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21-2152-RR52526

Kansas Aviation Research and Technology (KART)

Zone 3: Fastener “Direct” Attachment Composite Database Test Report

DISCLAIMER

The results and data of this report apply only to the test articles as listed in the Customer Equipment List and in the environments described.

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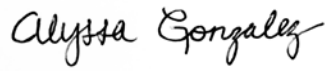
Report No: 21-2152-RR52526

Revision -	
Written by: 	Date: 06/14/2021
Reviewed by: 	Date: 06/15/2021
Approved by: Kyle McMullen	Date:

Section	Description
All	Initial Release of Document

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List of Abbreviations, Acronyms, and Symbols

A, Amp	Amperes
ARP	Aerospace Recommended Practice
C	Coulomb
°F	Degrees Fahrenheit
DC, dc	Direct Current
DEL	Direct Effects of Lightning
ETL	Environmental Test Laboratory
EUT	Equipment Under Test
Hz	Hertz (measure of Frequency)
KART	Kansas Aviation Research and Technology
kA	Kilo amperes
kA^2s	Kilo amperes squared seconds (measure of action integral)
kHz	Kilohertz
MHz	Megahertz
µJ	micro joules
µΩ	Micro ohms
µs	Microseconds
mΩ	Milliohms
ms	Milliseconds
NIAR	National Institute for Aviation Research
Ω	Ohms
RH	Relative humidity
SAE	Society of Automotive Engineers
TP	Test point

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LIST OF FIGURES

FIGURE **TITLE** **PAGE**

1.0 References and Applicable Documents

Unless otherwise noted the revision at the time of the releases of this document shall apply.

1.1 Specifications and Standards

Document Number	Description
SAE Aerospace ARP 5412B Revised 2013	Aircraft Lightning Environment and Related Test Waveforms
SAE Aerospace ARP 5414B Reaffirmed 2012	Aircraft Lightning Zone
SAE Aerospace ARP 5416A Revised 2013	Aircraft Lightning Test Methods
SAE Aerospace ARP 5577 Reaffirmed 2008	Aircraft Lightning Direct Effects Certification
AGATE Rev C	Lightning Direct Effects Handbook

2.0 Scope

This document contains the test results for high current direct effects of lightning testing of the KART Zone 3 Direct Attachment Data Base test articles listed in Table 1. This test was performed in accordance with the test methods defined in SAE ARP 5416A, with the waveform parameters defined in SAE ARP 5412B based on the aircraft lightning zones in SAE ARP 5414B.

Testing took place at the NIAR Environmental Test Lab located at 3800 S. Oliver Wichita, Kansas 67210 and took place from June 8, 2021 to June 14, 2021.

The test data is provided in Appendix A. Photographs of the test setups can be found in Appendix B. Test logs are provided in Appendix C. Appendix D contains the test article engineering drawings.

3.0 General Requirements

This report is a summary of the equipment tested, test environment used, test procedures used, and the results of the testing performed at the NIAR Environmental Test Laboratory on the KART test articles.

Test article design

The test article design represented generic composite wing skin fuel tank structure. The test articles consisted of two flat skin panels fastened to an angle bracket representative

of internal structure. Fay sealant at mating surfaces and fastener shank sealant (PR-1440 Class B) was applied, as is common in fuel tank regions.

All composite panels consisted of:

- 15 plies of Cycom 5320-1 PW prepreg in a quasi-isotropic layup.
- The top skin surface ply contained Dexmet 3CU7-125FA expanded copper foil lightning strike protection.
- For composite panels fastened to an aluminum L-bracket, a M20/120 fiberglass ply was added beneath the bottom ply to prevent corrosion.

Fuel tank primer was applied to all surfaces of the test panels. Topcoat was applied to the exterior side only after assembly. Fuel tank primer and topcoat were excluded from a two-inch strip around the perimeter of the exterior skin panels to allow bonding to the generator return. One additional bonding location was defined on the L-bracket representative stringer to simulate current flow through internal structure.

Although protective seal caps or daub sealant are generally used for many standard production fuel tank installations, they were excluded from this testing to determine the performance of the fastener installations themselves without the containment of the caps.

Engineering drawings of the test articles are in Appendix D.

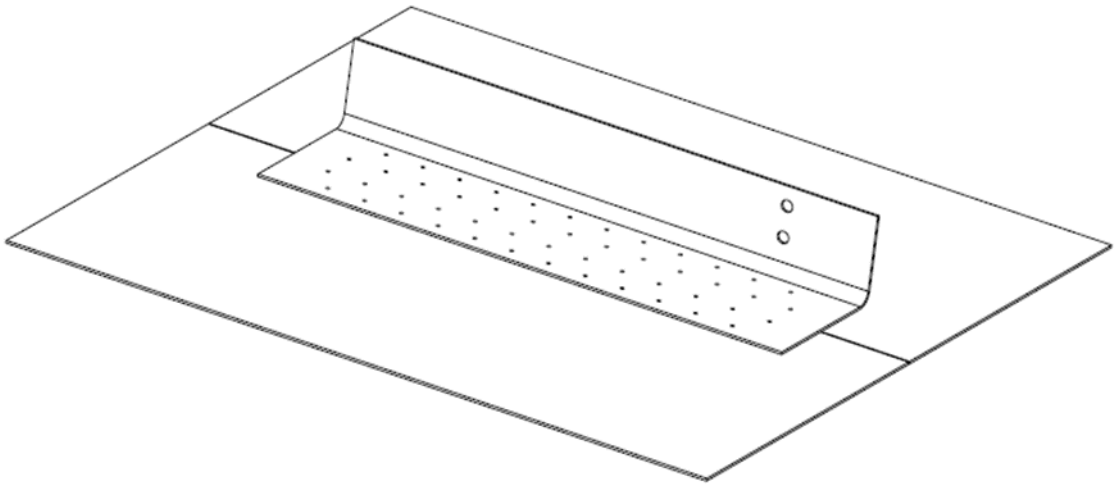


Figure 1: Inside view of test article showing the L-bracket fastened to the skin flat panels

The following is a listing of the equipment that was tested:

Table 1- Test Matrix

Part #	Serial #	Description	Fastener Pin	Fastener Collar	Comments
ZN35700-063	N48JJ	Hybrid clearance fit Hi-Lite	HST11BJ8-3	HST79CY8	TP1, TP3, TP4, TP5
ZN35700-065	N48JK	Composite clearance fit Hi-Lite	HST11BJ8-3	HST79CY8	TP1, TP2, TP3
ZN35700-067	N48JL	Hybrid clearance fit Hi-Lite	HL11VBJ8-3	HST79CY8	TP1, TP2, TP3
ZN35700-069	N48JM	Composite clearance fit Hi-Lite	HL11VBJ8-3	HST79CY8	TP1, TP2, TP3, TP4, TP5

3.1 General Test Setup

General test setup guidelines are available in SAE ARP5416A. A general test setup diagram for this testing is shown in Figure 2. A list of laboratory equipment used to complete this test is listed in Table 2.

Test waveform data can be found in Appendix A of this report. Test setup pictures can be found in Appendix B of this report.

Table 2 - Equipment Used For Lightning Direct Effects

Description	Manufacturer	Model Number	Serial Number	Cal Due Date
High Current Generator	NIAR	HC1	001	N/A
Current Monitor Probe	Pearson Electronics Inc.	301X"	147836	8/28/2021
Barometric Pressure and Humidity	Extech	SD700	Q774074	2/28/2022
Oscilloscope	Yokogawa	DL850E	91P313729	9/30/2021
HV Power Supply	Spellman	SL8PN2000X4874	102151349-A00001	N/A
Current Probe 1:1500	Danisense	DS600IDSA	14170020014	12/12/2021
Current Monitor Probe	Pearson Electronics Inc.	1423	147997	8/28/2021
HV Power Supply	Spellman	STR70N6/200/3PHASE	102186808-A00003	N/A
Analog Voltage Input Module	Yokogawa	701250	91P321170	9/30/2021
Analog Voltage Input Module	Yokogawa	701250	91P321166	9/30/2021
Milliohm Meter	Hioki	RM3548	160526789	9/30/2021
4 Channel 100MHz 1GSa/s	Rigol	DS1104	DS1ZA181305414	9/30/2021
Mass flow Controller Economical Gas	Omega Engineering Inc	FMA5543	483712-1	8/17/2021
0-50 L/min H2	Omega Engineering Inc	FMA5528-H2	370672-1	7/2/2021
Fuel Flow control	NIAR	FFC001	001	N/A
LCR Meter	Hewlett Packard	4263A	3145J02971	9/30/2021
High-Voltage Electrostatic Voltmeter	Trek	341B-L-CE	304	8/4/2021

Flammable Gas Ignition Detection

The flammable gas ignition source detection method was utilized in accordance with SAE ARP 5416A section 7.7.2. A 7% hydrogen by volume mixed with 93% air was selected as the gas mixture for the flammable gas detection method.

The test setup consisted of a fuel flow setup and a voltage spark source setup. The fuel flow setup included the hydrogen and air mass flow controllers, and the associated tubing, hoses, and test chamber containing the flammable gas mixture, and the foil blowout panel. The spark source setup consisted of the spark source circuit, the high voltage power supply, the electrostatic voltmeter, and the oscilloscope for the electrostatic voltmeter. The spark source capacitance was measured with a capacitance bridge.

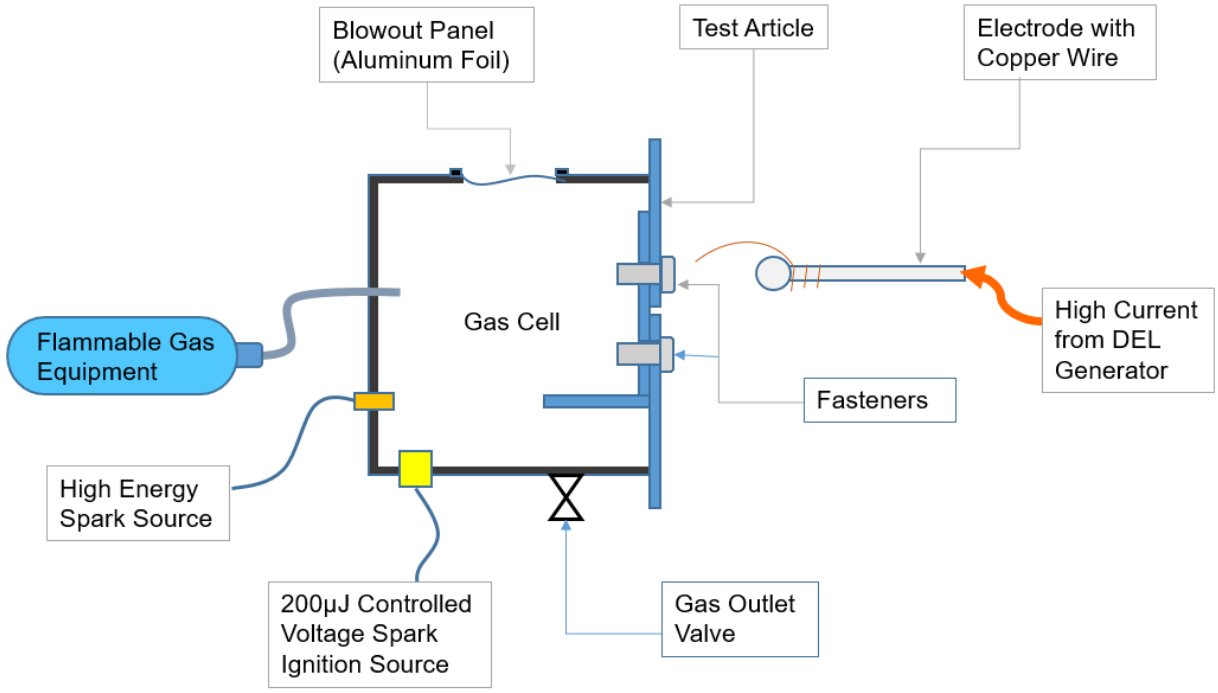


Figure 2: Schematic of Test Setup

High Current Generator

The test panels were installed near the output of the high current generator, allowing the arc to be discharged into the panel via the jet-diverting electrode. The panels were electrically bonded to the generator return. General test setup schematics are shown in Figures 3-4.

A high current probe for each waveform Component A/5, B, and C*, recorded the waveform outputs of the generator. The required parameters for each waveform Component are listed in Tables 3, 4, and 5.

Waveform verification was performed by discharging a high-current shot into an aluminum plate terminated to the generator return.

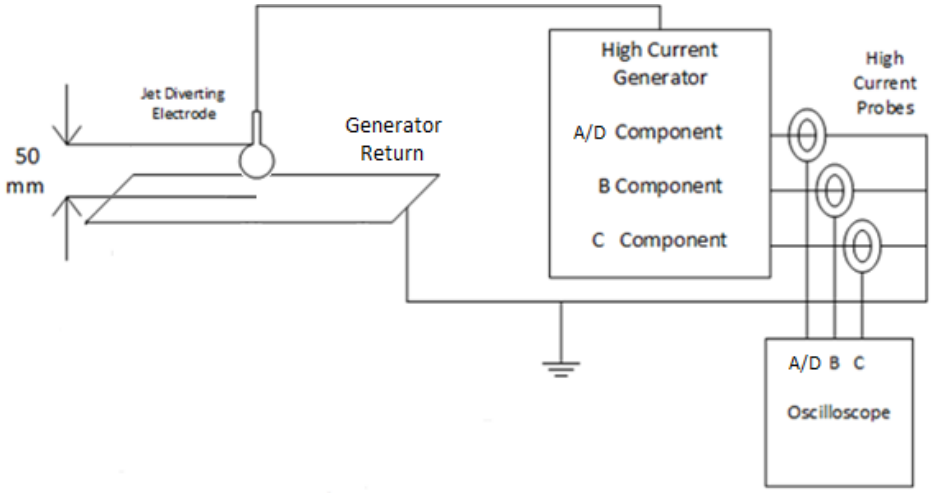


Figure 3: Circuit Schematic for Lightning Testing

The arc was directed to the selected test location using an initiating wire extending from the jet-diverting electrode to 50 mm from the surface of the test article, as depicted in Figure 3 and Figure 4.

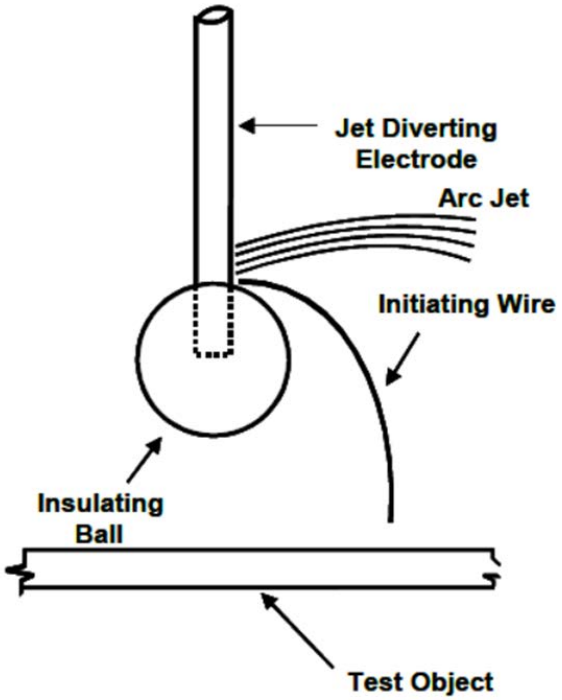


Figure 4: Schematic of Lightning Attachment

Table 3: Component A/5 Requirement

Peak Amplitude	40kA ± 10%
Action Integral	80kA^{2}s ± 20%
Rise Time to 90% Peak	< 50µs
Total Duration	< 500µs

Table 4: Component B Requirement

Average Amplitude	2kA ± 20%
Charge Transfer	10C ± 10%
Total Duration	5ms ± 10%

Table 5: Component C* Requirement

Average Amplitude	≥ 400A
Charge Transfer	18C ± 20%
Total Duration	45ms ± 20%

3.2 Test Witnessing

Testing was conducted by NIAR's Alyssa Gonzalez and Rebeka Khajehpour.

