55	1.55	1.55						
47600	1.55	1.55	1.55						
47800	1.55	1.55	1.55						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
48000	1.55	1.55	1.55						
48200	1.55	1.55	1.55						
48400	1.55	1.55	1.55						
48600	1.55	1.55	1.55						
48800	1.55	1.55	1.55						
49000	1.55	1.55	1.55						
49200	1.55	1.55	1.55						
49400	1.55	1.55	1.55						
49600	1.55	1.55	1.55						
49800	1.55	1.55	1.55						
50000	1.55	1.55	1.55	1.55	1.55	1.55	1.5	1.5	1.5
50200	1.55	1.55	1.55						
50400	1.55	1.55	1.55						
50600	1.55	1.55	1.55						
50800	1.55	1.55	1.55						
51000	1.55	1.55	1.55						
51200	1.55	1.55	1.55						
51400	1.55	1.55	1.55						
51600	1.55	1.55	1.55						
51800	1.55	1.55	1.55						
52000	1.55	1.55	1.55						
52200	1.55	1.55	1.55						
52400	1.55	1.55	1.55						
52600	1.55	1.55	1.55						
52800	1.55	1.55	1.55						
53000	1.55	1.55	1.55						
53200	1.55	1.55	1.55						
53400	1.55	1.55	1.55						
53600	1.55	1.55	1.55						
53800	1.55	1.55	1.55						
54000	1.55	1.55	1.55						
54200	1.55	1.55	1.55						
54400	1.55	1.55	1.55						
54600	1.55	1.55	1.55						
54800	1.55	1.55	1.55						
55000	1.55	1.55	1.55						
55200	1.55	1.55	1.55						
55400	1.55	1.55	1.55						
55600	1.55	1.55	1.55						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
55800	1.55	1.55	1.55						
56000	1.55	1.55	1.55						
56200	1.55	1.55	1.55						
56400	1.55	1.55	1.55						
56600	1.55	1.55	1.55						
56800	1.55	1.55	1.55						
57000	1.55	1.55	1.55						
57200	1.55	1.55	1.55						
57400	1.55	1.55	1.55						
57600	1.55	1.55	1.55						
57800	1.55	1.55	1.55						
58000	1.55	1.55	1.55						
58200	1.55	1.55	1.55						
58400	1.55	1.55	1.55						
58600	1.55	1.55	1.55						
58800	1.55	1.55	1.55						
59000	1.55	1.55	1.55						
59200	1.55	1.55	1.55						
59400	1.55	1.55	1.55						
59600	1.55	1.55	1.55						
59800	1.55	1.55	1.55						
60000	1.55	1.55	1.55	1.55	1.55	1.55	1.5	1.5	1.5
60100	1.55	1.55	1.55						
60200	1.55	1.55	1.55						
60400	1.55	1.55	1.55						
60600	1.55	1.55	1.55						
61000	1.55	1.55	1.55						
61200	1.55	1.55	1.55						
61400	1.55	1.55	1.55						
61600	1.55	1.55	1.55						
61800	1.55	1.55	1.55						
62600	1.575	1.55	1.5625						
63000	1.575	1.55	1.5625						
63400	1.575	1.55	1.5625						
63800	1.575	1.55	1.5625						
64000	1.575	1.55	1.5625						
64400	1.575	1.55	1.5625						
64800	1.575	1.55	1.5625						
65000	1.575	1.55	1.5625						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
65400	1.575	1.55	1.5625						
65800	1.6	1.55	1.575						
66000	1.6	1.55	1.575						
66400	1.6	1.55	1.575						
66800	1.6	1.55	1.575						
67000	1.6	1.55	1.575						
67400	1.6125	1.55	1.58125						
67800	1.6125	1.55	1.58125						
68000	1.6125	1.55	1.58125						
68400	1.6125	1.55	1.58125						
68800	1.6125	1.55	1.58125						
69200	1.6125	1.55	1.58125						
69600	1.6125	1.55	1.58125						
70000	1.625	1.55	1.5875						
70400	1.625	1.55	1.5875						
70800	1.625	1.55	1.5875						
71400	1.6375	1.55	1.59375						
71800	1.6375	1.55	1.59375						
72400	1.6375	1.55	1.59375						
72800	1.6375	1.55	1.59375						
73400	1.65	1.55	1.6						
73800	1.65	1.55	1.6						
74400	1.65	1.55	1.6						
74800	1.65	1.55	1.6						
75400	1.6625	1.55	1.60625						
75800	1.6625	1.55	1.60625						
76400	1.6625	1.55	1.60625						
76800	1.6625	1.55	1.60625						
77200	1.6625	1.55	1.60625						
77600	1.6625	1.55	1.60625						
78000	1.6625	1.55	1.60625						
78400	1.6625	1.55	1.60625						
78800	1.6875	1.55	1.61875						
79200	1.6875	1.55	1.61875						
79600	1.6875	1.55	1.61875						
80000	1.7	1.55	1.625	1.6	1.5625	1.58125	1.6	1.45	1.525
80100	1.7	1.55	1.625						
80400	1.7	1.55	1.625						
80600	1.7	1.55	1.625						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
80800	1.7	1.55	1.625						
81000	1.7	1.55	1.625						
81300	1.7	1.55	1.625						
81500	1.7	1.55	1.625						
81700	1.7	1.55	1.625						
82000	1.7	1.55	1.625						
82200	1.7	1.55	1.625						
82400	1.75	1.55	1.65						
82600	1.75	1.55	1.65						
82800	1.75	1.55	1.65						
83000	1.75	1.55	1.65						
83400	1.75	1.55	1.65						
83500	1.75	1.55	1.65						
83600	1.75	1.55	1.65						
83800	1.75	1.55	1.65						
84000	1.75	1.55	1.65						
84200	1.75	1.55	1.65						
84600	1.75	1.55	1.65						
84800	1.75	1.55	1.65						
84800	1.75	1.55	1.65						
85000	1.75	1.55	1.65						
85200	1.75	1.55	1.65						
85400	1.75	1.55	1.65						
85500	1.75	1.55	1.65						
85600	1.75	1.55	1.65						
85800	1.75	1.55	1.65						
86000	1.75	1.55	1.65						
86200	1.75	1.55	1.65						
86400	1.75	1.55	1.65						
86500	1.75	1.55	1.65						
86600	1.75	1.55	1.65						
86800	1.75	1.55	1.65						
87000	1.75	1.55	1.65						
87200	1.75	1.55	1.65						
87400	1.75	1.55	1.65						
87500	1.75	1.55	1.65						
87600	1.75	1.55	1.65						
87800	1.75	1.55	1.65						
88000	1.75	1.55	1.65						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
88200	1.75	1.55	1.65						
88400	1.75	1.55	1.65						
88500	1.75	1.55	1.65						
88600	1.75	1.55	1.65						
88800	1.75	1.55	1.65						
89000	1.75	1.55	1.65						
89200	1.75	1.55	1.65						
89400	1.75	1.55	1.65						
89600	1.75	1.55	1.65						
89800	1.75	1.55	1.65						
90000	1.75	1.55	1.65	1.7625	1.5625	1.6625	1.65	1.5	1.575

Figure I-8. Half-crack length data during fatigue for the UA repair (tabular)

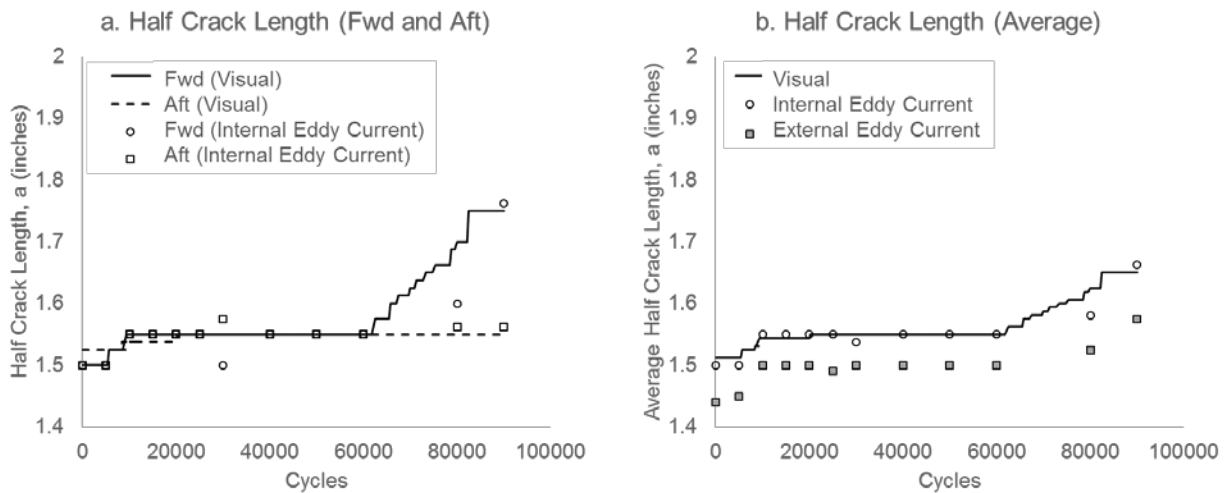


Figure I-9. The UA repair crack-growth data during fatigue (90,000 cycles): (a) forward and aft half-crack length and (b) average half-crack length

UNDER-DESIGNED B/EP REPAIRS (UB)

Table I-4 provides the half-crack length data of UB repair during pre-cracking. Figure I-10 shows the corresponding half-crack length as a function of fatigue cycles. Figure I-11 provides the half-crack length data during fatigue cycling. Figure I-12a shows the fwd and aft half-crack length, and figure I-12b shows averaged half-crack length as function of fatigue cycles.