4.0 Testing

Gas flammability verification was performed prior to testing per the procedure in SAE ARP 5416A Section 7.7.2. Nine successful ignitions were completed with an arc energy of 200μJ or less.

Generator waveform verifications were performed into an aluminum panel terminated to the generator return via formed copper straps. After the waveform verification was completed, the first test panel was installed. A minimum of three fastener test points (TP) per panel were selected at the farthest locations from each other as possible to avoid effects of conditioning from one test point to the next (see Figure 5).

All test panels were clamped into the test fixture and covered with duct tape to insulate fasteners and surfaces near the desired test point to act as a dielectric in the regions where arc attachment was not desired. The selected fastener test point was left without tape, and the initiating wire was directed to the head of the fastener for the selected test point. A fiberglass frame was inserted between the panel and the fixture to further insulate from inadvertent arcing between the test panel and the fixture.

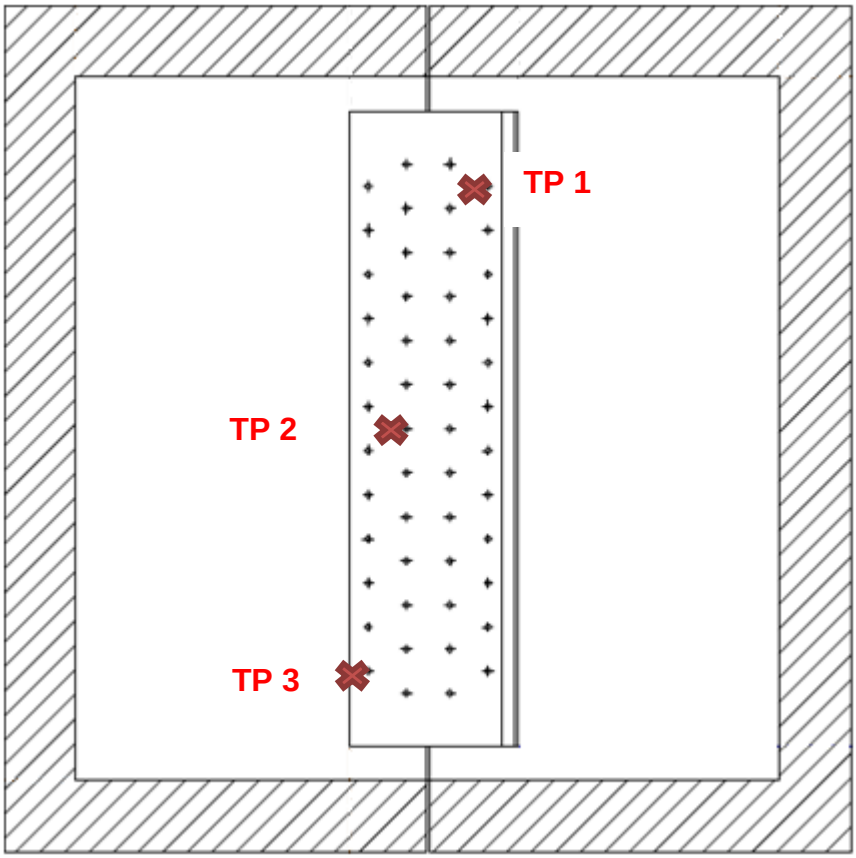


Figure 5: Schematic of Test Point Locations on the Interior of the Panel

Test Procedure

1. Initiate a lightning discharge to an aluminum dummy test article to verify that the output of the lightning generator falls within the required waveform parameters.
2. Seal the flammable gas chamber and perform the flammable gas verification procedure to verify that the gas mixture will ignite at least nine out of ten times.
3. Install the test article onto the test fixture with C-clamps.
4. Seal gas test chamber and fill the chamber with the flammable gas mixture, displacing five test volumes.
5. Initiate a lightning discharge to the test article.
6. If ignition due to the lightning test occurs, that test point is considered a failure, move on to the next test point. If ignition due to the lightning test did not occur,

ignite the flammable gas mixture with the controlled voltage spark ignition source to prove that the atmosphere was ignitable during the lightning test.

7. Repeat steps 3-6 for each test point on each test article.

Condition of Panels Received

Panel -063 was received in the condition specified in the engineering drawing.

Panels -065 and -069 were received with the fastener hole pattern misaligned with the edges and centerline seam of the panels. These panels were determined to be acceptable for the purpose of lighting testing, since the slight misalignment was not expected to result in an increase in current density or conditioning at any test point.

Panel -067 was originally received with the incorrect fasteners installed. The fasteners replaced with the correct ones containing the Hi-Kote coating. Sealant application was repeated and the topcoat was reapplied, along with touch-up primer application on the interior side of the panel. This was not expected to affect the sparking performance of the fastener installations since all fasteners were installed in clearance fit, and thus no damage to the panels or holes was expected during removal or reinstallation of fasteners.

Test Results

Panel -063 was the first panel tested. After TP1, there was visible conditioning at many of the untested fasteners, so TP2 was not tested on Panel -063. TP1 Component B was outside of spec, so an additional test point was added. TP3 was tested next, followed by the additional TP 4 and TP 5. Panel -063 was tested a total of four times.

Panel -065 was tested successfully with compliant waveforms at TP1, TP2, and TP3.

Panel -069 was tested a total of five times because the Component C* was out of spec for TP2, and the action integral was out of spec for TP1, so additional test points were added to obtain three total test points with compliant waveforms.

Panel -067 was tested successfully with compliant waveforms at TP1, TP2, and TP3.

Two test points ignited the flammable mixture during this testing. These test points were Panel -065 TP1, an HST11BJ8-5 fastener installed in a panel with a composite L-bracket, and Panel -067 TP2, an HST11AG8-5 fastener installed in a panel with an aluminum L-bracket.

The waveform data for each test is listed in Appendix A.

The post-test gas flammability verification was successfully completed after each test point. The spark ignition energies for each test point are shown in Table 6.

Table 6: Gas Calibration and Post-test Gas Flammability Verification Data

Trial or Test Point	Spark Energy, µJ	Ignition on 1st spark?
Gas Cal 1	166	yes
Gas Cal 2	166	yes
Gas Cal 3	162	yes
Gas Cal 4	171	yes
Gas Cal 5	171	yes
Gas Cal 6	166	yes
Gas Cal 7	162	yes
Gas Cal 8	162	yes
Gas Cal 9	162	yes
-063 TP1 (invalid test, B bank)	166	yes
-063 TP3	162	yes
-063 TP4	180	yes
-063 TP5	157	yes
-065 TP3 (no spark energy recorded)	<180	yes
-065 TP2	162	yes
-065 TP1 (ignited during test)	N/A	N/A
-069 TP3	162	yes
-069 TP2	166	yes
-069 TP1	171	yes
-069 TP4	175	yes
-069 TP5	175	yes
-067 TP3	137	yes
-067 TP2 (ignited during test)	N/A	N/A
-067 TP1	148	yes

5.0 Conclusions

Two test points produced ignition sources during this testing. These were Panel -065 TP1 and Panel -067 TP2. For each of these configurations, only one of the three test points ignited the flammable gas during the test.

For all lightning tests that did not result in an ignition source, the ignitability of the flammable mixture was successfully verified post-test by the <200 µJ voltage spark source.

Visible damage to the fasteners as a result of lightning testing included melting and scorching on the front (exterior) side of the test article. No visible damage was evident on the back (interior) side of most of the test panels, with the exception of Panel -069 TP3, which showed scorching near the fastener on the interior side; however, this test point did not cause an ignition of the flammable mixture. A sample photo of the exterior-side fastener damage is shown in Figure 6. A sample photo of the interior-side fastener damage from Panel -069 TP3 is shown in Figure 7.

Figure 6: Sample Photo of Exterior Side Damage to Fastener

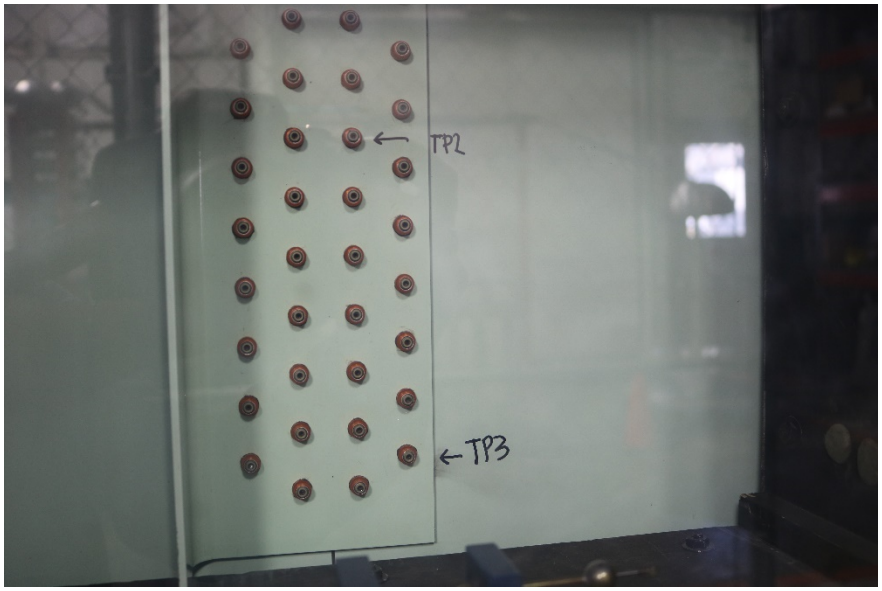


Figure 7: Interior Side Damage to Panel -069 TP3

As a result of this testing, the test article designs for Panels -063 and -069 evaluated in this test are sufficient to withstand direct attachment to fasteners in Zone 3 with waveform Components A/5, B, and C*.

The test article designs for Panels -065 and -067 did not withstand direct attachment to fasteners in Zone 3 with waveform Components A/5, B, and C* and cannot be recommended for use without sufficient changes in configuration design and/or manufacturing process to eliminate this risk.

Appendix A - Test Data

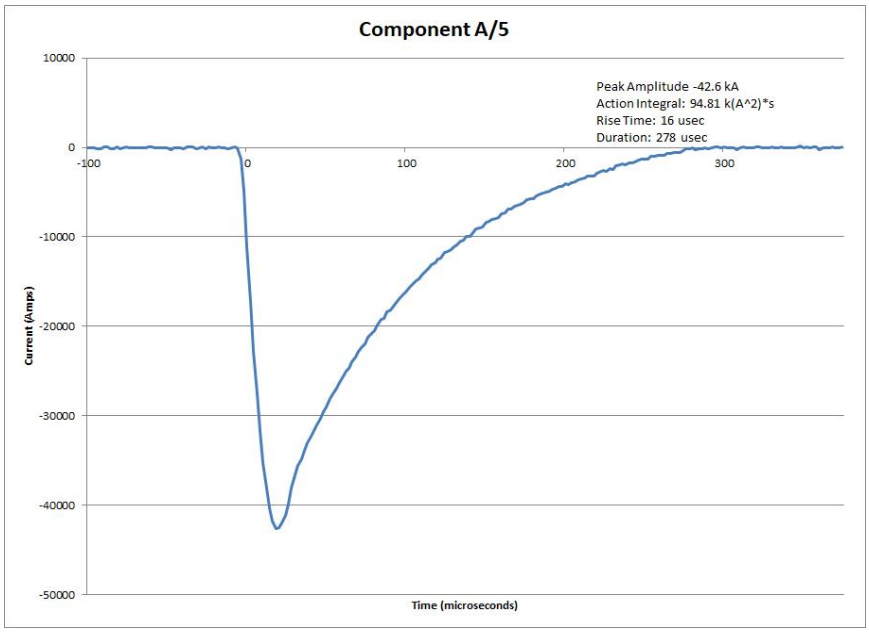


Figure 1: Arc Entry Test -063 - TP1 - Component A/5

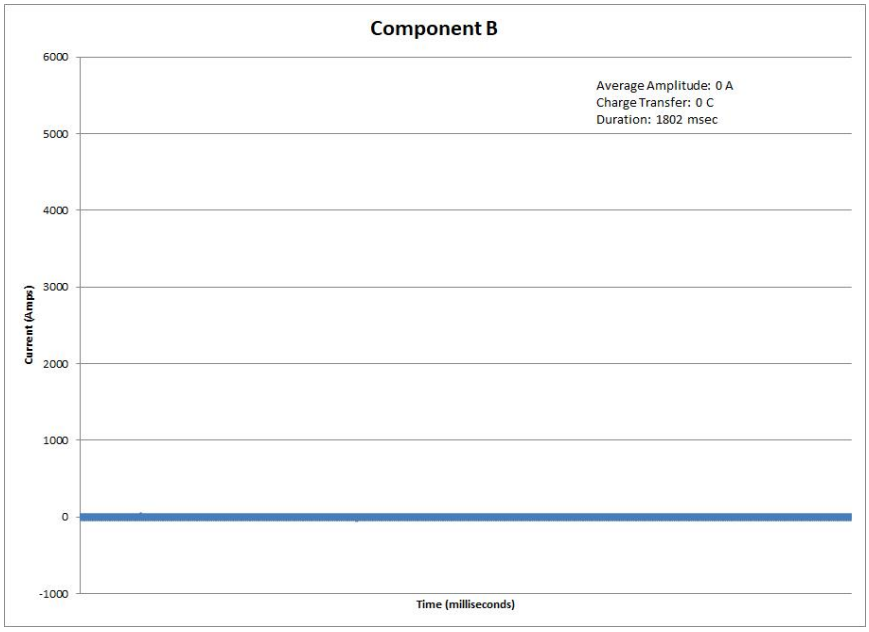


Figure 2: Arc Entry Test -063 - TP1 - Component B - noncompliant

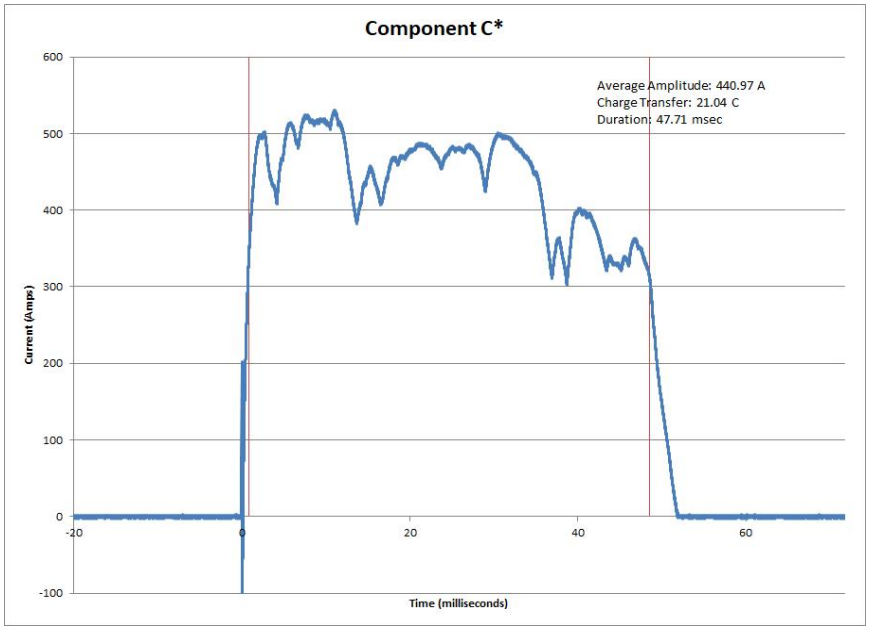


Figure 3: Arc Entry Test -063 - TP1 - Component C*

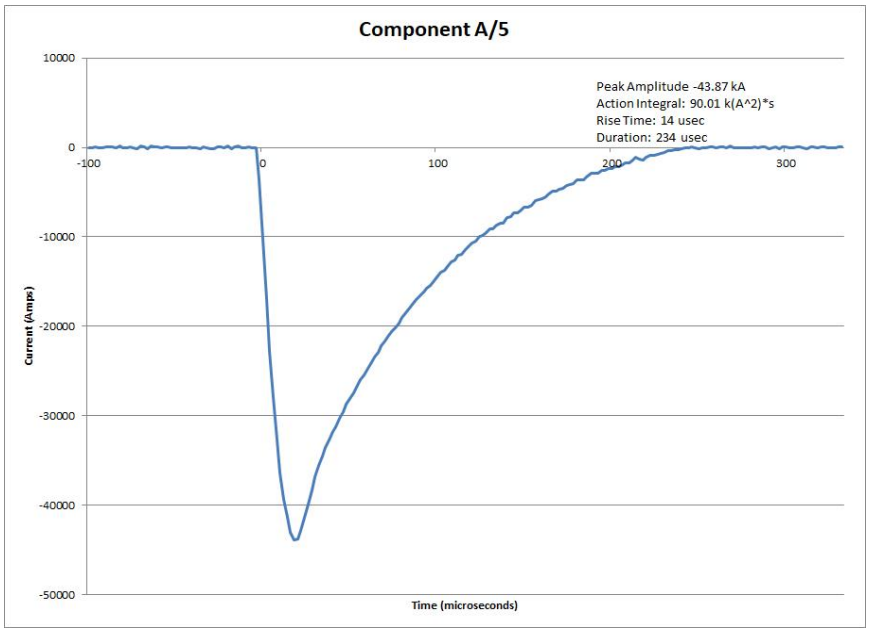


Figure 4: Arc Entry Test -063 - TP3 - Component A/5

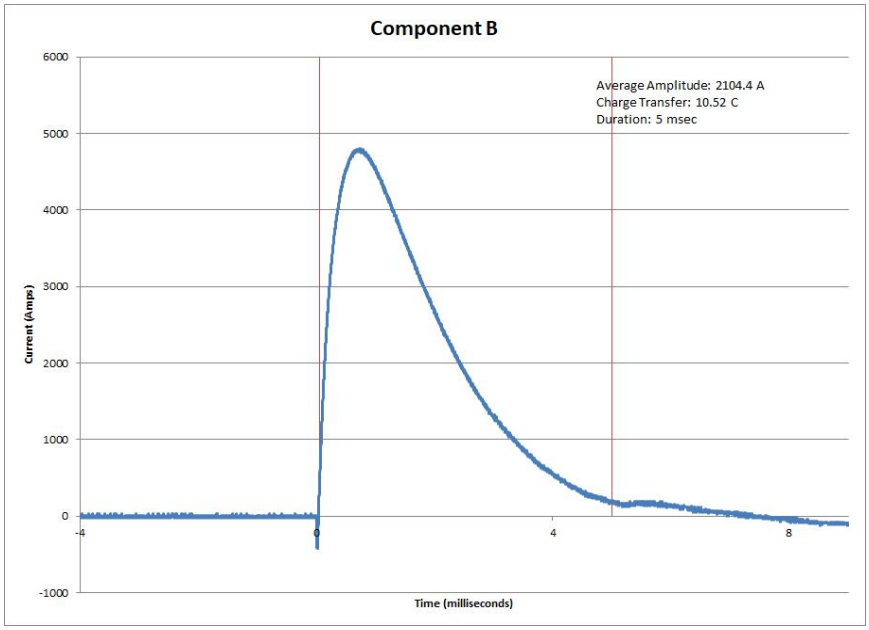


Figure 5: Arc Entry Test -063 - TP3 - Component B

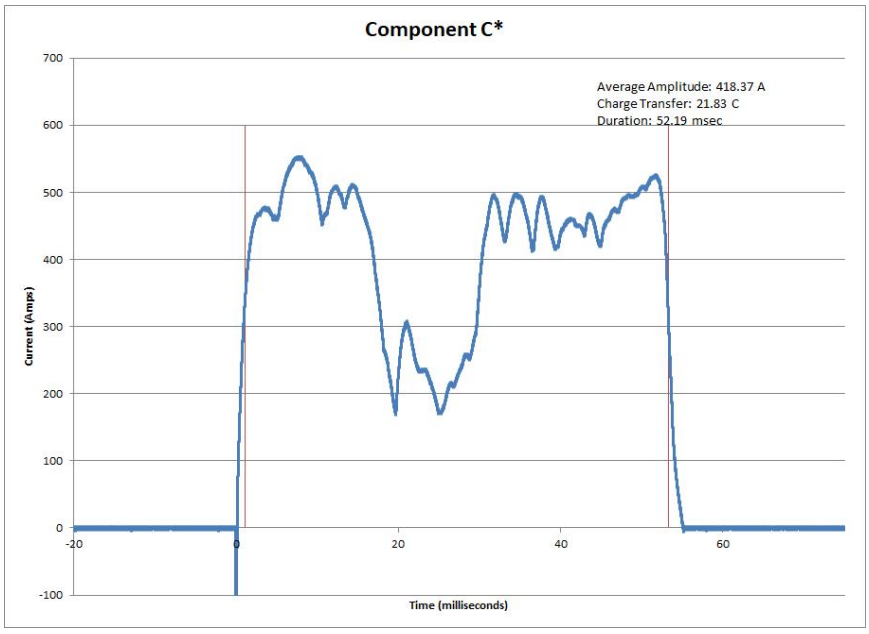


Figure 6: Arc Entry Test -063 - TP3 - Component C*

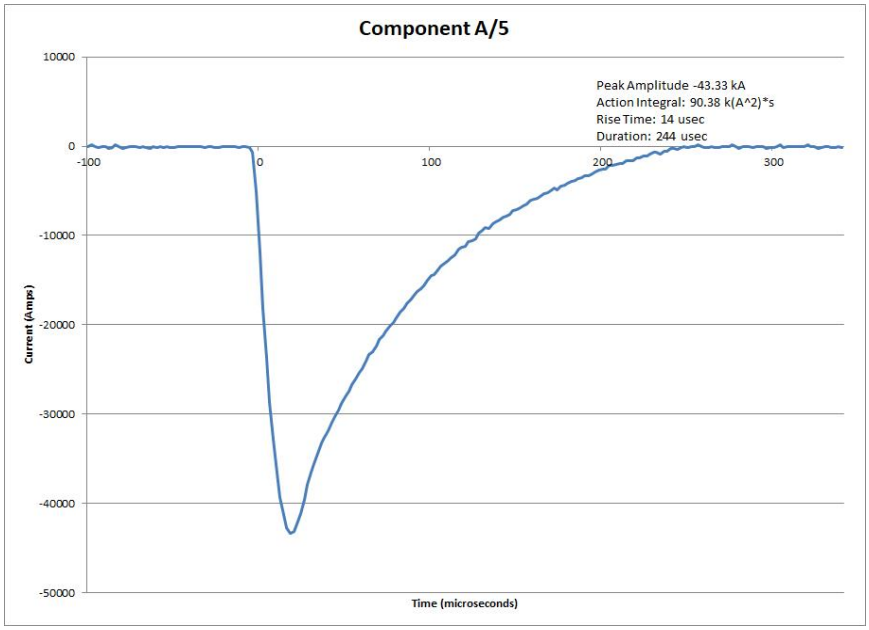


Figure 7: Arc Entry Test -063 - TP4 - Component A/5

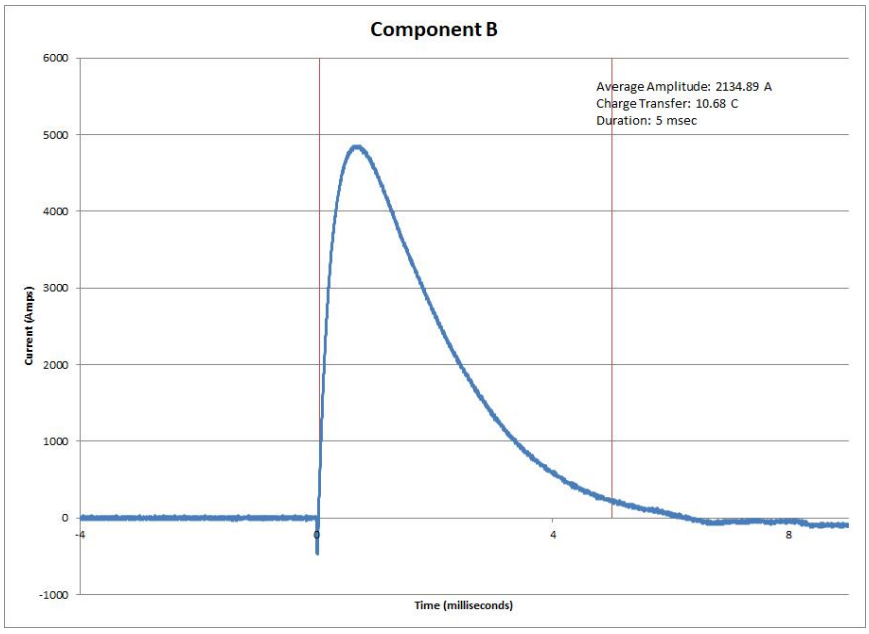


Figure 8: Arc Entry Test -063 - TP4 - Component B

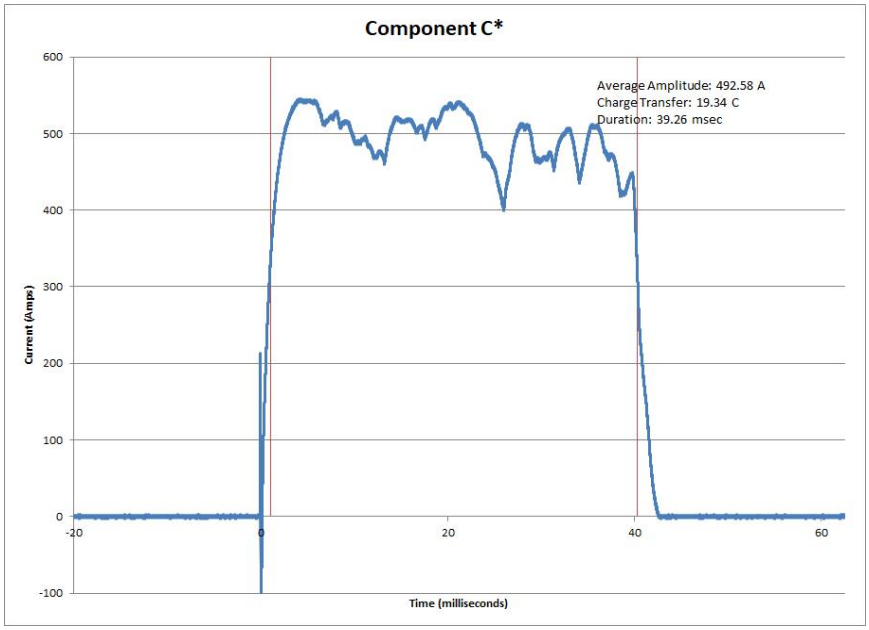