Table I-4. Half-crack length during pre-cracking for the UB repair (tabular)

Cycles	Visual	
	a _{AFT} (in.)	a _{FWD} (in.)
250	1.410	1.400
400	1.440	1.440
600	1.440	1.440
700	1.440	1.440
900	1.450	1.450
1000	1.450	1.450
1100	1.450	1.460
1200	1.460	1.475
1400	1.475	1.480

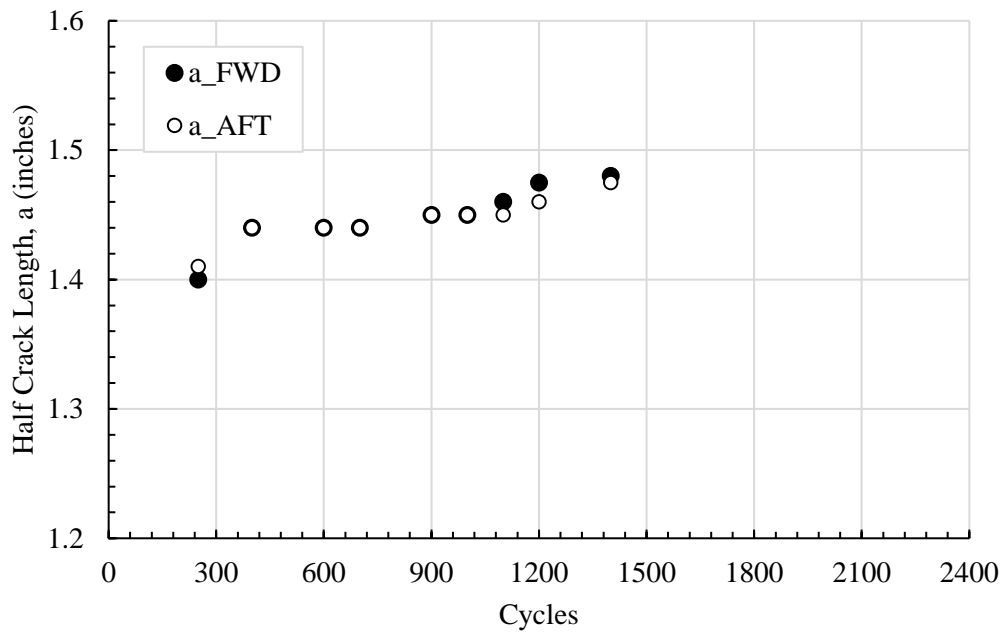


Figure I-10. Half-crack length during pre-cracking for the UB repair

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
0	1.525	1.525	1.525	1.525	1.55	1.5375	1.45	1.55	1.5
1000	1.525	1.525	1.525						
2000	1.525	1.525	1.525						
3000	1.525	1.525	1.525						
4000	1.525	1.525	1.525						
5000	1.525	1.525	1.525	1.55	1.55	1.55	1.5	1.55	1.525
5200	1.525	1.525	1.525						
5400	1.525	1.525	1.525						
5600	1.525	1.55	1.5375						
5600	1.525	1.55	1.5375						
6000	1.525	1.55	1.5375						
6200	1.525	1.55	1.5375						
6400	1.525	1.55	1.5375						
6600	1.525	1.55	1.5375						
6800	1.55	1.55	1.55						
7000	1.55	1.55	1.55						
7600	1.55	1.55	1.55						
7800	1.55	1.55	1.55						
8000	1.55	1.55	1.55						
8200	1.55	1.55	1.55						
8400	1.55	1.55	1.55						
8800	1.55	1.5625	1.55625						
9200	1.55	1.5625	1.55625						
8600	1.55	1.5625	1.55625						
9400	1.5625	1.575	1.56875						
9600	1.5625	1.575	1.56875						
9800	1.5625	1.575	1.56875						
10000	1.575	1.575	1.575	1.575	1.575	1.575	1.55	1.65	1.6
10200	1.575	1.575	1.575						
10400	1.575	1.575	1.575						
10600	1.575	1.575	1.575						
10800	1.575	1.575	1.575						
11000	1.575	1.575	1.575						
11200	1.575	1.575	1.575						
11600	1.575	1.575	1.575						
11800	1.6	1.6	1.6						
12000	1.6	1.6	1.6						
12200	1.6	1.6	1.6						
12400	1.6	1.6	1.6						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
11400	1.6	1.6	1.6						
12600	1.6	1.6	1.6						
12800	1.6	1.6	1.6						
13400	1.6	1.6	1.6						
13600	1.6	1.6	1.6						
13800	1.6	1.6	1.6						
14000	1.6	1.6	1.6						
14200	1.6	1.6	1.6						
14400	1.6	1.6125	1.60625						
14600	1.6	1.6125	1.60625						
14800	1.6125	1.625	1.61875						
15000	1.6125	1.625	1.61875	1.625	1.65	1.6375	1.66	1.76	1.71
15200	1.6125	1.625	1.61875						
15400	1.625	1.625	1.625						
15600	1.625	1.625	1.625						
15800	1.625	1.625	1.625						
16000	1.625	1.625	1.625						
16200	1.625	1.625	1.625						
16400	1.625	1.625	1.625						
16600	1.625	1.625	1.625						
16800	1.625	1.625	1.625						
17000	1.65	1.65	1.65						
17200	1.65	1.65	1.65						
17400	1.65	1.65	1.65						
17600	1.65	1.65	1.65						
17800	1.65	1.65	1.65						
18000	1.65	1.65	1.65						
18200	1.65	1.65	1.65						
18400	1.65	1.65	1.65						
18600	1.65	1.65	1.65						
18800	1.65	1.65	1.65						
19000	1.65	1.65	1.65						
19200	1.675	1.65	1.6625						
19400	1.675	1.65	1.6625						
19600	1.675	1.65	1.6625						
19800	1.675	1.6625	1.66875						
20000	1.675	1.6625	1.66875	1.675	1.7	1.6875	1.58	1.71	1.645
20200	1.675	1.6625	1.66875						
20400	1.675	1.6625	1.66875						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
20600	1.675	1.6625	1.66875						
20800	1.7	1.7	1.7						
21000	1.7	1.7	1.7						
21200	1.7	1.7	1.7						
21400	1.7	1.7	1.7						
21600	1.7	1.7	1.7						
21800	1.7	1.7	1.7						
22000	1.7	1.7	1.7						
22200	1.7	1.7	1.7						
22400	1.7	1.7	1.7						
22600	1.7	1.7	1.7						
22800	1.7	1.7125	1.70625						
23000	1.7	1.7125	1.70625						
23200	1.7	1.7125	1.70625						
23400	1.7	1.725	1.7125						
23600	1.7	1.725	1.7125						
23800	1.725	1.7375	1.73125						
24000	1.725	1.7375	1.73125						
24200	1.725	1.7375	1.73125						
24400	1.725	1.7375	1.73125						
24600	1.725	1.7375	1.73125						
24800	1.725	1.7375	1.73125						
25000	1.725	1.7375	1.73125	1.75	1.75	1.75	1.65	1.76	1.705
25200	1.725	1.75	1.7375						
25400	1.75	1.8	1.775						
25600	1.75	1.8	1.775						
25800	1.75	1.775	1.7625						
26000	1.75	1.775	1.7625						
26200	1.75	1.775	1.7625						
26400	1.75	1.775	1.7625						
26600	1.7625	1.775	1.76875						
26800	1.7625	1.775	1.76875						
27000	1.7625	1.775	1.76875						
27200	1.7625	1.775	1.76875						
27400	1.7625	1.775	1.76875						
27600	1.7625	1.775	1.76875						
27800	1.7625	1.775	1.76875						
28000	1.775	1.8	1.7875						
28200	1.775	1.8	1.7875						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
28400	1.775	1.8	1.7875						
28600	1.775	1.8	1.7875						
28800	1.775	1.8	1.7875						
29000	1.775	1.8	1.7875						
29200	1.7875	1.8	1.79375						
29400	1.7875	1.8	1.79375						
29600	1.7875	1.8	1.79375						
29800	1.8	1.8	1.8						
30000	1.8	1.8	1.8	1.85	1.85	1.85	1.7	1.85	1.775
30200	1.8	1.8	1.8						
30400	1.8	1.8	1.8						
30600	1.8	1.8	1.8						
30800	1.8	1.8	1.8						
31000	1.8	1.8125	1.80625						
31200	1.8	1.8125	1.80625						
31400	1.8	1.8125	1.80625						
31600	1.8	1.825	1.8125						
31800	1.8	1.825	1.8125						
32000	1.8125	1.825	1.81875						
32200	1.8125	1.8	1.80625						
32400	1.8125	1.8	1.80625						
32600	1.825	1.8375	1.83125						
32800	1.825	1.8375	1.83125						
33000	1.8375	1.8375	1.8375						
33200	1.8375	1.8375	1.8375						
33400	1.85	1.8375	1.84375						
33600	1.85	1.8375	1.84375						
33800	1.85	1.8375	1.84375						
34000	1.85	1.85	1.85						
34200	1.85	1.85	1.85						
34400	1.85	1.85	1.85						
34600	1.85	1.85	1.85						
34800	1.85	1.85	1.85						
35000	1.85	1.85	1.85						
35200	1.875	1.85	1.8625						
35400	1.875	1.85	1.8625						
35600	1.875	1.85	1.8625						
35800	1.875	1.85	1.8625						
36000	1.875	1.85	1.8625						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
36200	1.9	1.875	1.8875						
36400	1.9	1.875	1.8875						
36600	1.9	1.875	1.8875						
36800	1.9	1.875	1.8875						
37000	1.9	1.875	1.8875						
37200	1.9	1.8875	1.89375						
37400	1.9	1.8875	1.89375						
37600	1.9	1.8875	1.89375						
37800	1.9125	1.9	1.90625						
38000	1.9125	1.9	1.90625						
38200	1.9125	1.9	1.90625						
38400	1.9125	1.9	1.90625						
38600	1.9125	1.9	1.90625						
38800	1.9125	1.9	1.90625						
39000	1.9125	1.9	1.90625						
39200	1.9125	1.9	1.90625						
39400	1.925	1.9	1.9125						
39600	1.925	1.925	1.925						
39800	1.925	1.925	1.925						
40000	1.925	1.925	1.925	1.95	1.925	1.9375	1.85	1.95	1.9
40200	1.95	1.925	1.9375						
40400	1.95	1.925	1.9375						
40600	1.95	1.925	1.9375						
40800	1.95	1.925	1.9375						
41000	1.95	1.9375	1.94375						
41200	1.95	1.9375	1.94375						
41400	1.95	1.9375	1.94375						
41600	1.95	1.9375	1.94375						
41800	1.95	1.9375	1.94375						
42000	1.9625	1.9375	1.95						
42200	1.9625	1.9375	1.95						
42400	1.975	1.95	1.9625						
42600	1.975	1.95	1.9625						
42800	1.975	1.95	1.9625						
43000	1.975	1.95	1.9625						
43200	1.975	1.95	1.9625						
43400	1.975	1.95	1.9625						
43600	1.9875	1.9625	1.975						
43800	1.9875	1.9625	1.975						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
44000	2	1.9625	1.98125						
44200	2	1.975	1.9875						
44400	2	1.975	1.9875						
44600	2	1.975	1.9875						
44800	2	1.975	1.9875						
45000	2	1.975	1.9875						
45200	2	1.975	1.9875						
45400	2.0125	1.9875	2						
45600	2.025	1.9875	2.00625						
45800	2.025	1.9875	2.00625						
46000	2.025	2	2.0125						
46200	2.025	2	2.0125						
46400	2.025	2	2.0125						
46600	2.025	2	2.0125						
46800	2.025	2	2.0125						
47000	2.05	2.0125	2.03125						
47200	2.05	2.025	2.0375						
47400	2.05	2.025	2.0375						
47600	2.05	2.05	2.05						
47800	2.05	2.05	2.05						
48000	2.05	2.05	2.05						
48200	2.05	2.05	2.05						
48400	2.05	2.05	2.05						
48600	2.05	2.05	2.05						
48800	2.05	2.05	2.05						
49000	2.05	2.05	2.05						
49200	2.05	2.05	2.05						
49400	2.075	2.0625	2.06875						
49600	2.075	2.0625	2.06875						
49800	2.075	2.0625	2.06875						
50000	2.075	2.0625	2.06875	2.1	2.1	2.1	2.125	2.125	2.125
50200	2.075	2.0625	2.06875						
50400	2.075	2.0625	2.06875						
50600	2.075	2.0625	2.06875						
50800	2.075	2.075	2.075						
51000	2.075	2.1	2.0875						
51200	2.075	2.1	2.0875						
51400	2.075	2.1	2.0875						
51600	2.0875	2.1	2.09375						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
51800	2.0875	2.1	2.09375						
52000	2.0875	2.1	2.09375						
52200	2.0875	2.1	2.09375						
52400	2.0875	2.1	2.09375						
52600	2.0875	2.1	2.09375						
52800	2.1	2.1	2.1						
53000	2.1	2.1	2.1						
53200	2.1	2.1	2.1						
53400	2.1	2.125	2.1125						
53600	2.1	2.125	2.1125						
53800	2.1	2.125	2.1125						
54000	2.1	2.125	2.1125						
54200	2.1	2.125	2.1125						
54400	2.1	2.125	2.1125						
54600	2.1	2.15	2.125						
54800	2.1	2.15	2.125						
55000	2.1	2.15	2.125						
55200	2.1	2.15	2.125						
55400	2.1125	2.15	2.13125						
55600	2.1125	2.15	2.13125						
55800	2.1125	2.15	2.13125						
56000	2.125	2.1625	2.14375						
56200	2.125	2.1625	2.14375						
56400	2.125	2.1625	2.14375						
56600	2.125	2.1625	2.14375						
56800	2.125	2.1625	2.14375						
57000	2.125	2.1625	2.14375						
57200	2.15	2.2	2.175						
57400	2.15	2.2	2.175						
57600	2.175	2.2	2.1875						
57800	2.175	2.2	2.1875						
58000	2.2	2.2	2.2						
58200	2.2	2.2	2.2						
58400	2.2	2.2	2.2						
58600	2.2	2.2	2.2						
58800	2.2	2.2	2.2						
59000	2.2	2.2125	2.20625						
59200	2.2	2.2125	2.20625						
59400	2.2	2.225	2.2125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
59600	2.2	2.225	2.2125						
59800	2.2	2.225	2.2125						
60000	2.2	2.225	2.2125	2.25	2.275	2.2625	2.17	2.29	2.23
60100	2.2	2.225	2.2125						
60200	2.2	2.225	2.2125						
60400	2.2	2.225	2.2125						
60600	2.2	2.225	2.2125						
61000	2.2125	2.225	2.21875						
61200	2.2125	2.225	2.21875						
61400	2.2125	2.225	2.21875						
61600	2.2125	2.225	2.21875						
61800	2.2125	2.225	2.21875						
62600	2.25	2.225	2.2375						
63000	2.25	2.225	2.2375						
63400	2.25	2.225	2.2375						
63800	2.25	2.225	2.2375						
64000	2.25	2.225	2.2375						
64400	2.25	2.225	2.2375						
64800	2.25	2.225	2.2375						
65000	2.25	2.225	2.2375						
65400	2.25	2.225	2.2375						
65800	2.2625	2.225	2.24375						
66000	2.2625	2.225	2.24375						
66400	2.3	2.275	2.2875						
66800	2.3	2.275	2.2875						
67000	2.3	2.275	2.2875						
67400	2.3	2.3	2.3						
67800	2.3	2.3	2.3						
68000	2.3	2.3	2.3						
68400	2.3	2.3	2.3						
68800	2.3	2.3	2.3						
69200	2.3	2.3	2.3						
69600	2.325	2.325	2.325						
70000	2.35	2.325	2.3375						
70400	2.375	2.325	2.35						
70800	2.375	2.325	2.35						
71400	2.4	2.3625	2.38125						
71800	2.4	2.3625	2.38125						
72400	2.425	2.4	2.4125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
72800	2.425	2.4	2.4125						
73400	2.425	2.4	2.4125						
73800	2.425	2.4	2.4125						
74400	2.45	2.4	2.425						
74800	2.45	2.4	2.425						
75400	2.45	2.425	2.4375						
75800	2.45	2.425	2.4375						
76400	2.45	2.4375	2.44375						
76800	2.45	2.4375	2.44375						
77200	2.475	2.45	2.4625						
77600	2.475	2.45	2.4625						
78000	2.475	2.45	2.4625						
78400	2.475	2.45	2.4625						
78800	2.475	2.45	2.4625						
79200	2.475	2.45	2.4625						
79600	2.475	2.4875	2.48125						
80000	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.55	2.525
80100	2.55	2.5	2.525						
80400	2.55	2.5	2.525						
80600	2.55	2.5	2.525						
80800	2.55	2.55	2.55						
81000	2.5625	2.55	2.55625						
81300	2.5625	2.55	2.55625						
81500	2.6	2.55	2.575						
81700	2.6	2.55	2.575						
82000	2.6	2.55	2.575						
82200	2.6	2.55	2.575						
82400	2.6	2.55	2.575						
82600	2.6	2.55	2.575						
82800	2.6	2.55	2.575						
83000	2.6	2.575	2.5875						
83400	2.6	2.575	2.5875						
83500	2.6	2.575	2.5875						
83600	2.6	2.575	2.5875						
83800	2.6	2.6	2.6						
84000	2.65	2.6	2.625						
84200	2.65	2.6	2.625						
84600	2.65	2.6	2.625						
84800	2.65	2.6	2.625						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
84800	2.65	2.6	2.625						
85000	2.65	2.6	2.625						
85200	2.65	2.6	2.625						
85400	2.65	2.6	2.625						
85500	2.65	2.6	2.625						
85600	2.65	2.6	2.625						
85800	2.65	2.6	2.625						
86000	2.65	2.6	2.625						
86200	2.65	2.6	2.625						
86400	2.675	2.625	2.65						
86500	2.675	2.625	2.65						
86600	2.675	2.625	2.65						
86800	2.675	2.625	2.65						
87000	2.675	2.625	2.65						
87200	2.675	2.625	2.65						
87400	2.675	2.625	2.65						
87500	2.675	2.625	2.65						
87600	2.675	2.625	2.65						
87800	2.675	2.625	2.65						
88000	2.675	2.625	2.65						
88200	2.675	2.625	2.65						
88400	2.675	2.625	2.65						
88500	2.675	2.65	2.6625						
88600	2.675	2.65	2.6625						
88800	2.675	2.65	2.6625						
89000	2.675	2.65	2.6625						
89200	2.675	2.675	2.675						
89400	2.675	2.675	2.675						
89600	2.675	2.675	2.675						
89800	2.675	2.675	2.675						
90000	2.675	2.675	2.675	2.75	2.725	2.7375	2.65	2.75	2.7