Figure 9: Arc Entry Test -063 - TP4 - Component C*

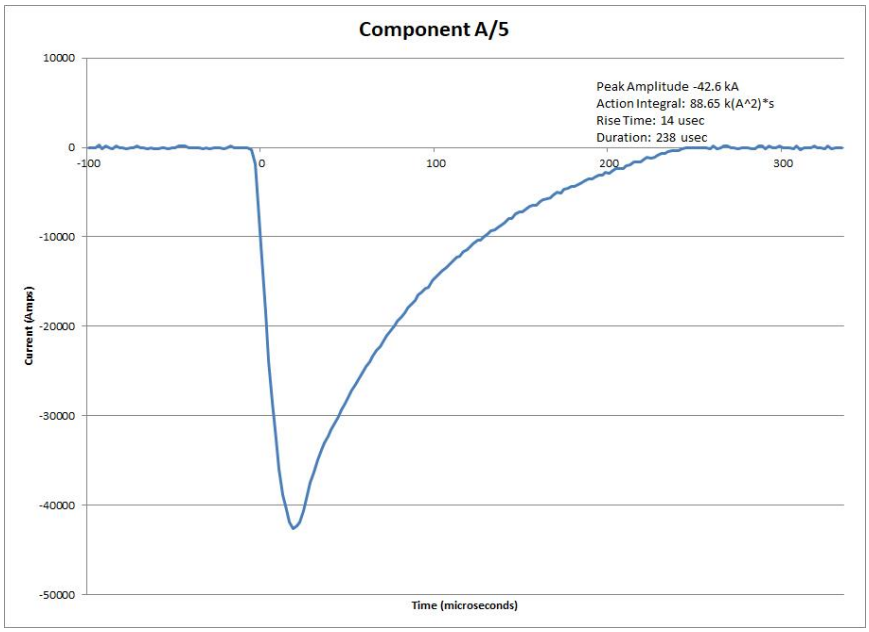


Figure 10: Arc Entry Test -063 - TP5 - Component A/5

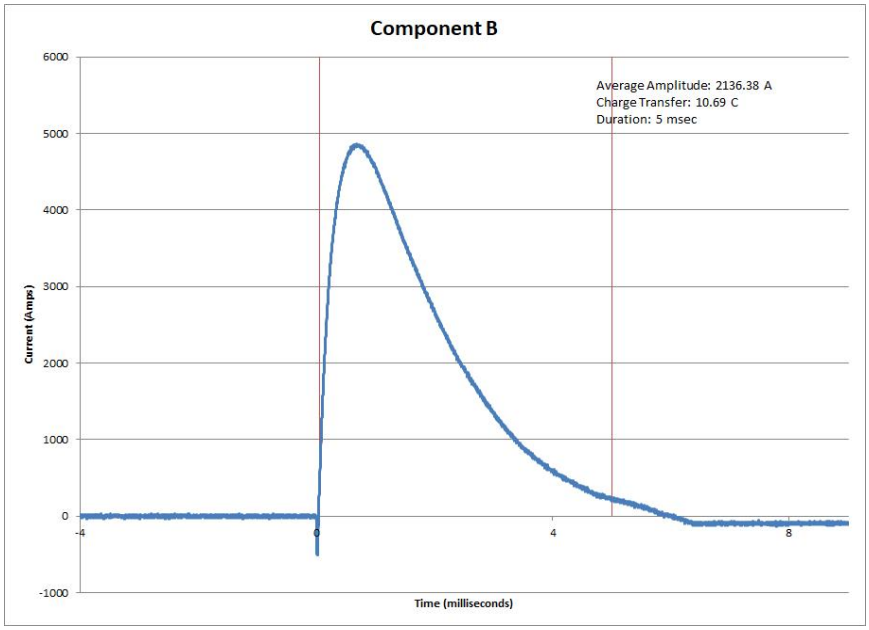


Figure 11: Arc Entry Test -063 - TP5 - Component B

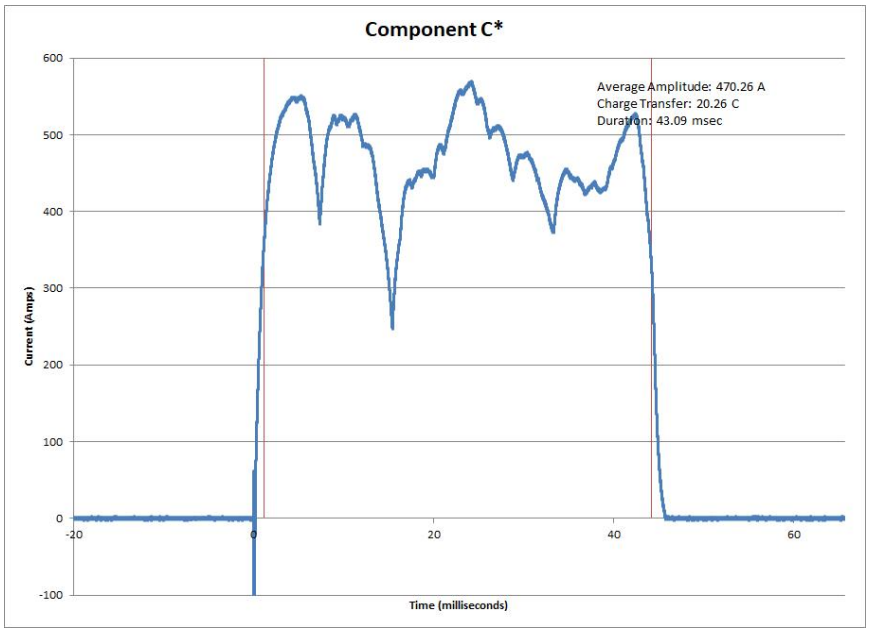


Figure 12: Arc Entry Test -063 - TP5 - Component C*

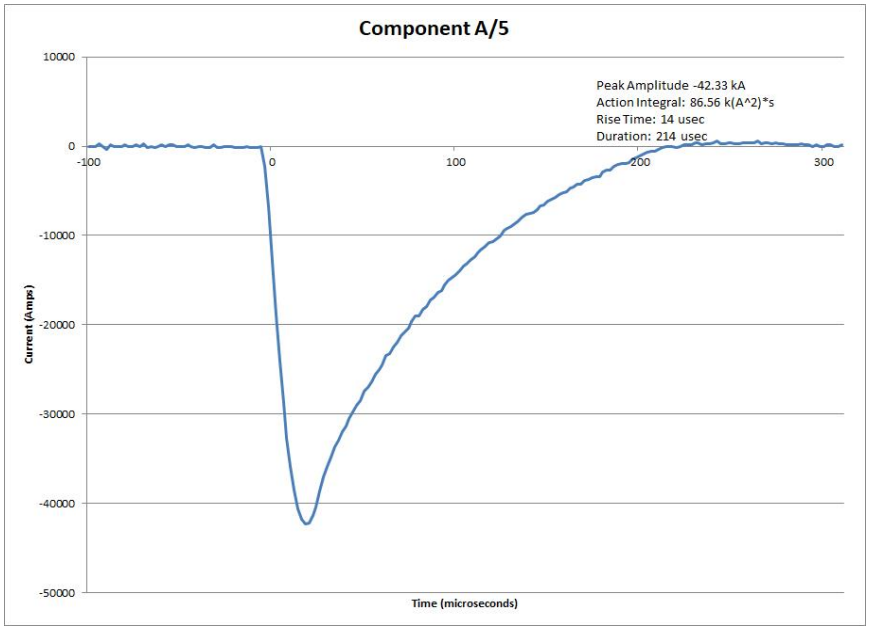


Figure 13: Arc Entry Test -065 - TP1 - Component A/5

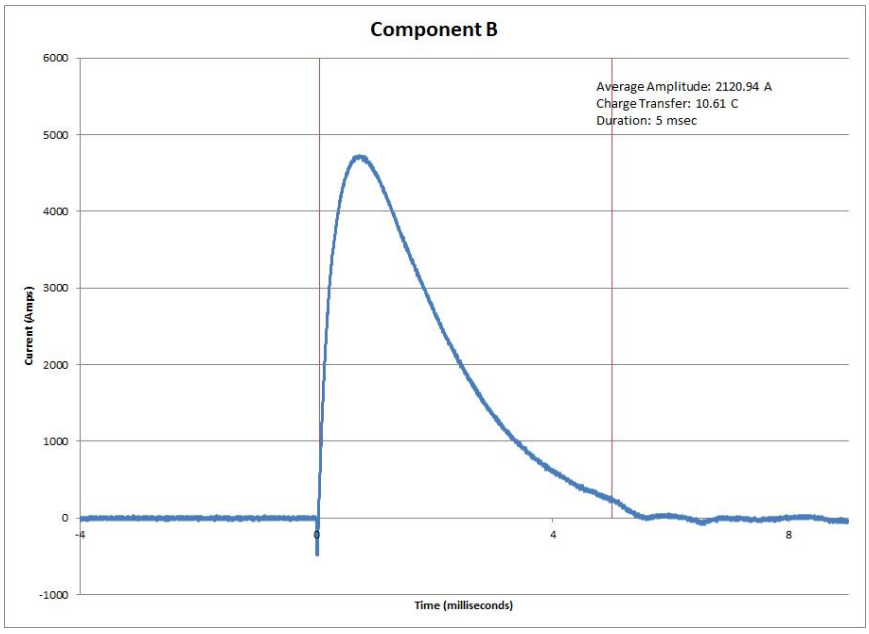


Figure 14: Arc Entry Test -065 - TP1 - Component B

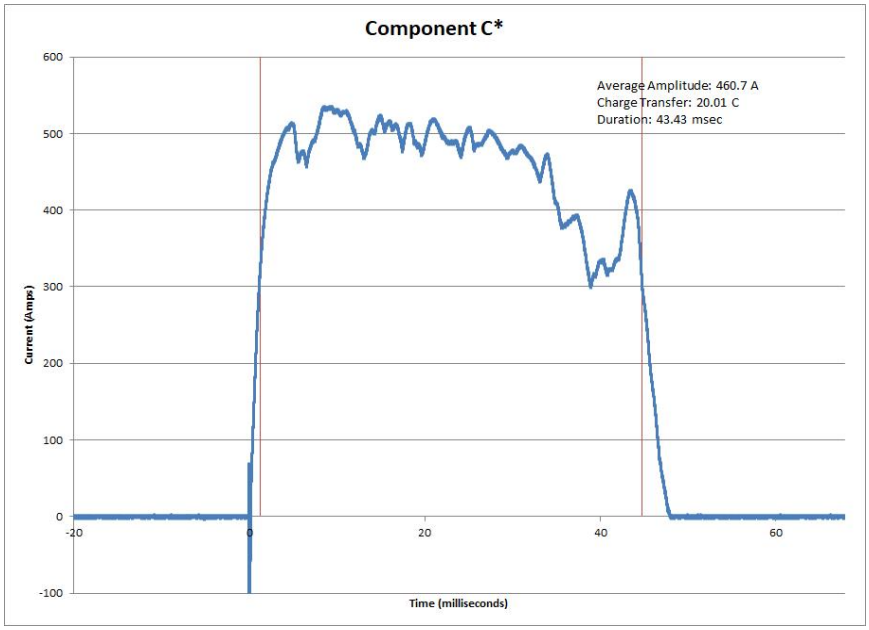


Figure 15: Arc Entry Test -065 - TP1 - Component C*

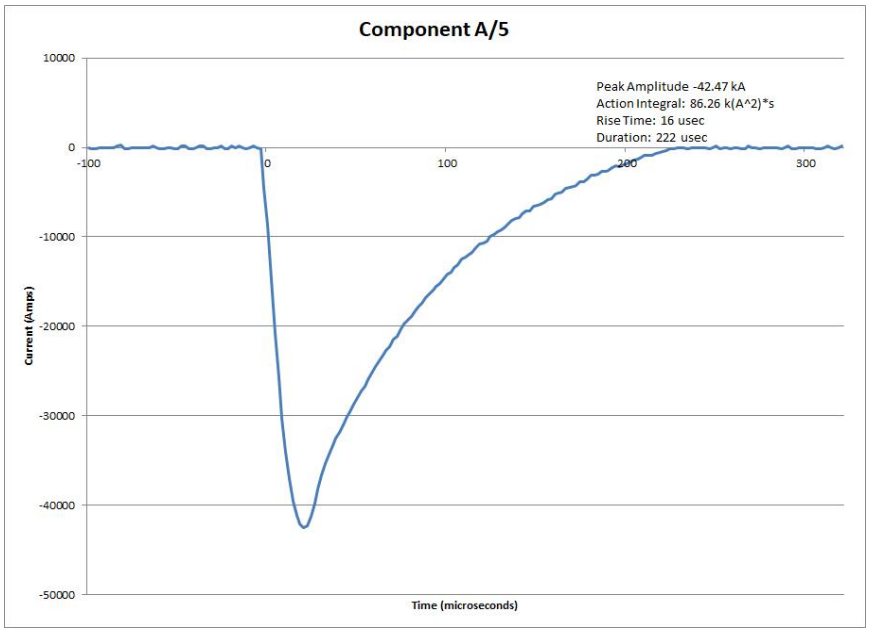


Figure 16: Arc Entry Test -065 - TP2 - Component A/5

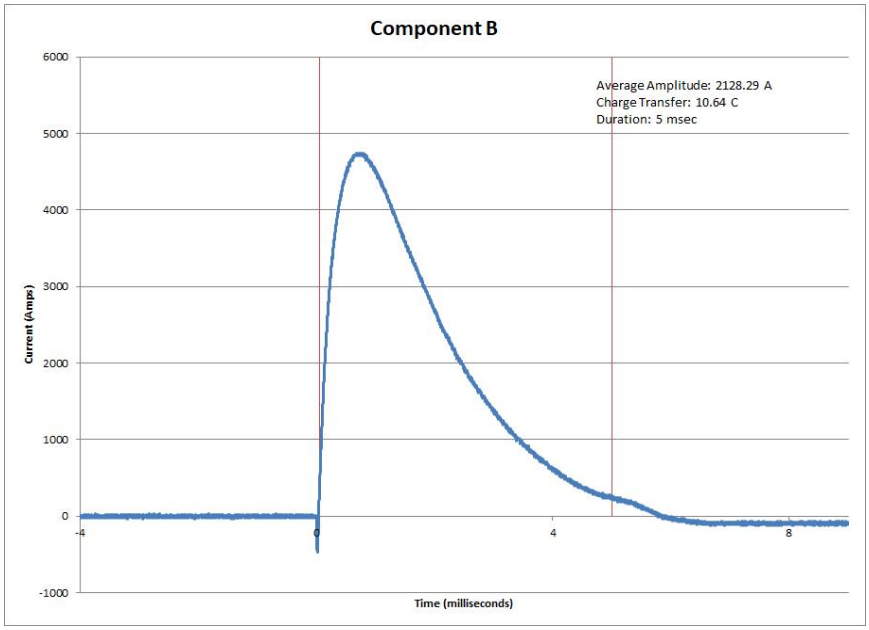


Figure 17: Arc Entry Test -065 - TP2 - Component B