Figure I-11. Half-crack length data during fatigue for the UB repair (tabular)

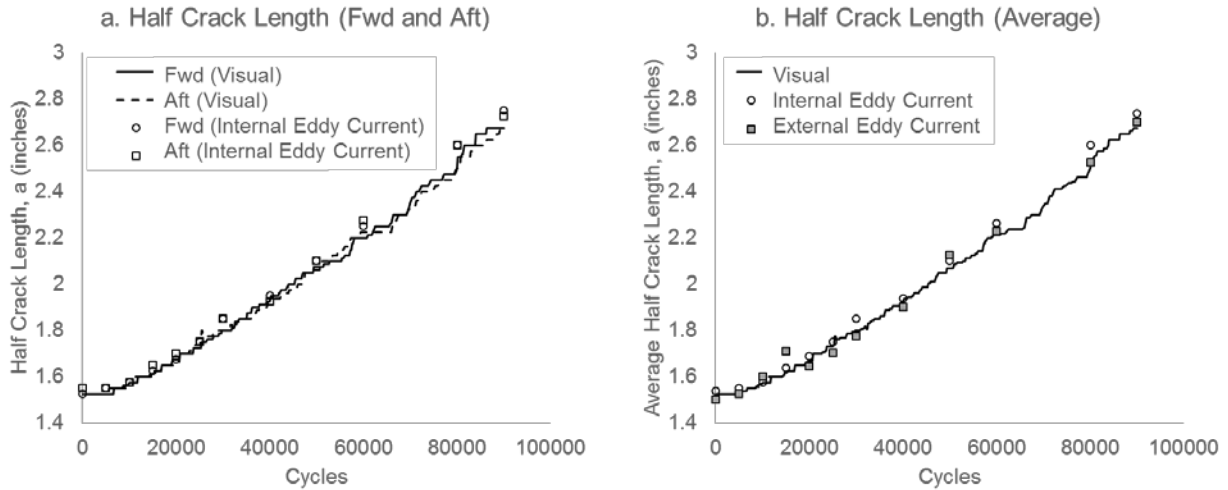


Figure I-12. The UB repair crack-growth data during fatigue (90,000 cycles): (a) forward and aft half-crack length and (b) average half-crack length

UNDER-DESIGNED DISBOND REPAIRS

Reference aluminum and B/Ep repairs were subjected to hot-wet conditions to a total of 80,000 cycles, and cold-dry conditions to a total 20,000 cycles.

UNDER-DESIGNED DISBOND ALUMINUM REPAIRS

Table I-5 provides the half-crack length data of under-designed disband aluminum (UDA) repair during pre-cracking. Figure I-13 shows the corresponding half-crack length as a function of fatigue cycles. Figure I-14 provides the half-crack length data during fatigue cycling. Figure I-15a shows the fwd and aft half-crack length, and figure I-15b shows averaged half-crack length as a function of fatigue cycles.