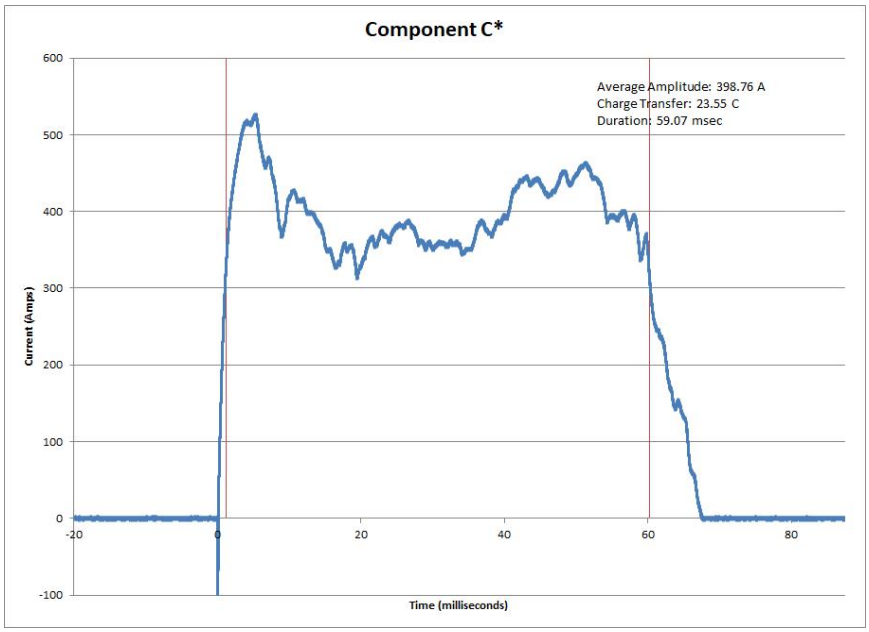


Figure 18: Arc Entry Test -065 - TP2 - Component C*

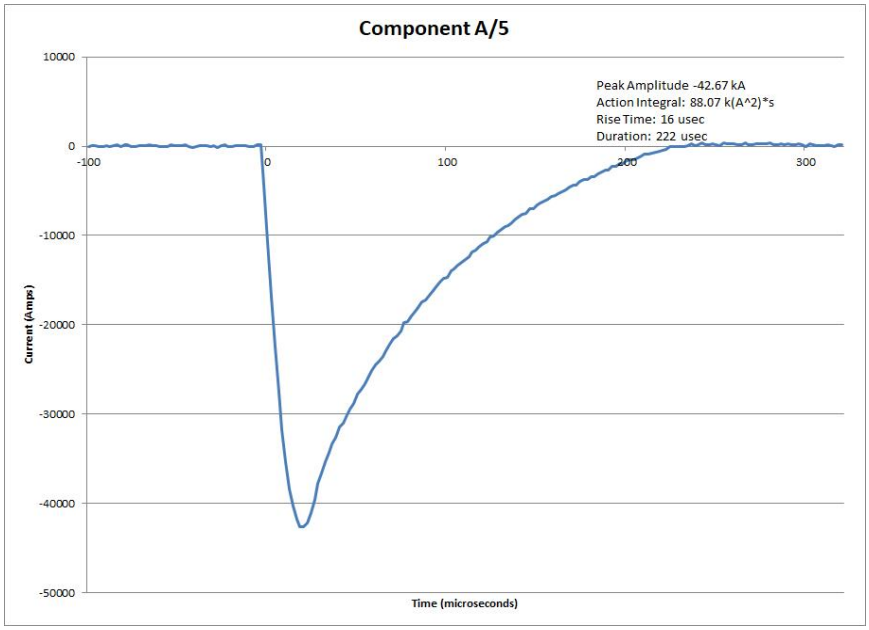


Figure 19: Arc Entry Test -065 - TP3 - Component A/5

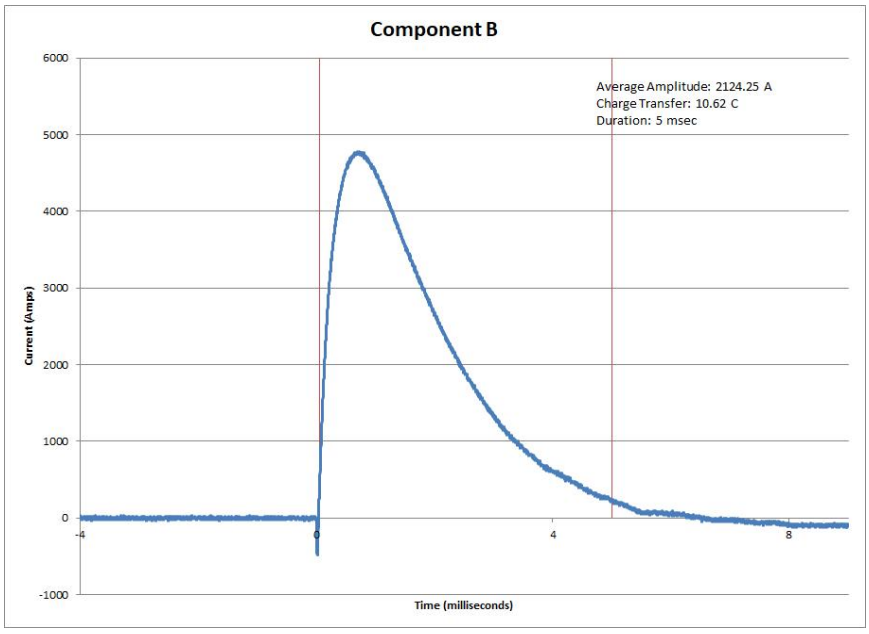


Figure 20: Arc Entry Test -065 - TP3 - Component B

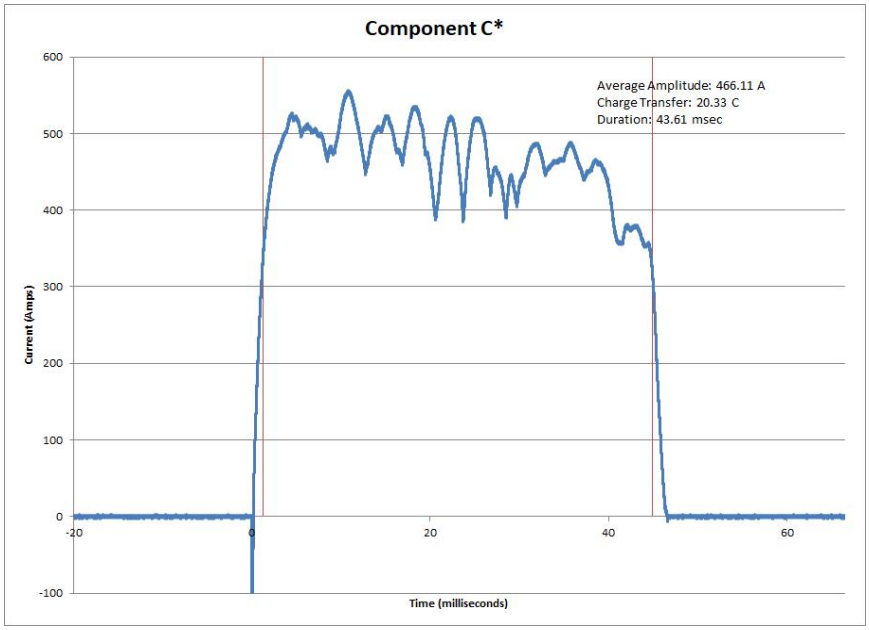


Figure 21: Arc Entry Test -065 - TP3 - Component C*

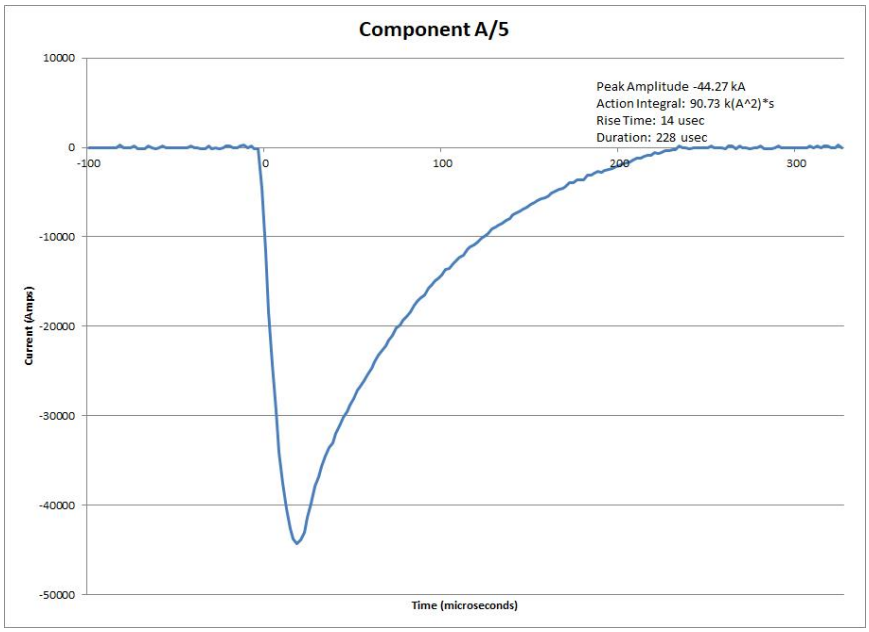


Figure 22: Arc Entry Test -067 - TP1 - Component A/5

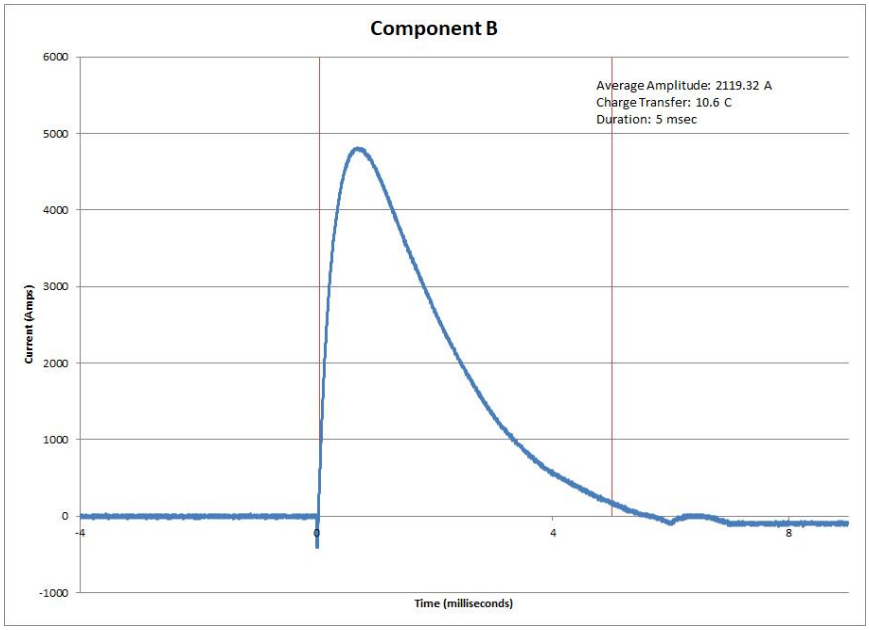


Figure 23: Arc Entry Test -067 - TP1 - Component B

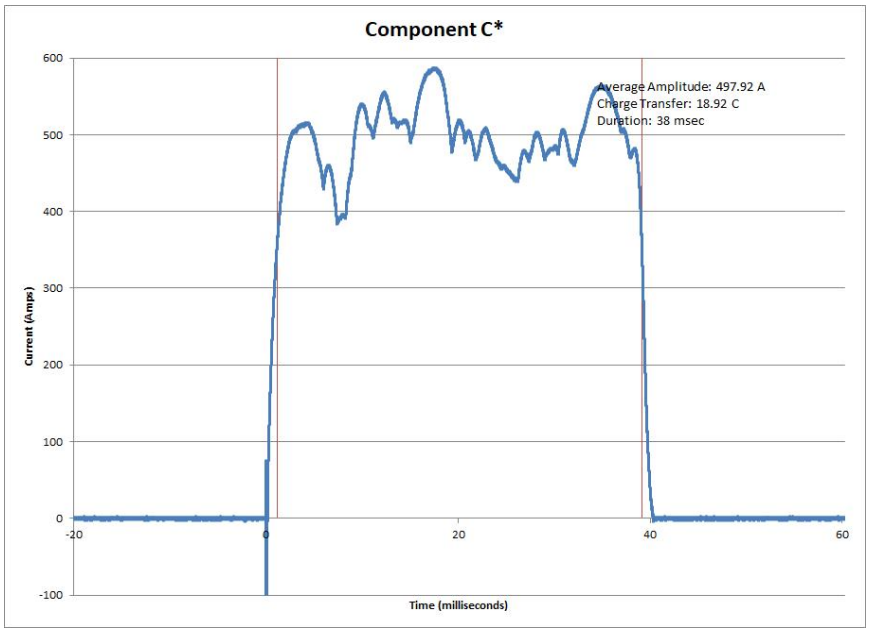


Figure 24: Arc Entry Test -067 - TP1 - Component C*

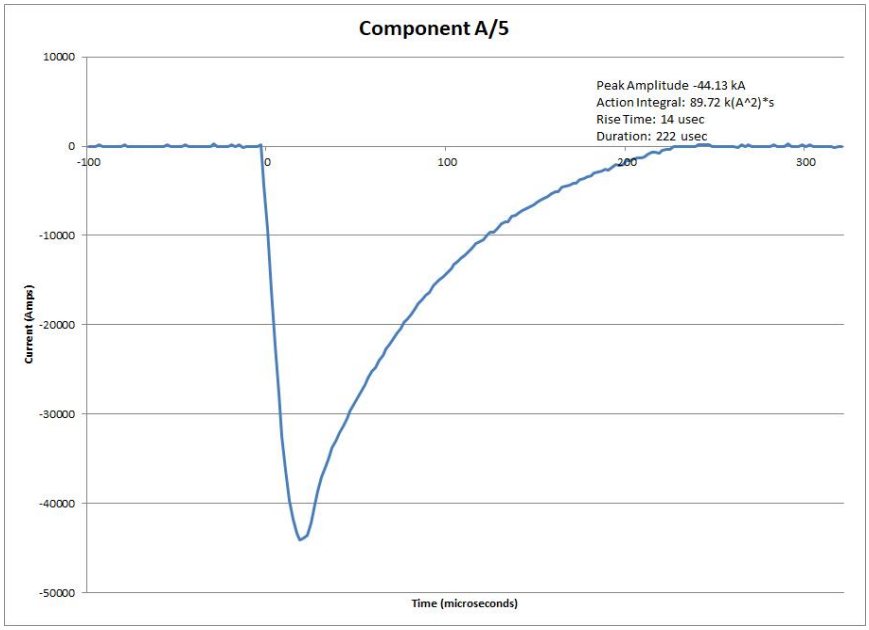


Figure 25: Arc Entry Test -067 - TP2 - Component A/5

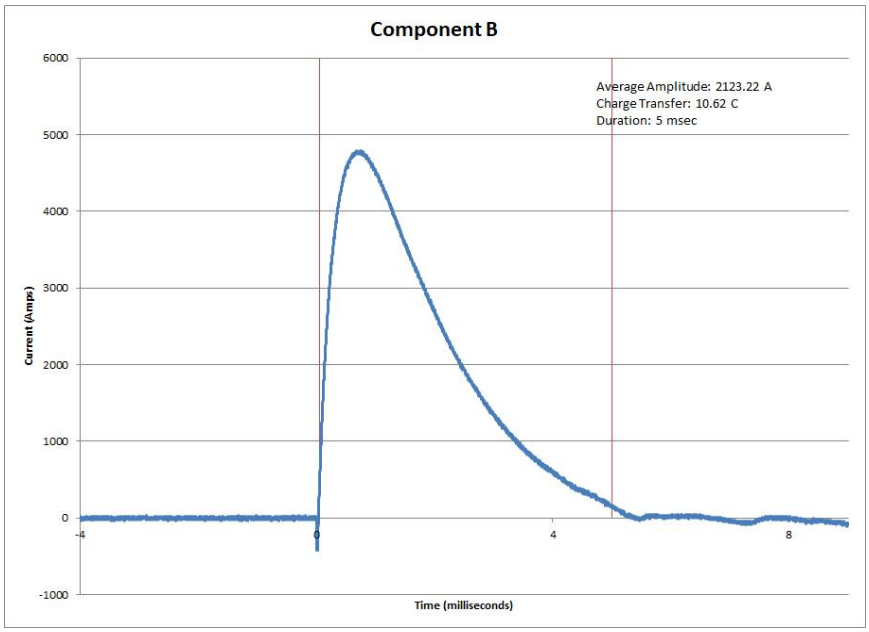


Figure 26: Arc Entry Test -067 - TP2 - Component B

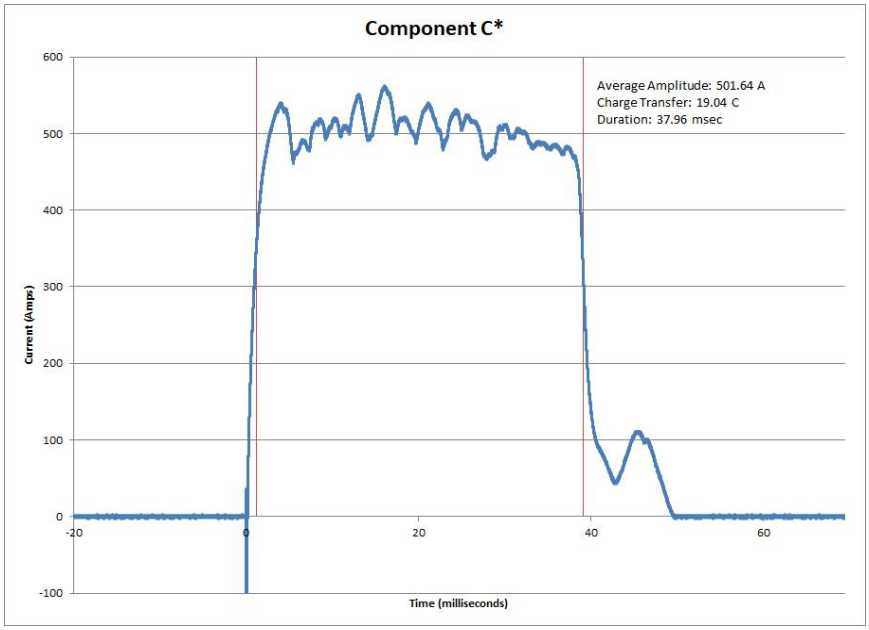


Figure 27: Arc Entry Test -067 - TP2 - Component C*

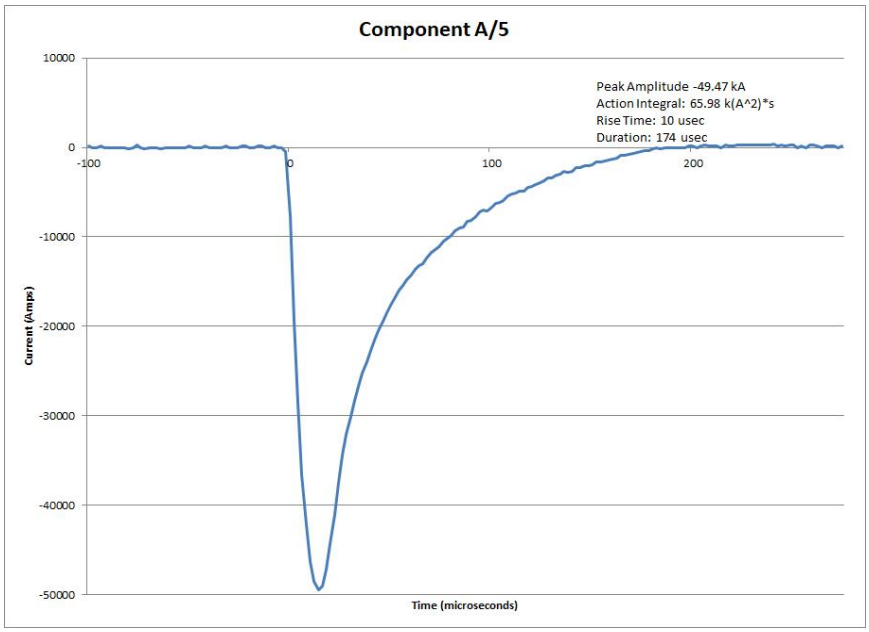


Figure 28: Arc Entry Test -067 - TP3 - Component A/5

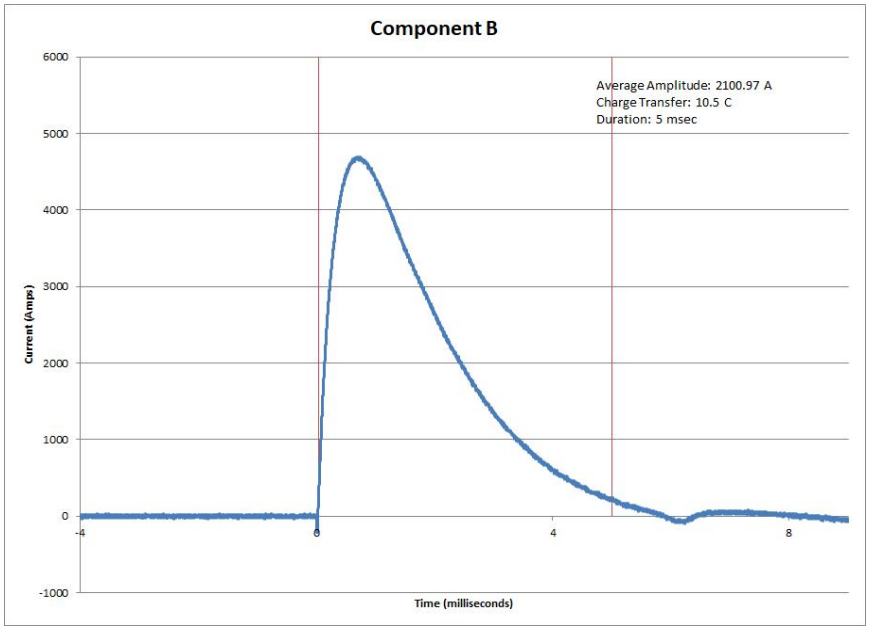


Figure 29: Arc Entry Test -067 - TP3 - Component B

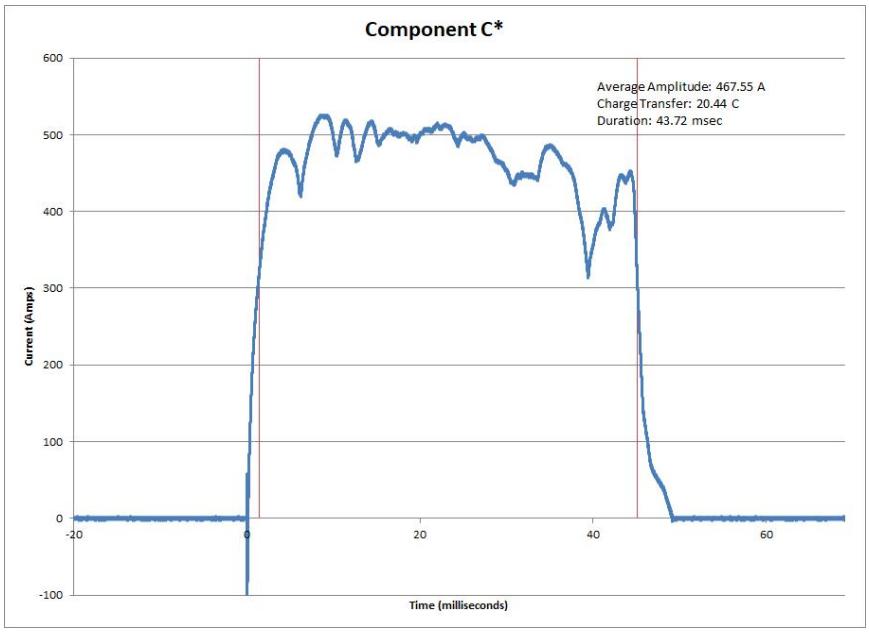


Figure 30: Arc Entry Test -067 - TP3 - Component C*

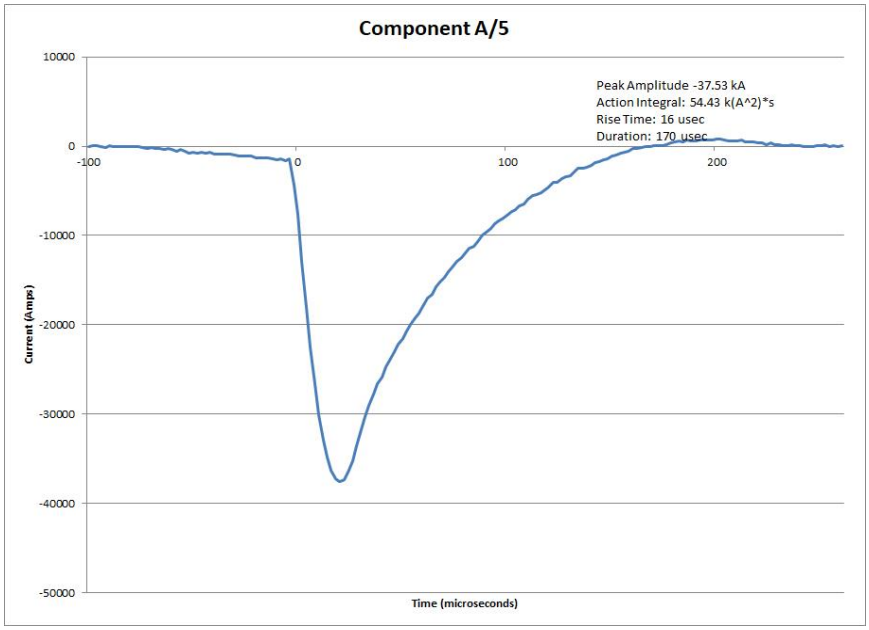


Figure 31: Arc Entry Test -069 - TP1 - Component A/5

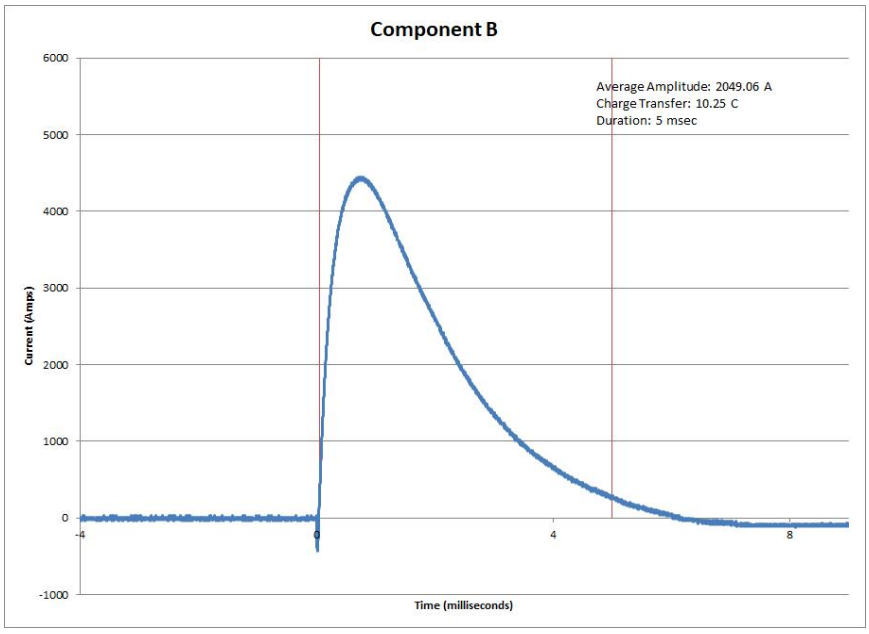


Figure 32: Arc Entry Test -069 - TP1 - Component B

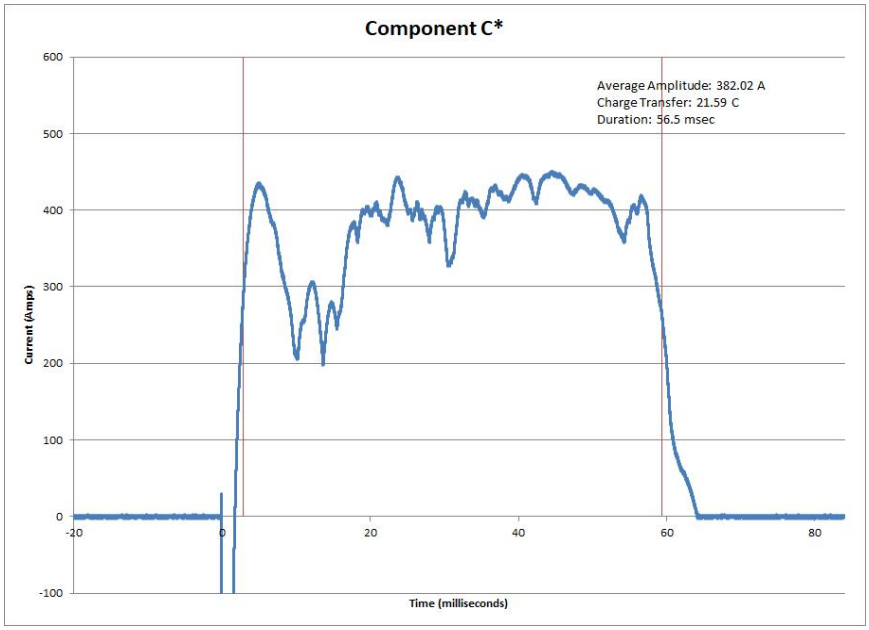


Figure 33: Arc Entry Test -069 - TP1 - Component C*

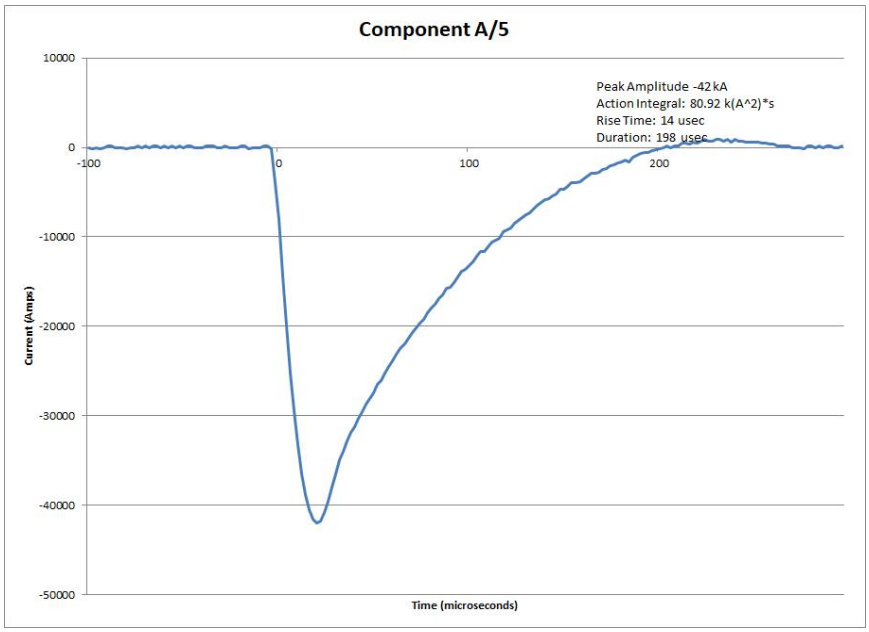


Figure 34: Arc Entry Test -069 - TP2 - Component A/5

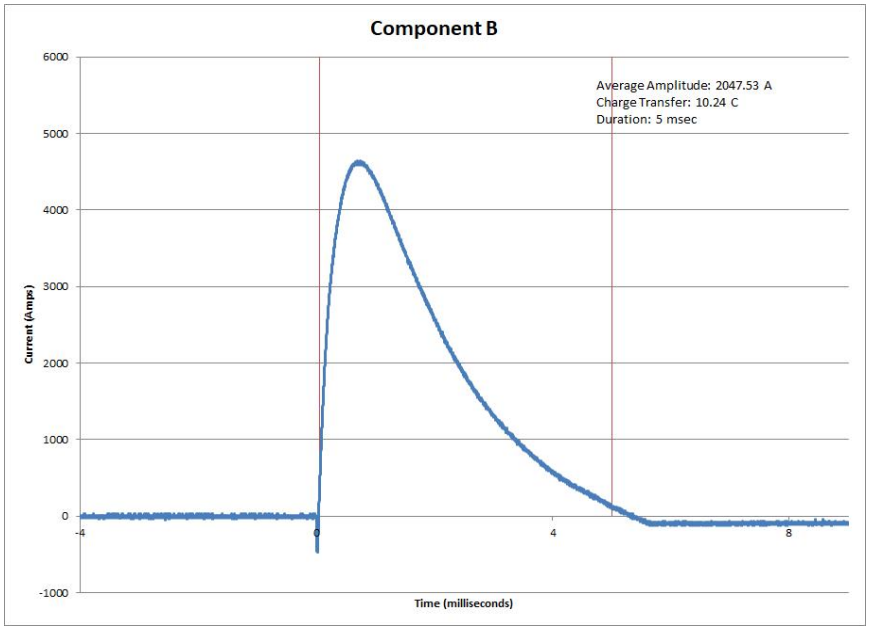