Table I-5. Half-crack length during pre-cracking for the UDA repair (tabular)

Cycles	Visual	
	a _{AFT} (in.)	a _{FWD} (in.)
250	1.425	1.400
400	1.425	1.400
600	1.440	1.440
700	1.440	1.440
900	1.440	1.440
1000	1.440	1.450
1100	1.450	1.450
1200	1.465	1.450
1400	1.475	1.470

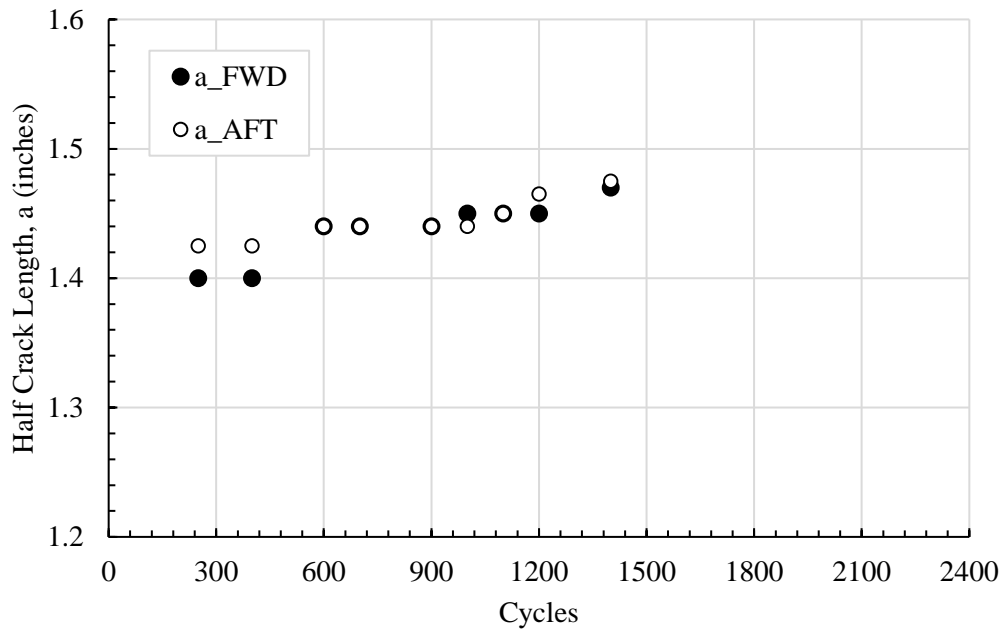


Figure I-13. Half-crack length during pre-cracking for the UDA repair

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
0	1.5	1.475	1.4875	1.55	1.525	1.5375	1.56	1.5	1.53
1000	1.55	1.5	1.525						
2000	1.55	1.5	1.525						
3000	1.55	1.5	1.525						
4000	1.55	1.5	1.525						
5000	1.55	1.5	1.525	1.55	1.55	1.55	1.5	1.4	1.45
5001	1.55	1.5	1.525						
5200	1.55	1.5	1.525						
5400	1.55	1.5	1.525						
5600	1.55	1.5	1.525						
5600	1.55	1.5	1.525						
6000	1.55	1.525	1.5375						
6200	1.55	1.525	1.5375						
6400	1.55	1.525	1.5375						
6600	1.55	1.525	1.5375						
6800	1.55	1.525	1.5375						
7000	1.55	1.525	1.5375						
7600	1.55	1.525	1.5375						
7800	1.55	1.55	1.55						
8000	1.55	1.55	1.55						
8200	1.55	1.55	1.55						
8400	1.55	1.55	1.55						
8800	1.55	1.55	1.55						
9200	1.55	1.55	1.55						
8600	1.55	1.55	1.55						
9400	1.575	1.55	1.5625						
9600	1.575	1.55	1.5625						
9800	1.575	1.55	1.5625						
10000	1.575	1.55	1.5625	1.6	1.575	1.5875	1.6	1.55	1.575
10200	1.575	1.55	1.5625						
10400	1.575	1.55	1.5625						
10600	1.6	1.55	1.575						
10800	1.6	1.575	1.5875						
11000	1.6	1.575	1.5875						
11200	1.6	1.575	1.5875						
11600	1.6	1.6	1.6						
11800	1.6	1.6	1.6						
12000	1.6	1.6	1.6						
12200	1.6	1.6	1.6						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
12400	1.6	1.6	1.6						
11400	1.6	1.6	1.6						
12600	1.625	1.6	1.6125						
12800	1.625	1.6	1.6125						
13400	1.625	1.625	1.625						
13600	1.625	1.625	1.625						
13800	1.625	1.625	1.625						
14000	1.625	1.625	1.625						
14200	1.625	1.625	1.625						
14400	1.65	1.625	1.6375						
14600	1.65	1.625	1.6375						
14800	1.65	1.625	1.6375						
15000	1.65	1.625	1.6375	1.65	1.675	1.6625	1.72	1.68	1.7
15200	1.65	1.65	1.65						
15400	1.65	1.65	1.65						
15600	1.65	1.65	1.65						
15800	1.65	1.65	1.65						
16000	1.65	1.65	1.65						
16200	1.65	1.65	1.65						
16400	1.65	1.65	1.65						
16600	1.65	1.65	1.65						
16800	1.65	1.65	1.65						
17000	1.6625	1.675	1.66875						
17200	1.675	1.675	1.675						
17400	1.675	1.675	1.675						
17600	1.675	1.675	1.675						
17800	1.675	1.675	1.675						
18000	1.675	1.675	1.675						
18200	1.675	1.675	1.675						
18400	1.675	1.675	1.675						
18600	1.675	1.675	1.675						
18800	1.675	1.675	1.675						
19000	1.675	1.675	1.675						
19200	1.7	1.675	1.6875						
19400	1.7	1.675	1.6875						
19600	1.7	1.675	1.6875						
19800	1.7	1.675	1.6875						
20000	1.7	1.675	1.6875	1.7	1.75	1.725	1.72	1.7	1.71
20200	1.7	1.7	1.7						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
20400	1.7	1.7	1.7						
20600	1.7	1.7	1.7						
20800	1.7	1.7	1.7						
21000	1.725	1.75	1.7375						
21200	1.725	1.75	1.7375						
21400	1.725	1.75	1.7375						
21600	1.725	1.75	1.7375						
21800	1.725	1.75	1.7375						
22000	1.725	1.75	1.7375						
22200	1.725	1.75	1.7375						
22400	1.725	1.75	1.7375						
22600	1.725	1.75	1.7375						
22800	1.725	1.75	1.7375						
23000	1.725	1.75	1.7375						
23200	1.725	1.75	1.7375						
23400	1.725	1.75	1.7375						
23600	1.725	1.75	1.7375						
23800	1.725	1.775	1.75						
24000	1.725	1.775	1.75						
24200	1.725	1.775	1.75						
24400	1.725	1.7875	1.75625						
24600	1.725	1.7875	1.75625						
24800	1.725	1.7875	1.75625						
25000	1.725	1.7875	1.75625	1.8	1.825	1.8125	1.85	1.82	1.835
25200	1.8	1.8	1.8						
25400	1.8	1.8	1.8						
25600	1.8	1.8	1.8						
25800	1.85	1.8	1.825						
26000	1.85	1.8	1.825						
26200	1.85	1.8	1.825						
26400	1.85	1.8	1.825						
26600	1.85	1.8	1.825						
26800	1.85	1.8	1.825						
27000	1.85	1.8	1.825						
27200	1.85	1.8	1.825						
27400	1.85	1.8	1.825						
27600	1.85	1.8	1.825						
27800	1.85	1.8	1.825						
28000	1.8625	1.8	1.83125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
28200	1.8625	1.8	1.83125						
28400	1.875	1.8	1.8375						
28600	1.875	1.85	1.8625						
28800	1.875	1.85	1.8625						
29000	1.875	1.85	1.8625						
29200	1.875	1.85	1.8625						
29400	1.875	1.85	1.8625						
29600	1.875	1.85	1.8625						
29800	1.875	1.85	1.8625						
30000	1.875	1.85	1.8625	1.9	1.9	1.9	1.88	1.84	1.86
30200	1.875	1.85	1.8625						
30400	1.875	1.85	1.8625						
30600	1.875	1.85	1.8625						
30800	1.875	1.85	1.8625						
31000	1.875	1.85	1.8625						
31200	1.875	1.85	1.8625						
31400	1.875	1.85	1.8625						
31600	1.875	1.85	1.8625						
31800	1.875	1.85	1.8625						
32000	1.875	1.85	1.8625						
32200	1.875	1.85	1.8625						
32400	1.9	1.85	1.875						
32600	1.9	1.85	1.875						
32800	1.9	1.85	1.875						
33000	1.9	1.875	1.8875						
33200	1.9	1.875	1.8875						
33400	1.9	1.875	1.8875						
33600	1.9	1.9	1.9						
33800	1.9	1.9	1.9						
34000	1.9	1.9	1.9						
34200	1.9	1.9	1.9						
34400	1.9	1.9	1.9						
34600	1.925	1.9	1.9125						
34800	1.925	1.9	1.9125						
35000	1.95	1.9375	1.94375						
35200	1.95	1.9375	1.94375						
35400	1.95	1.9375	1.94375						
35600	1.95	1.9375	1.94375						
35800	1.95	1.95	1.95						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
36000	1.95	1.95	1.95						
36200	1.95	1.95	1.95						
36400	1.95	1.95	1.95						
36600	1.975	1.95	1.9625						
36800	1.975	1.95	1.9625						
37000	1.975	1.95	1.9625						
37200	1.975	1.95	1.9625						
37400	1.975	1.95	1.9625						
37600	1.975	1.95	1.9625						
37800	1.975	1.95	1.9625						
38000	1.975	1.95	1.9625						
38200	1.975	1.95	1.9625						
38400	1.975	1.95	1.9625						
38600	1.975	1.95	1.9625						
38800	1.975	1.95	1.9625						
39000	2	1.95	1.975						
39200	2	1.95	1.975						
39400	2	1.95	1.975						
39600	2	1.95	1.975						
39800	2	1.95	1.975						
40000	2	1.95	1.975	2	2	2	1.95	1.95	1.95
40200	2	1.95	1.975						
40400	2	1.95	1.975						
40600	2	1.95	1.975						
40800	2	1.95	1.975						
41000	2	1.9625	1.98125						
41200	2	1.9625	1.98125						
41400	2	1.9625	1.98125						
41600	2	1.9625	1.98125						
41800	2	1.9625	1.98125						
42000	2.025	2	2.0125						
42200	2.025	2	2.0125						
42400	2.025	2	2.0125						
42600	2.025	2	2.0125						
42800	2.025	2	2.0125						
43000	2.025	2	2.0125						
43200	2.0375	2	2.01875						
43400	2.0375	2	2.01875						
43600	2.0375	2	2.01875						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
43800	2.0375	2	2.01875						
44000	2.0375	2.025	2.03125						
44200	2.0375	2.025	2.03125						
44400	2.0375	2.025	2.03125						
44600	2.0375	2.025	2.03125						
44800	2.0375	2.025	2.03125						
45000	2.0375	2.0375	2.0375						
45200	2.0375	2.0375	2.0375						
45400	2.05	2.025	2.0375						
45600	2.05	2.025	2.0375						
45800	2.05	2.05	2.05						
46000	2.075	2.05	2.0625						
46200	2.075	2.05	2.0625						
46400	2.075	2.05	2.0625						
46600	2.075	2.05	2.0625						
46800	2.075	2.05	2.0625						
47000	2.075	2.05	2.0625						
47200	2.1	2.05	2.075						
47400	2.1	2.05	2.075						
47600	2.1	2.05	2.075						
47800	2.1	2.075	2.0875						
48000	2.1	2.05	2.075						
48200	2.1	2.075	2.0875						
48400	2.1	2.075	2.0875						
48600	2.1	2.075	2.0875						
48800	2.1	2.075	2.0875						
49000	2.1	2.075	2.0875						
49200	2.1	2.075	2.0875						
49400	2.1	2.075	2.0875						
49600	2.1	2.075	2.0875						
49800	2.1	2.075	2.0875						
50000	2.1	2.075	2.0875	2.125	2.15	2.1375	2.03	2.1	2.065
50200	2.1	2.075	2.0875						
50400	2.1	2.125	2.1125						
50600	2.1	2.125	2.1125						
50800	2.1	2.125	2.1125						
51000	2.1	2.125	2.1125						
51200	2.1	2.125	2.1125						
51400	2.1	2.125	2.1125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
51600	2.1	2.125	2.1125						
51800	2.1	2.125	2.1125						
52000	2.1	2.125	2.1125						
52200	2.1	2.125	2.1125						
52400	2.1	2.125	2.1125						
52600	2.1	2.125	2.1125						
52800	2.1	2.125	2.1125						
53000	2.1	2.125	2.1125						
53200	2.125	2.1375	2.13125						
53400	2.125	2.1375	2.13125						
53600	2.125	2.1375	2.13125						
53800	2.125	2.1375	2.13125						
54000	2.125	2.1375	2.13125						
54200	2.125	2.15	2.1375						
54400	2.125	2.15	2.1375						
54600	2.125	2.15	2.1375						
54800	2.125	2.15	2.1375						
55000	2.125	2.15	2.1375						
55200	2.15	2.15	2.15						
55400	2.15	2.15	2.15						
55600	2.1625	2.15	2.15625						
55800	2.1625	2.15	2.15625						
56000	2.1625	2.15	2.15625						
56200	2.1625	2.15	2.15625						
56400	2.1625	2.15	2.15625						
56600	2.1625	2.175	2.16875						
56800	2.1875	2.175	2.18125						
57000	2.1875	2.175	2.18125						
57200	2.1875	2.175	2.18125						
57400	2.1625	2.175	2.16875						
57600	2.1625	2.175	2.16875						
57800	2.1875	2.175	2.18125						
58000	2.1875	2.175	2.18125						
58200	2.1875	2.175	2.18125						
58400	2.1875	2.175	2.18125						
58600	2.2	2.175	2.1875						
58800	2.2	2.225	2.2125						
59000	2.2	2.225	2.2125						
59200	2.2	2.225	2.2125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
59400	2.2	2.225	2.2125						
59600	2.2	2.225	2.2125						
59800	2.2	2.225	2.2125						
60000	2.2	2.225	2.2125	2.225	2.25	2.2375	2.18	2.17	2.175
60100	2.2	2.225	2.2125						
60200	2.2	2.225	2.2125						
60400	2.2	2.225	2.2125						
60600	2.2	2.225	2.2125						
61000	2.2	2.225	2.2125						
61200	2.2	2.2125	2.20625						
61400	2.2	2.2125	2.20625						
61600	2.2	2.225	2.2125						
61800	2.2	2.225	2.2125						
62600	2.2	2.225	2.2125						
63000	2.2	2.225	2.2125						
63400	2.2	2.225	2.2125						
63800	2.2	2.225	2.2125						
64000	2.2	2.225	2.2125						
64400	2.2	2.225	2.2125						
64800	2.2	2.225	2.2125						
65000	2.2	2.225	2.2125						
65400	2.2	2.225	2.2125						
65800	2.25	2.225	2.2375						
66000	2.25	2.225	2.2375						
66400	2.25	2.225	2.2375						
66800	2.25	2.225	2.2375						
67000	2.275	2.225	2.25						
67400	2.275	2.225	2.25						
67800	2.275	2.225	2.25						
68000	2.275	2.225	2.25						
68400	2.275	2.225	2.25						
68800	2.275	2.225	2.25						
69200	2.275	2.225	2.25						
69600	2.275	2.225	2.25						
70000	2.275	2.225	2.25						
70400	2.275	2.25	2.2625						
70800	2.275	2.25	2.2625						
71400	2.3	2.25	2.275						
71800	2.3	2.25	2.275						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
72400	2.3	2.25	2.275						
72800	2.3	2.25	2.275						
73400	2.3	2.25	2.275						
73800	2.3	2.25	2.275						
74400	2.3	2.25	2.275						
74800	2.325	2.275	2.3						
75400	2.35	2.3	2.325						
75800	2.35	2.3	2.325						
76400	2.35	2.3	2.325						
76800	2.35	2.3	2.325						
77200	2.35	2.35	2.35						
77600	2.35	2.35	2.35						
78000	2.35	2.35	2.35						
78400	2.35	2.35	2.35						
78800	2.35	2.35	2.35						
79200	2.35	2.35	2.35						
79600	2.35	2.35	2.35						
80000	2.35	2.35	2.35	2.4	2.35	2.375	2.5	2.19	2.345
80200	2.35	2.35	2.35						
80400	2.35	2.35	2.35						
80600	2.35	2.35	2.35						
80800	2.35	2.35	2.35						
81000	2.35	2.35	2.35						
81300	2.35	2.35	2.35						
81500	2.35	2.4	2.375						
81700	2.375	2.4	2.3875						
82000	2.3875	2.4	2.39375						
82200	2.3875	2.4	2.39375						
82400	2.3875	2.4	2.39375						
82600	2.4	2.4	2.4						
82800	2.4	2.4	2.4						
83000	2.4	2.4	2.4						
83400	2.4	2.4	2.4						
83500	2.4	2.4	2.4						
83600	2.4	2.4	2.4						
83800	2.4	2.4	2.4						
84000	2.4	2.4	2.4						
84200	2.4	2.4	2.4						
84600	2.4	2.4	2.4						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)	a _{AFT} (inches)	a _{FWD} (inches)	a _{AVG} (inches)
84800	2.4	2.4	2.4						
84800	2.4	2.4	2.4						
85000	2.4	2.4	2.4						
85200	2.4	2.4	2.4						
85400	2.4	2.4	2.4						
85500	2.4	2.4	2.4						
85600	2.4	2.4	2.4						
85800	2.4	2.4	2.4						
86000	2.4	2.4	2.4						
86200	2.4	2.4	2.4						
86400	2.4	2.4	2.4						
86500	2.4	2.4	2.4						
86600	2.4	2.4	2.4						
86800	2.4	2.4	2.4						
87000	2.4	2.4	2.4						
87200	2.4	2.4	2.4						
87400	2.425	2.4	2.4125						
87500	2.425	2.4	2.4125						
87600	2.425	2.4	2.4125						
87800	2.425	2.4	2.4125						
88000	2.425	2.4	2.4125						
88200	2.425	2.4	2.4125						
88400	2.425	2.4	2.4125						
88500	2.425	2.4	2.4125						
88600	2.425	2.4	2.4125						
88800	2.425	2.4	2.4125						
89000	2.425	2.4	2.4125						
89200	2.425	2.4	2.4125						
89400	2.425	2.425	2.425						
89600	2.425	2.425	2.425						
89800	2.425	2.425	2.425						
90000	2.425	2.425	2.425	2.475	2.45	2.4625	2.5	2.4	2.45