Figure 35: Arc Entry Test -069 - TP2 - Component B

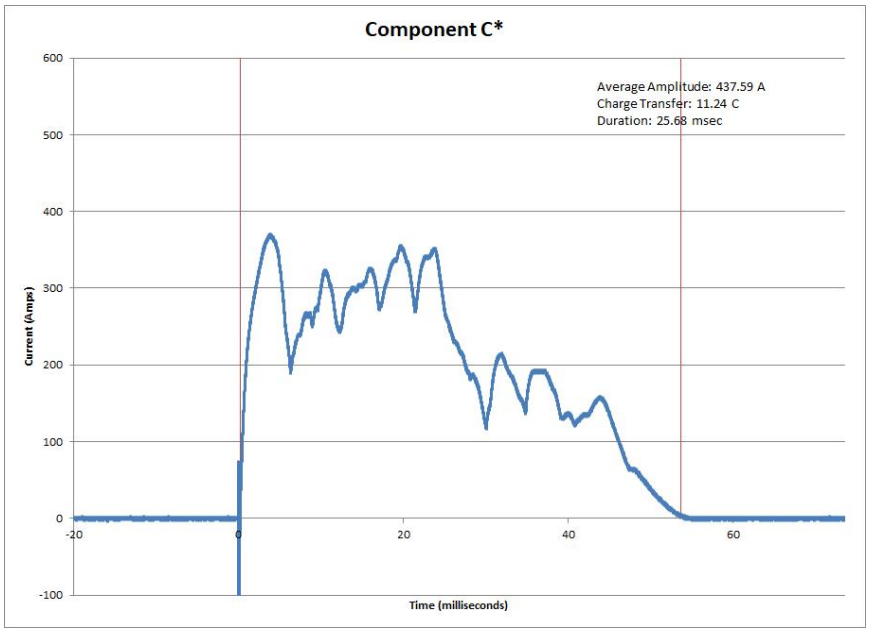


Figure 36: Arc Entry Test -069 - TP2 - Component C*

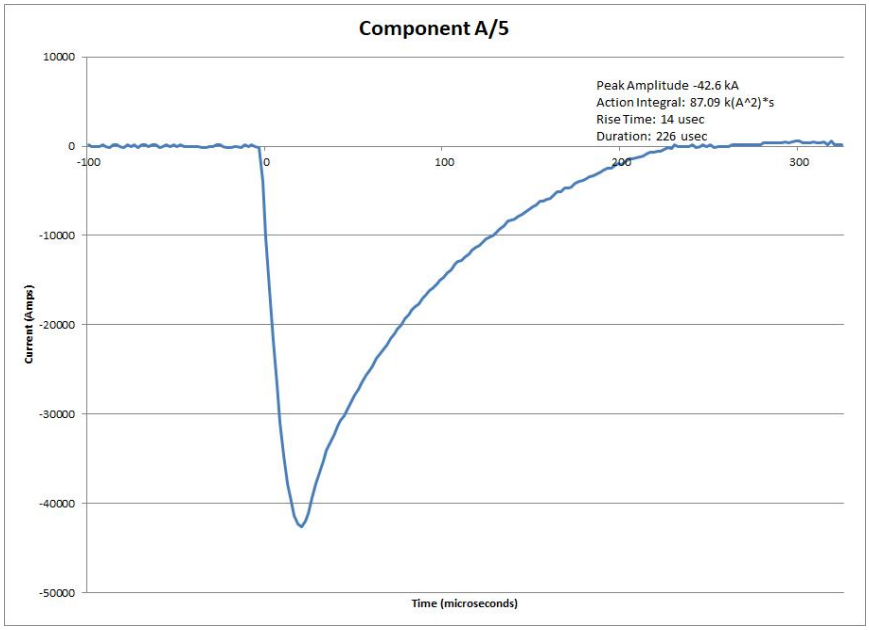


Figure 37: Arc Entry Test -069 - TP3 - Component A/5

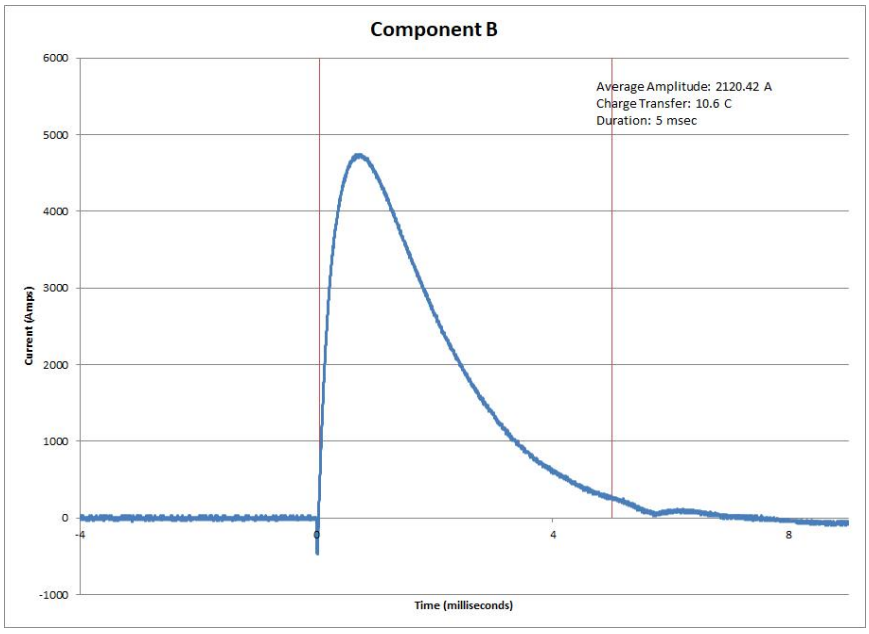


Figure 38: Arc Entry Test -069 - TP3 - Component B

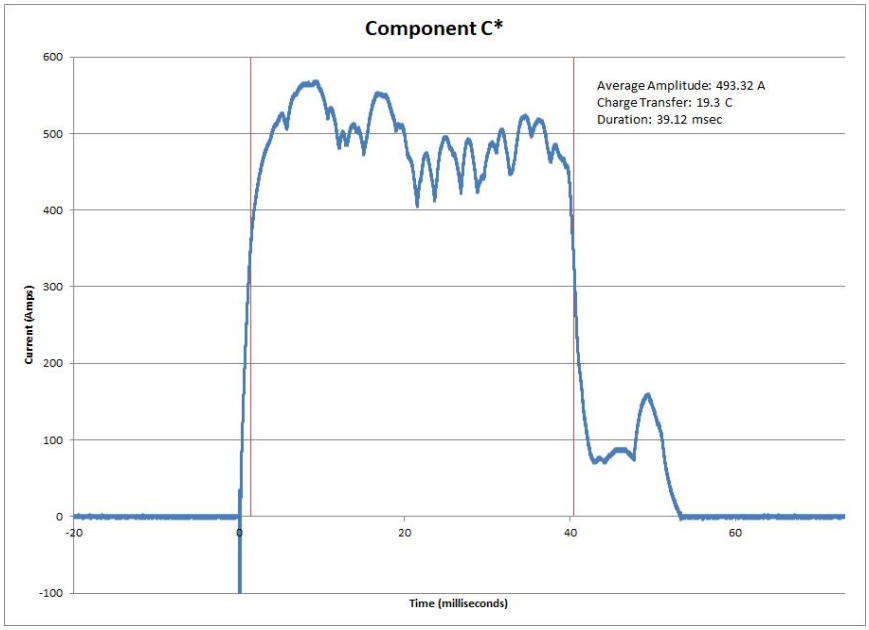


Figure 39: Arc Entry Test -069 - TP3 - Component C*

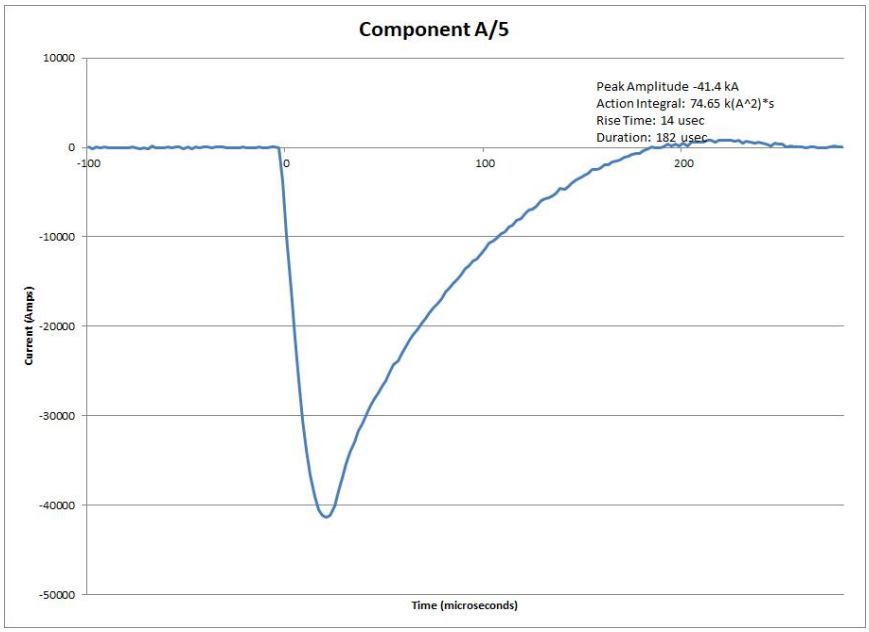


Figure 40: Arc Entry Test -069 - TP4 - Component A/5

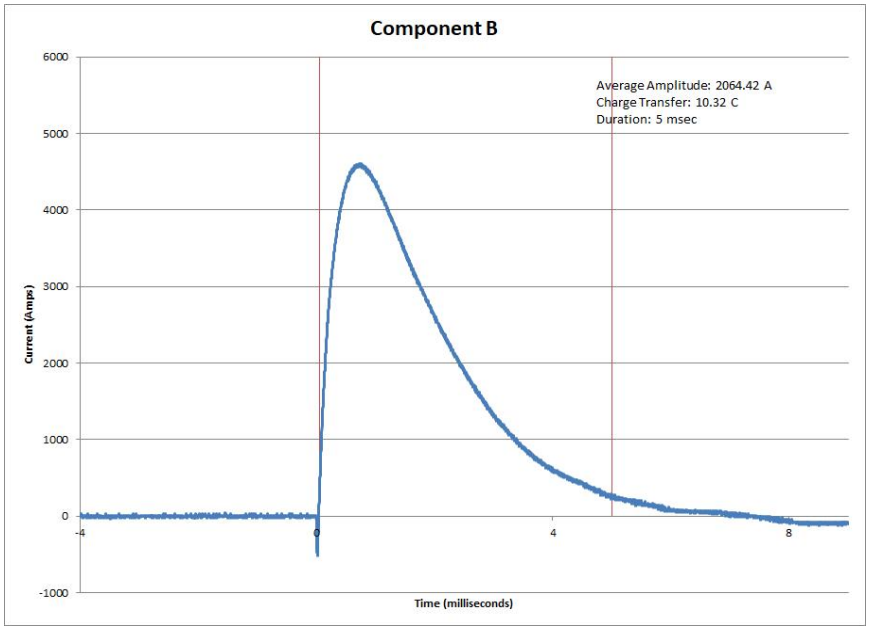


Figure 41: Arc Entry Test -069 - TP4 - Component B

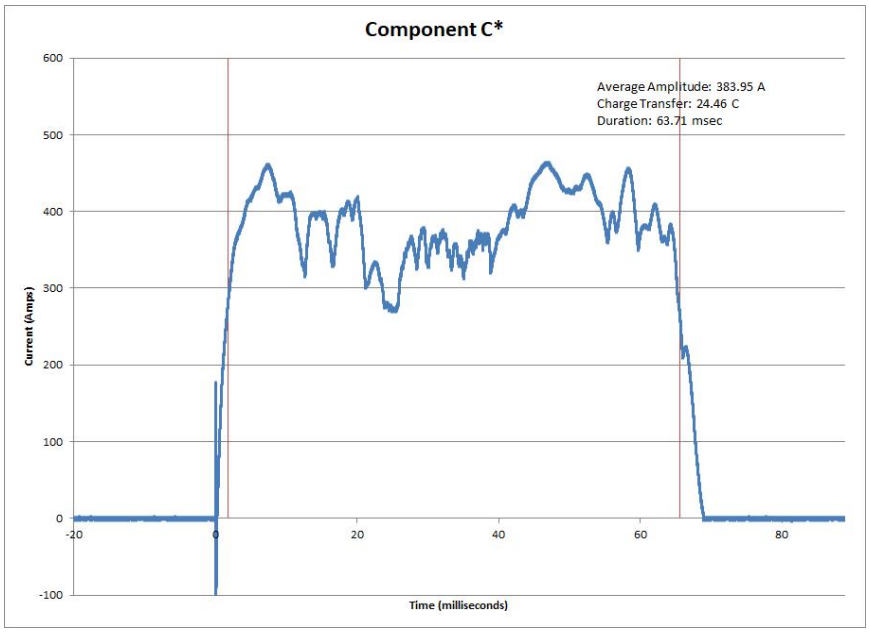


Figure 42: Arc Entry Test -069 - TP4 - Component C*

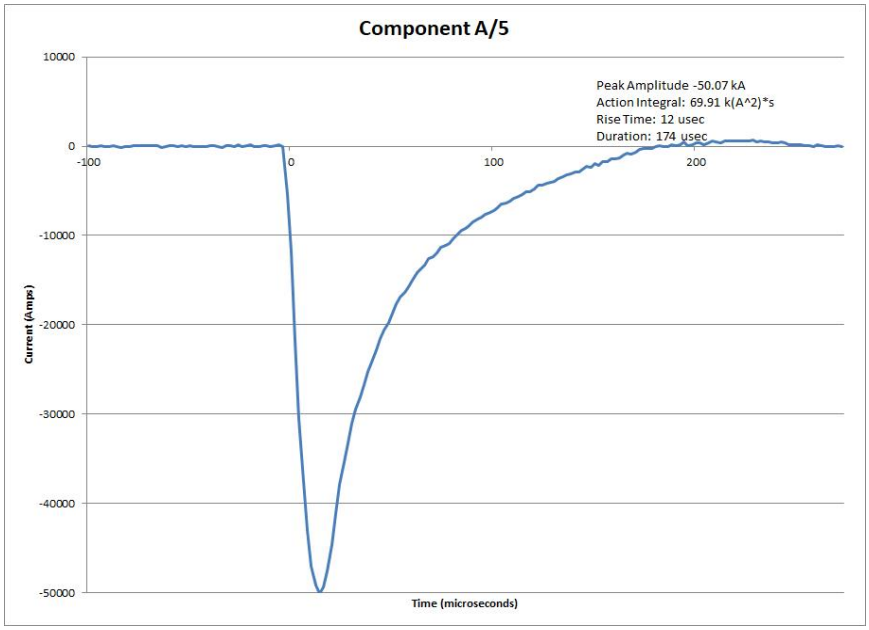


Figure 43: Arc Entry Test -069 - TP5 - Component A/5