Figure I-14. Half-crack length data during fatigue for the UDA repair (tabular)

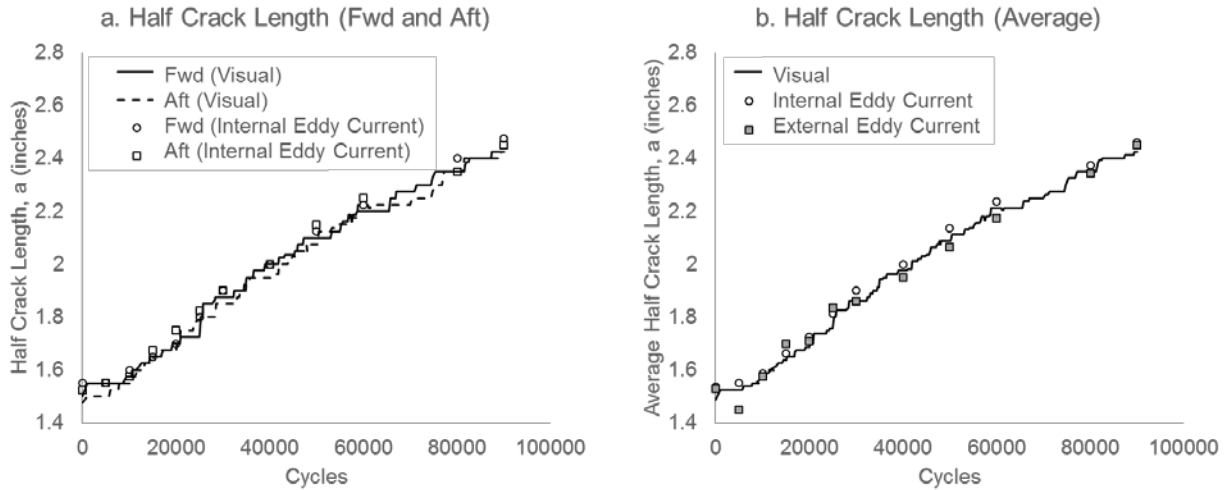


Figure I-15. The UDA repair crack-growth data during fatigue (90,000 cycles): (a) fwd and aft half-crack length and (b) average half-crack length

UNDER-DESIGNED DISBOND B/EP REPAIRS

Table I-6 provides the half-crack length data of under-designed disband (UDB) B/Ep repair during pre-cracking. Figure I-16 shows the corresponding half-crack length as a function of fatigue cycles. Figure I-17 provides the half-crack length data during fatigue cycling. Figure I-18a shows the fwd and aft half-crack length, and figure I-18b shows the averaged half-crack length as a function of fatigue cycles.

Table I-6. Half-crack length during pre-cracking for the UDB repair (tabular)

Cycles	Visual	
	a _{AFT} (in.)	a _{FWD} (in.)
250	1.400	1.425
400	1.450	1.425
600	1.450	1.425
700	1.450	1.425
900	1.450	1.425
1000	1.450	1.450
1100	1.460	1.460
1200	1.475	1.480
1400	1.480	1.500

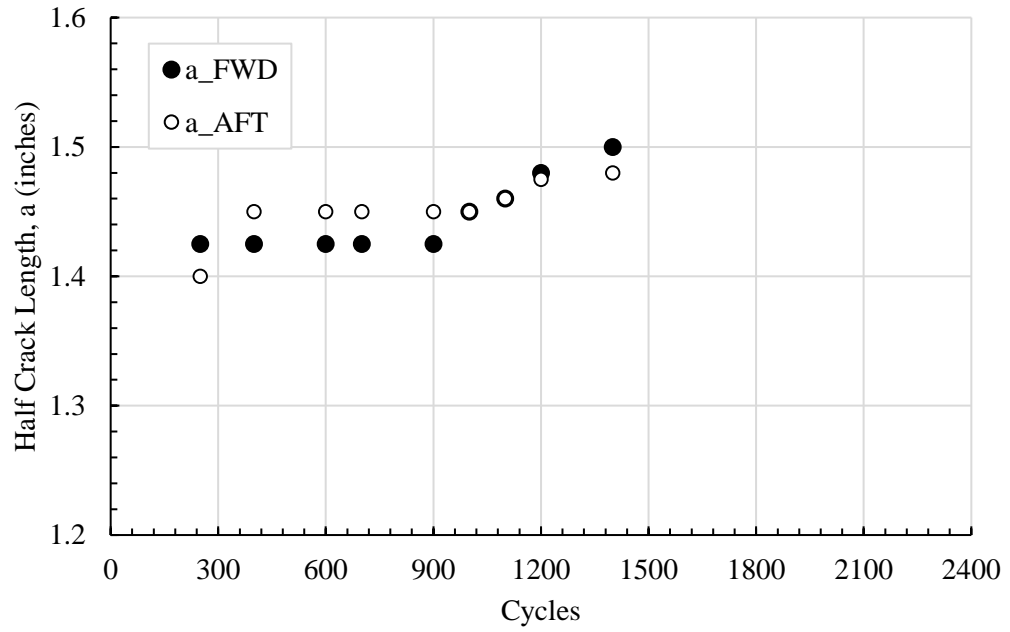


Figure I-16. Half-crack length during pre-cracking for the UDB repair

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
0	1.525	1.55	1.5375	1.55	1.55	1.55	1.45	1.6	1.525
1000	1.525	1.55	1.5375						
2000	1.55	1.55	1.55						
3000	1.55	1.55	1.55						
4000	1.55	1.55	1.55						
5000	1.575	1.575	1.575	1.6	1.6	1.6	1.55	1.55	1.55
5001	1.575	1.55	1.5625						
5200	1.575	1.575	1.575						
5400	1.575	1.6	1.5875						
5600	1.575	1.6	1.5875						
5600	1.575	1.6	1.5875						
6000	1.575	1.6	1.5875						
6200	1.575	1.6	1.5875						
6400	1.6	1.6	1.6						
6600	1.6	1.625	1.6125						
6800	1.6	1.625	1.6125						
7000	1.6	1.625	1.6125						
7600	1.6	1.625	1.6125						
7800	1.6	1.625	1.6125						
8000	1.6	1.625	1.6125						
8200	1.6	1.625	1.6125						
8400	1.625	1.65	1.6375						
8800	1.625	1.65	1.6375						
9200	1.625	1.65	1.6375						
8600	1.625	1.65	1.6375						
9400	1.6375	1.65	1.64375						
9600	1.6375	1.65	1.64375						
9800	1.65	1.65	1.65						
10000	1.65	1.65	1.65	1.65	1.675	1.6625	1.75	1.7	1.725
10200	1.65	1.65	1.65						
10400	1.65	1.65	1.65						
10600	1.65	1.65	1.65						
10800	1.65	1.675	1.6625						
11000	1.65	1.675	1.6625						
11200	1.65	1.7	1.675						
11600	1.675	1.6875	1.68125						
11800	1.675	1.7	1.6875						
12000	1.675	1.7	1.6875						
12200	1.675	1.7	1.6875						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
12400	1.675	1.7	1.6875						
11400	1.65	1.675	1.6625						
12600	1.675	1.7	1.6875						
12800	1.6875	1.7	1.69375						
13400	1.7	1.7	1.7						
13600	1.7	1.7	1.7						
13800	1.7	1.7	1.7						
14000	1.7	1.7	1.7						
14200	1.7	1.7	1.7						
14400	1.7	1.7	1.7						
14600	1.7	1.7	1.7						
14800	1.725	1.725	1.725						
15000	1.725	1.725	1.725	1.725	1.775	1.75	1.76	2.02	1.89
15200	1.725	1.725	1.725						
15400	1.725	1.725	1.725						
15600	1.725	1.725	1.725						
15800	1.725	1.725	1.725						
16000	1.725	1.75	1.7375						
16200	1.725	1.75	1.7375						
16400	1.725	1.75	1.7375						
16600	1.725	1.75	1.7375						
16800	1.7375	1.75	1.74375						
17000	1.75	1.75	1.75						
17200	1.75	1.75	1.75						
17400	1.75	1.75	1.75						
17600	1.75	1.75	1.75						
17800	1.75	1.75	1.75						
18000	1.75	1.75	1.75						
18200	1.775	1.75	1.7625						
18400	1.775	1.75	1.7625						
18600	1.775	1.775	1.775						
18800	1.775	1.775	1.775						
19000	1.775	1.8	1.7875						
19200	1.775	1.8	1.7875						
19400	1.775	1.8	1.7875						
19600	1.775	1.8	1.7875						
19800	1.7875	1.8125	1.8						
20000	1.7875	1.8125	1.8	1.8	1.85	1.825	1.85	1.89	1.87
20200	1.8	1.825	1.8125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
20400	1.8	1.825	1.8125						
20600	1.8	1.825	1.8125						
20800	1.825	1.85	1.8375						
21000	1.825	1.85	1.8375						
21200	1.825	1.85	1.8375						
21400	1.825	1.85	1.8375						
21600	1.85	1.85	1.85						
21800	1.825	1.875	1.85						
22000	1.825	1.875	1.85						
22200	1.85	1.875	1.8625						
22400	1.85	1.875	1.8625						
22600	1.85	1.875	1.8625						
22800	1.85	1.875	1.8625						
23000	1.85	1.875	1.8625						
23200	1.85	1.875	1.8625						
23400	1.85	1.89	1.87						
23600	1.85	1.875	1.8625						
23800	1.85	1.875	1.8625						
24000	1.85	1.9	1.875						
24200	1.85	1.9	1.875						
24400	1.85	1.9	1.875						
24600	1.85	1.9	1.875						
24800	1.85	1.9	1.875						
25000	1.85	1.9	1.875	1.875	1.9	1.8875	1.9	2	1.95
25200	1.875	1.9	1.8875						
25400	1.875	1.9	1.8875						
25600	1.875	1.9	1.8875						
25800	1.875	1.9	1.8875						
26000	1.875	1.9	1.8875						
26200	1.9	1.9	1.9						
26400	1.9	1.9	1.9						
26600	1.9	1.925	1.9125						
26800	1.9	1.95	1.925						
27000	1.9	1.95	1.925						
27200	1.9	1.95	1.925						
27400	1.9	1.95	1.925						
27600	1.9	1.95	1.925						
27800	1.9	1.95	1.925						
28000	1.925	1.95	1.9375						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
28200	1.925	1.95	1.9375						
28400	1.925	1.95	1.9375						
28600	1.925	1.95	1.9375						
28800	1.925	1.975	1.95						
29000	1.925	1.975	1.95						
29200	1.9375	1.975	1.95625						
29400	1.9375	1.975	1.95625						
29600	1.9375	1.975	1.95625						
29800	1.9375	1.975	1.95625						
30000	1.95	1.975	1.9625	1.95	2	1.975	1.95	2	1.975
30200	1.95	1.975	1.9625						
30400	1.95	1.975	1.9625						
30600	1.95	2	1.975						
30800	1.95	2	1.975						
31000	1.95	2	1.975						
31200	1.95	2	1.975						
31400	1.95	2	1.975						
31600	1.95	2	1.975						
31800	1.95	2	1.975						
32000	1.95	2	1.975						
32200	1.95	2	1.975						
32400	1.95	2	1.975						
32600	2	2.05	2.025						
32800	2	2.05	2.025						
33000	2	2.05	2.025						
33200	2	2.05	2.025						
33400	2	2.05	2.025						
33600	2	2.05	2.025						
33800	2	2.05	2.025						
34000	2	2.05	2.025						
34200	2	2.05	2.025						
34400	2	2.05	2.025						
34600	2	2.05	2.025						
34800	2	2.05	2.025						
35000	2.025	2.05	2.0375						
35200	2.025	2.075	2.05						
35400	2.025	2.075	2.05						
35600	2.025	2.075	2.05						
35800	2.025	2.075	2.05						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
36000	2.025	2.1	2.0625						
36200	2.05	2.1	2.075						
36400	2.05	2.1	2.075						
36600	2.05	2.1	2.075						
36800	2.05	2.1	2.075						
37000	2.05	2.1	2.075						
37200	2.05	2.1	2.075						
37400	2.05	2.1	2.075						
37600	2.05	2.1	2.075						
37800	2.05	2.1	2.075						
38000	2.05	2.125	2.0875						
38200	2.05	2.125	2.0875						
38400	2.05	2.125	2.0875						
38600	2.05	2.125	2.0875						
38800	2.05	2.125	2.0875						
39000	2.05	2.125	2.0875						
39200	2.1	2.15	2.125						
39400	2.1	2.15	2.125						
39600	2.1	2.15	2.125						
39800	2.1	2.1625	2.13125	2.15	2.175	2.1625	2.1	2.2	2.15
40000	2.1	2.1625	2.13125						
40200	2.1	2.1625	2.13125						
40400	2.1	2.1625	2.13125						
40600	2.1	2.1625	2.13125						
40800	2.1	2.1625	2.13125						
41000	2.1	2.175	2.1375						
41200	2.1	2.175	2.1375						
41400	2.1	2.175	2.1375						
41600	2.1	2.175	2.1375						
41800	2.1	2.175	2.1375						
42000	2.1	2.1875	2.14375						
42200	2.1	2.1875	2.14375						
42400	2.1	2.1875	2.14375						
42600	2.1	2.1875	2.14375						
42800	2.15	2.1875	2.16875						
43000	2.15	2.1875	2.16875						
43200	2.15	2.2125	2.18125						
43400	2.15	2.2125	2.18125						
43600	2.15	2.2125	2.18125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
43800	2.15	2.2125	2.18125						
44000	2.1625	2.2125	2.1875						
44200	2.1625	2.225	2.19375						
44400	2.1625	2.225	2.19375						
44600	2.1625	2.225	2.19375						
44800	2.175	2.1875	2.18125						
45000	2.175	2.2375	2.20625						
45200	2.175	2.2375	2.20625						
45400	2.175	2.25	2.2125						
45600	2.175	2.25	2.2125						
45800	2.2	2.25	2.225						
46000	2.2	2.25	2.225						
46200	2.2	2.225	2.2125						
46400	2.2	2.275	2.2375						
46600	2.2	2.275	2.2375						
46800	2.2	2.275	2.2375						
47000	2.2	2.275	2.2375						
47200	2.2	2.3	2.25						
47400	2.2	2.3	2.25						
47600	2.2	2.3	2.25						
47800	2.2	2.3125	2.25625						
48000	2.2	2.3	2.25						
48200	2.2	2.3125	2.25625						
48400	2.2	2.3125	2.25625						
48600	2.225	2.325	2.275						
48800	2.225	2.325	2.275						
49000	2.225	2.325	2.275						
49200	2.225	2.325	2.275						
49400	2.25	2.325	2.2875						
49600	2.25	2.325	2.2875						
49800	2.25	2.325	2.2875						
50000	2.25	2.325	2.2875	2.3	2.375	2.3375	2.4	2.4	2.4
50200	2.25	2.325	2.2875						
50400	2.25	2.35	2.3						
50600	2.25	2.35	2.3						
50800	2.25	2.35	2.3						
51000	2.25	2.375	2.3125						
51200	2.3	2.375	2.3375						
51400	2.3	2.35	2.325						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
51600	2.3375	2.375	2.35625						
51800	2.3375	2.375	2.35625						
52000	2.3375	2.375	2.35625						
52200	2.3375	2.375	2.35625						
52400	2.35	2.375	2.3625						
52600	2.35	2.375	2.3625						
52800	2.35	2.3875	2.36875						
53000	2.35	2.4	2.375						
53200	2.35	2.4	2.375						
53400	2.4	2.4	2.4						
53600	2.4	2.4	2.4						
53800	2.4	2.4	2.4						
54000	2.4	2.4	2.4						
54200	2.4	2.4	2.4						
54400	2.4	2.4125	2.40625						
54600	2.4125	2.4125	2.4125						
54800	2.4125	2.425	2.41875						
55000	2.4125	2.425	2.41875						
55200	2.4125	2.45	2.43125						
55400	2.4125	2.45	2.43125						
55600	2.4125	2.45	2.43125						
55800	2.425	2.45	2.4375						
56000	2.425	2.45	2.4375						
56200	2.425	2.4625	2.44375						
56400	2.45	2.4625	2.45625						
56600	2.45	2.4625	2.45625						
56800	2.45	2.4625	2.45625						
57000	2.45	2.475	2.4625						
57200	2.45	2.475	2.4625						
57400	2.45	2.475	2.4625						
57600	2.475	2.475	2.475						
57800	2.475	2.475	2.475						
58000	2.475	2.5	2.4875						
58200	2.475	2.5	2.4875						
58400	2.475	2.5	2.4875						
58600	2.475	2.5	2.4875						
58800	2.5	2.525	2.5125						
59000	2.5	2.525	2.5125						
59200	2.5	2.525	2.5125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
59400	2.5	2.525	2.5125						
59600	2.5125	2.5375	2.525						
59800	2.5125	2.5375	2.525						
60000	2.5125	2.5375	2.525	2.525	2.5625	2.54375	2.65	2.6	2.625
60100	2.5125	2.5375	2.525						
60200	2.5125	2.5375	2.525						
60400	2.5125	2.5375	2.525						
60600	2.5125	2.5375	2.525						
61000	2.5125	2.575	2.54375						
61200	2.5125	2.575	2.54375						
61400	2.5125	2.575	2.54375						
61600	2.5125	2.575	2.54375						
61800	2.5125	2.575	2.54375						
62600	2.5125	2.575	2.54375						
63000	2.5125	2.575	2.54375						
63400	2.55	2.575	2.5625						
63800	2.55	2.575	2.5625						
64000	2.55	2.6125	2.58125						
64400	2.575	2.625	2.6						
64800	2.575	2.625	2.6						
65000	2.575	2.625	2.6						
65400	2.575	2.625	2.6						
65800	2.575	2.625	2.6						
66000	2.575	2.625	2.6						
66400	2.6	2.625	2.6125						
66800	2.6	2.625	2.6125						
67000	2.6	2.625	2.6125						
67400	2.625	2.65	2.6375						
67800	2.625	2.65	2.6375						
68000	2.625	2.65	2.6375						
68400	2.6375	2.675	2.65625						
68800	2.6375	2.675	2.65625						
69200	2.6375	2.675	2.65625						
69600	2.6375	2.675	2.65625						
70000	2.6375	2.675	2.65625						
70400	2.6625	2.7	2.68125						
70800	2.7	2.7	2.7						
71400	2.7	2.725	2.7125						
71800	2.7	2.725	2.7125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
72400	2.7	2.725	2.7125						
72800	2.7	2.75	2.725						
73400	2.725	2.75	2.7375						
73800	2.725	2.75	2.7375						
74400	2.75	2.75	2.75						
74800	2.75	2.775	2.7625						
75400	2.75	2.775	2.7625						
75800	2.75	2.775	2.7625						
76400	2.75	2.775	2.7625						
76800	2.75	2.775	2.7625						
77200	2.8	2.775	2.7875						
77600	2.8	2.8	2.8						
78000	2.8	2.8	2.8						
78400	2.8	2.8	2.8						
78800	2.8	2.8	2.8						
79200	2.825	2.825	2.825						
79600	2.825	2.825	2.825						
80000	2.825	2.825	2.825	2.85	2.85	2.85	2.875	2.9	2.8875
80100	2.85	2.875	2.8625						
80400	2.85	2.875	2.8625						
80600	2.85	2.89	2.87						
80800	2.85	2.875	2.8625						
81000	2.85	2.875	2.8625						
81300	2.85	2.875	2.8625						
81500	2.85	2.9	2.875						
81700	2.85	2.9	2.875						
82000	2.8625	2.9	2.88125						
82200	2.8625	2.9	2.88125						
82400	2.8625	2.9	2.88125						
82600	2.8625	2.9	2.88125						
82800	2.875	2.9	2.8875						
83000	2.875	2.9	2.8875						
83400	2.875	2.9	2.8875						
83500	2.9	2.9	2.9						
83600	2.9	2.9	2.9						
83800	2.9	2.925	2.9125						
84000	2.9	2.925	2.9125						
84200	2.925	2.925	2.925						
84600	2.925	2.925	2.925						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
84800	2.925	2.925	2.925						
84800	2.925	2.925	2.925						
85000	2.925	2.925	2.925						
85200	2.925	2.95	2.9375						
85400	2.925	2.95	2.9375						
85500	2.925	2.95	2.9375						
85600	2.925	2.95	2.9375						
85800	2.925	2.95	2.9375						
86000	2.925	2.95	2.9375						
86200	2.925	2.95	2.9375						
86400	2.925	2.95	2.9375						
86500	2.925	2.95	2.9375						
86600	2.925	2.95	2.9375						
86800	2.925	2.95	2.9375						
87000	2.975	2.95	2.9625						
87200	2.975	2.975	2.975						
87400	2.975	2.975	2.975						
87500	2.975	2.975	2.975						
87600	2.975	2.975	2.975						
87800	2.975	2.975	2.975						
88000	2.975	2.975	2.975						
88200	2.975	2.975	2.975						
88400	2.975	2.975	2.975						
88500	2.975	2.975	2.975						
88600	2.975	2.975	2.975						
88800	2.975	2.975	2.975						
89000	2.975	2.975	2.975						
89200	2.975	3	2.9875						
89400	3	3	3						
89600	3	3	3						
89800	3	3	3						
90000	3	3	3	3.075	3.05	3.0625	2.9	3.1	3

Figure I-17. Half-crack length data during fatigue for the UDB repair (tabular)

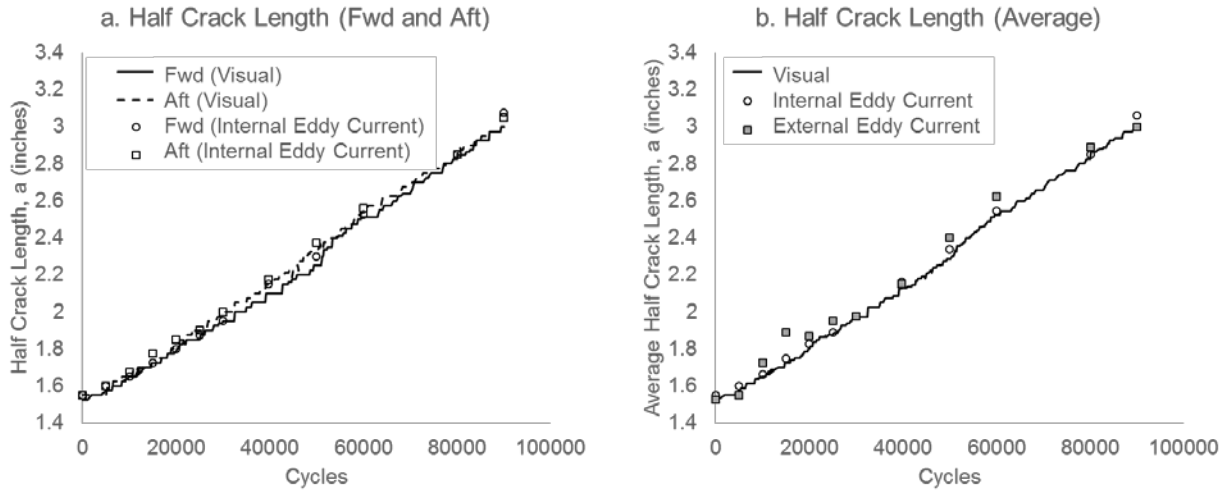


Figure I-18. The UDB repair crack-growth data during fatigue (90,000 cycles): (a) forward and aft half-crack length and (b) average half-crack length

HAND-SANDED REPAIRS

Hand-sanded (HS) aluminum repairs were subjected to hot-wet conditions to 20,000 cycles and cold-dry conditions to 20,000 cycles.

HS ALUMINUM REPAIRS

Table I-7 provides the half-crack length data of HS repair during pre-cracking. Figure I-19 shows the corresponding half-crack length as a function of fatigue cycles. Figure I-20 provides the half-crack length data during fatigue cycling. Figure I-21a shows the fwd and aft half-crack length, and figure I-21b shows averaged half-crack length as a function of fatigue cycles.

Table I-7. Half-crack length during pre-cracking for the HS repair (tabular)

Cycles	Visual	
	a _{AFT} (in.)	a _{FWD} (in.)
600		1.42
800		1.43
1000	1.427	1.443
1100	1.438	1.462
1200	1.445	1.464
1400	1.447	1.465
1500	1.449	1.47
1600	1.453	1.472
1700	1.457	1.478
1800	1.466	1.487
1900	1.471	1.495
2000	1.477	1.498
2083	1.481	1.5

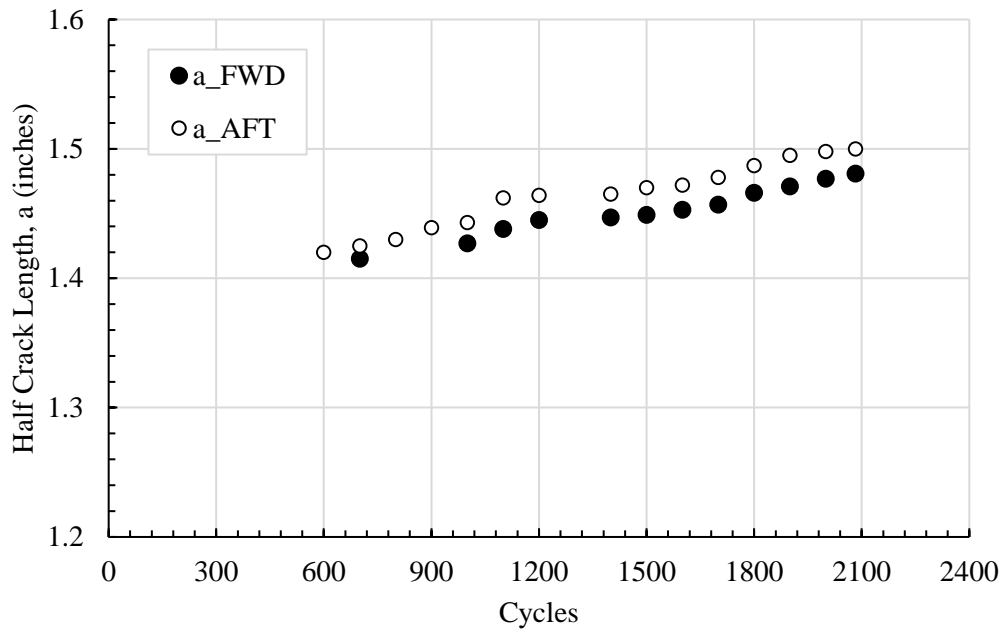


Figure I-19. Half-crack length during pre-cracking for the HS repair

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
0	1.525	1.525	1.525	1.55	1.55	1.55	1.47	1.563	1.5165
100	1.525	1.525	1.525						
200	1.525	1.525	1.525						
400	1.525	1.525	1.525						
600	1.525	1.525	1.525						
1000	1.525	1.5375	1.53125						
1200	1.525	1.5375	1.53125						
1400	1.525	1.5375	1.53125						
1600	1.525	1.5375	1.53125						
1800	1.525	1.5375	1.53125						
2600	1.525	1.5375	1.53125						
3000	1.525	1.5375	1.53125						
3400	1.525	1.5375	1.53125						
3800	1.525	1.5375	1.53125						
4000	1.525	1.5375	1.53125						
4400	1.525	1.5375	1.53125						
4800	1.525	1.5375	1.53125						
5000	1.525	1.5375	1.53125						
5400	1.525	1.5375	1.53125						
5800	1.525	1.5375	1.53125						
6000	1.525	1.5375	1.53125						
6400	1.525	1.5375	1.53125						
6800	1.525	1.5375	1.53125						
7000	1.525	1.5375	1.53125						
7400	1.525	1.5375	1.53125						
7800	1.525	1.5375	1.53125						
8000	1.525	1.5375	1.53125						
8400	1.525	1.5375	1.53125						
8800	1.525	1.5375	1.53125						
9200	1.525	1.5375	1.53125						
9600	1.525	1.5375	1.53125						
10000	1.525	1.5375	1.53125						
10400	1.525	1.5375	1.53125						
10800	1.525	1.5375	1.53125						
11400	1.525	1.5375	1.53125						
11800	1.525	1.5375	1.53125						
12400	1.525	1.5375	1.53125						
12800	1.525	1.5375	1.53125						
13400	1.525	1.5375	1.53125						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
13800	1.525	1.5375	1.53125						
14400	1.525	1.5375	1.53125						
14800	1.525	1.5375	1.53125						
15400	1.5375	1.5375	1.5375						
15800	1.5375	1.5375	1.5375						
16400	1.5375	1.5375	1.5375						
16800	1.5375	1.5375	1.5375						
17200	1.5625	1.5375	1.55						
17600	1.5625	1.5375	1.55						
18000	1.5625	1.5375	1.55						
18400	1.5625	1.5375	1.55						
18800	1.5625	1.5375	1.55						
19200	1.5625	1.5375	1.55						
19600	1.5625	1.5375	1.55						
20000	1.5625	1.55	1.55625	1.5625	1.55	1.55625	1.45	1.45	1.45
20100	1.5625	1.55	1.55625						
20100	1.5625	1.55	1.55625						
20400	1.5625	1.55	1.55625						
20600	1.5625	1.55	1.55625						
20800	1.5625	1.55	1.55625						
21000	1.5625	1.55	1.55625						
21300	1.5625	1.55	1.55625						
21500	1.5625	1.55	1.55625						
21700	1.5625	1.55	1.55625						
22000	1.5625	1.55	1.55625						
22200	1.5625	1.55	1.55625						
22400	1.5625	1.55	1.55625						
22600	1.5625	1.55	1.55625						
22800	1.5625	1.55	1.55625						
23000	1.5625	1.55	1.55625						
23400	1.5625	1.55	1.55625						
23500	1.5625	1.55	1.55625						
23600	1.5625	1.55	1.55625						
23800	1.5625	1.55	1.55625						
24000	1.5625	1.55	1.55625						
24200	1.5625	1.55	1.55625						
24600	1.5625	1.55	1.55625						
24800	1.5625	1.55	1.55625						
25000	1.5625	1.55	1.55625						

CYCLES	VISUAL			INTERNAL HFEC			EXTERNAL LFEC		
	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)	aAFT (inches)	aFWD (inches)	aAVG (inches)
25200	1.575	1.55	1.5625						
25400	1.5625	1.55	1.55625						
25500	1.5625	1.55	1.55625						
25600	1.5625	1.55	1.55625						
25800	1.5625	1.55	1.55625						
26000	1.5625	1.55	1.55625						
26200	1.5625	1.55	1.55625						
26400	1.5625	1.55	1.55625						
26500	1.5625	1.55	1.55625						
26600	1.5625	1.55	1.55625						
26800	1.5625	1.55	1.55625						
27000	1.5625	1.55	1.55625						
27200	1.5625	1.55	1.55625						
27400	1.5625	1.55	1.55625						
27500	1.5625	1.55	1.55625						
27600	1.5625	1.55	1.55625						
27800	1.5625	1.55	1.55625						
28000	1.5625	1.55	1.55625						
28200	1.5625	1.55	1.55625						
28400	1.5625	1.55	1.55625						
28500	1.5625	1.55	1.55625						
28600	1.5625	1.55	1.55625						
28800	1.5625	1.55	1.55625						
29000	1.5625	1.55	1.55625						
29200	1.5625	1.55	1.55625						
29400	1.5625	1.55	1.55625						
29600	1.5625	1.55	1.55625						
29800	1.5625	1.55	1.55625						
30000	1.5625	1.55	1.55625	1.55	1.575	1.5625	1.5	1.6	1.55

Figure I-20. Half-crack length data during fatigue for the HS repair (tabular)

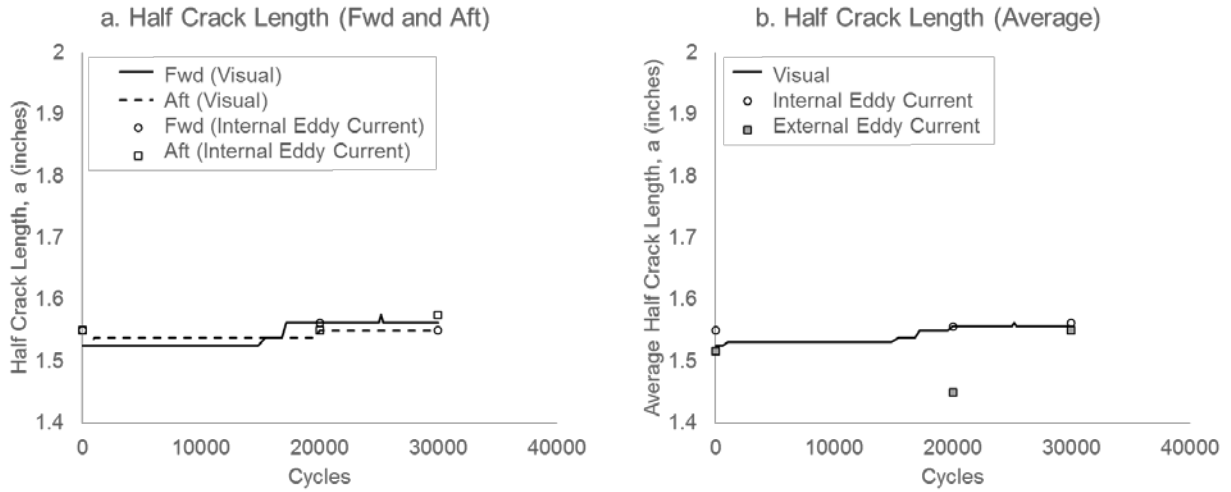


Figure I-21. The HS repair crack-growth data during fatigue (30,000 cycles): (a) forward and aft half-crack length and (b) average half-crack length