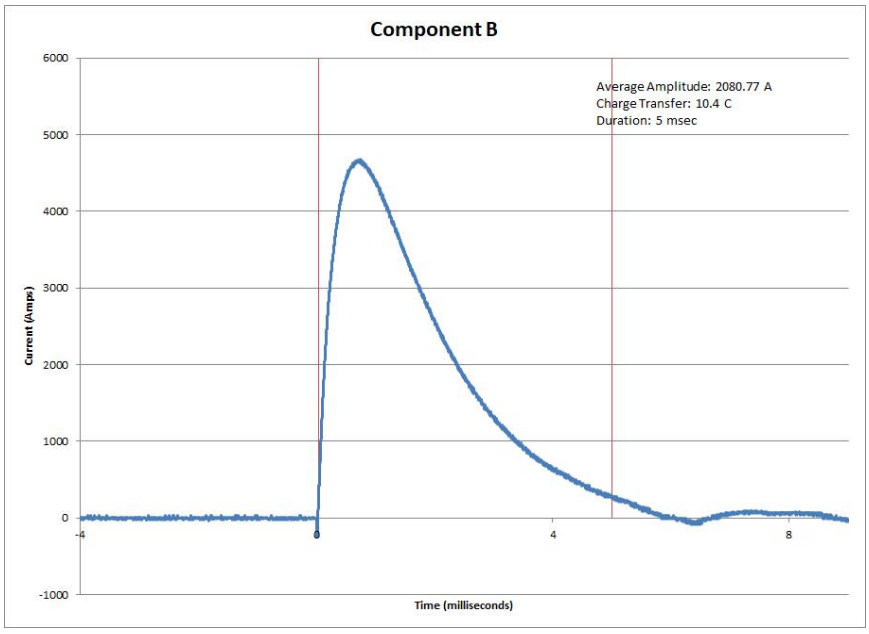


Figure 44: Arc Entry Test -069 - TP5 - Component B

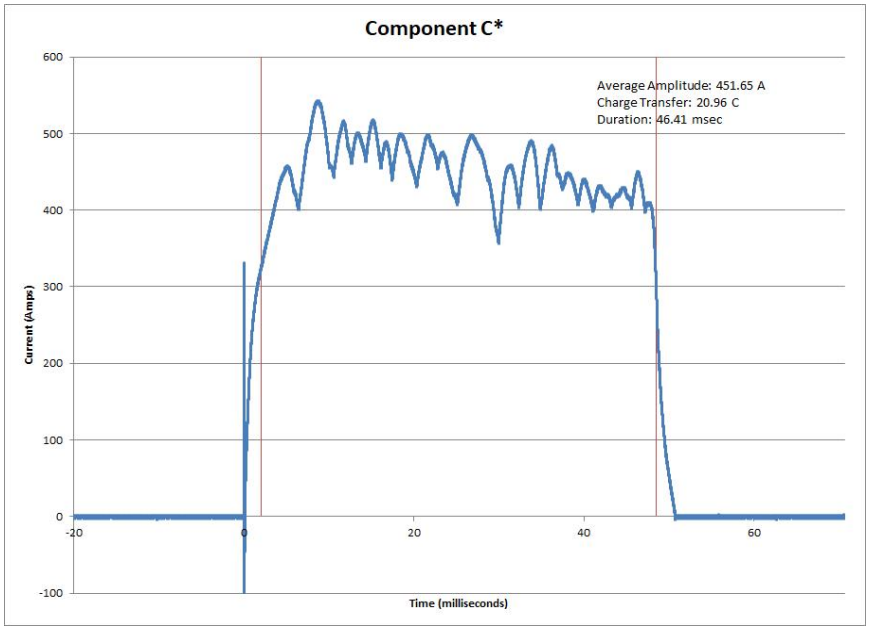


Figure 45: Arc Entry Test -069 - TP5 - Component C*

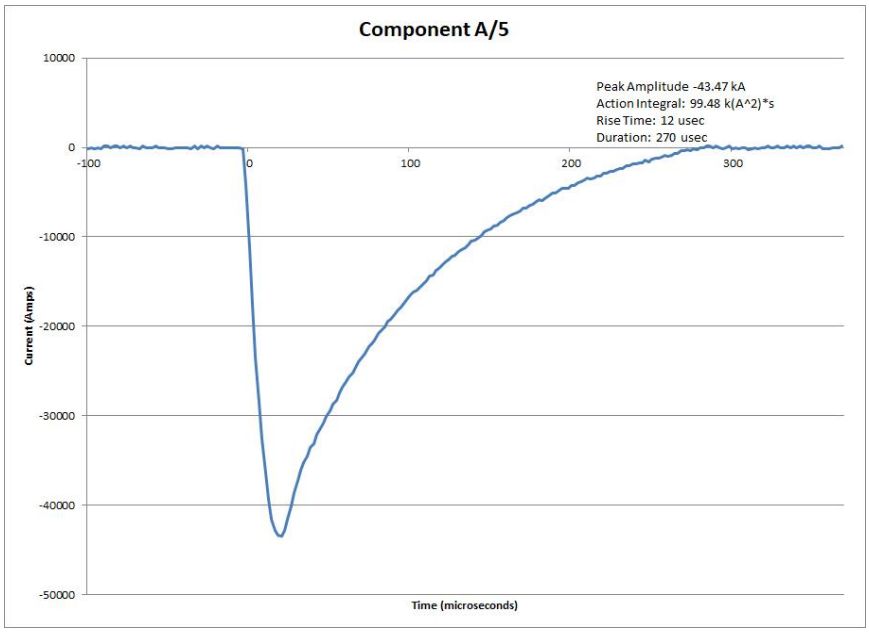


Figure 46: Arc Entry Test - Waveform Verification Al Panel - Component A/5

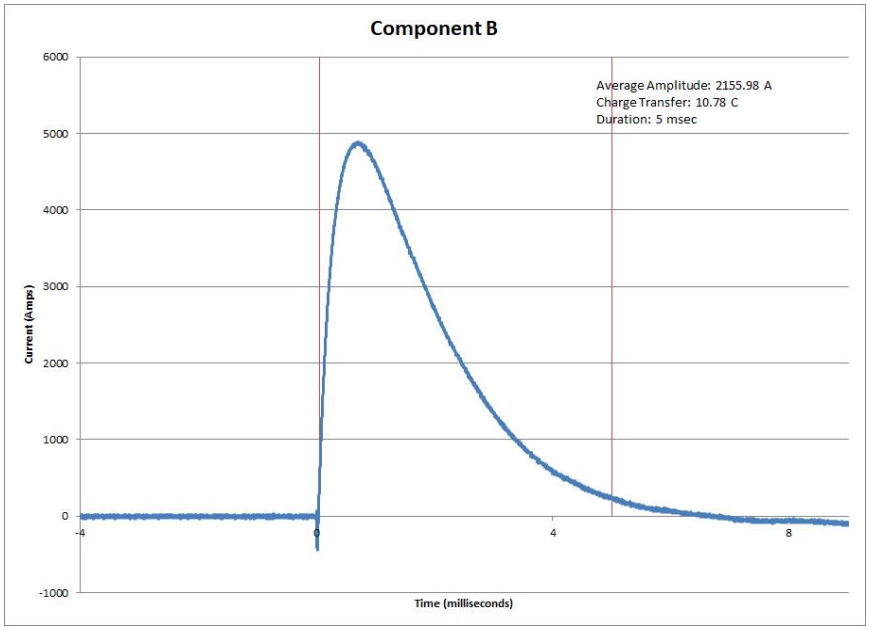


Figure 47: Arc Entry Test - Waveform Verification Al Panel - Component B

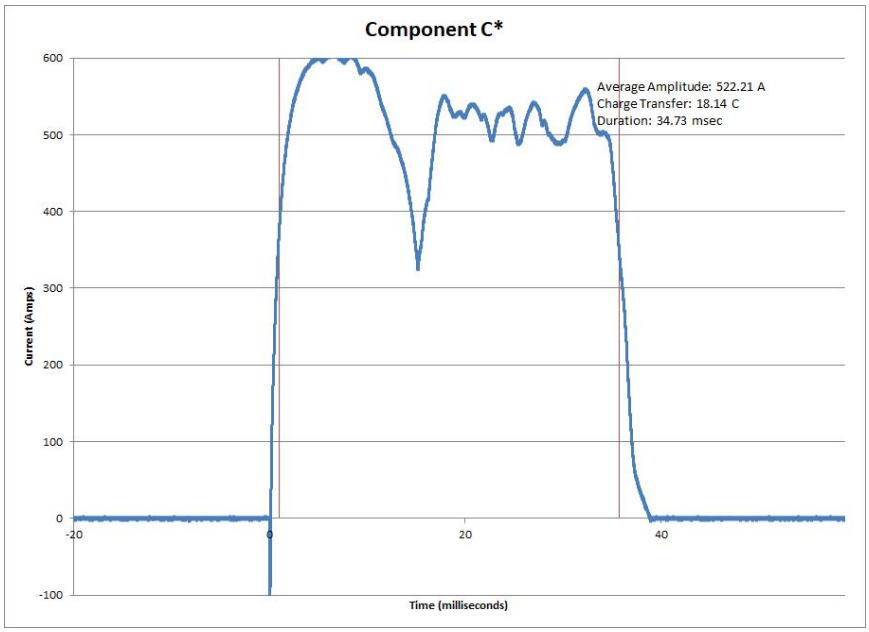


Figure 48: Arc Entry Test - Waveform Verification Al Panel - Component C*

Appendix B - Test Photos

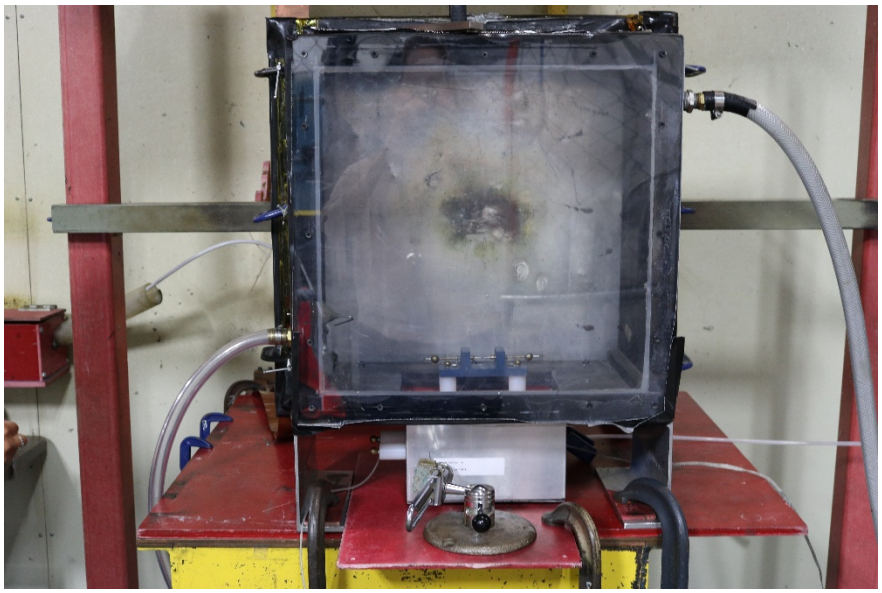


Figure 1: Arc Entry Test -General Test Setup-1

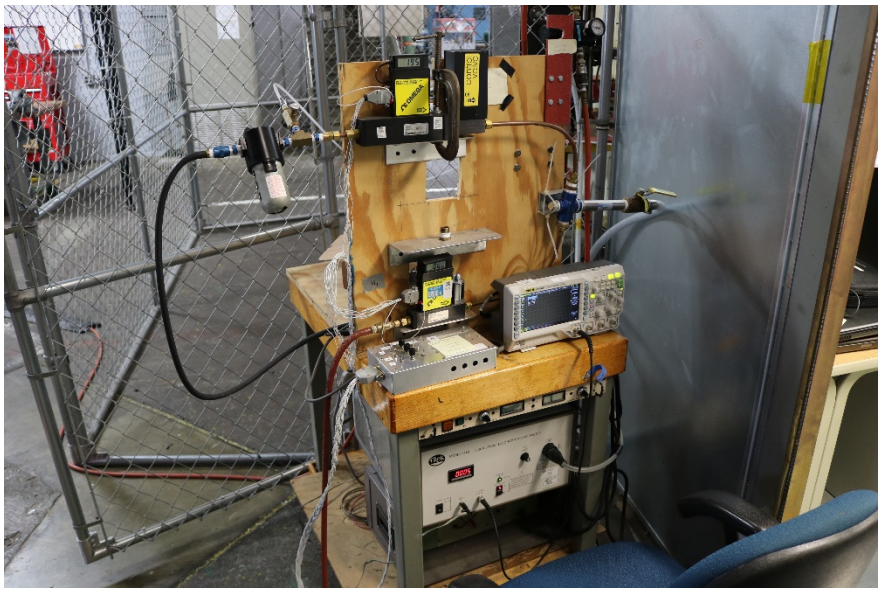


Figure 2: Arc Entry Test -General Test Setup-2

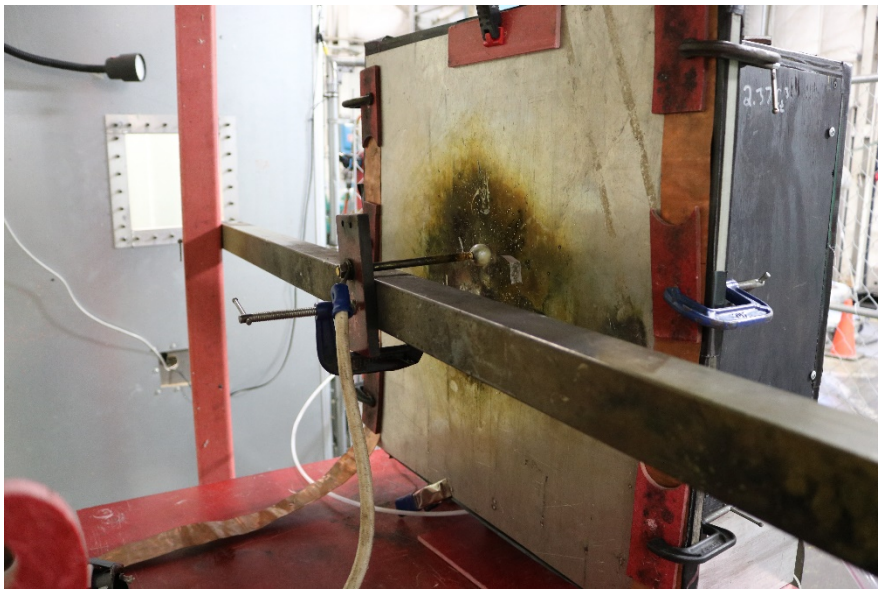


Figure 3: Arc Entry Test -Waveform Verification-Zone 3

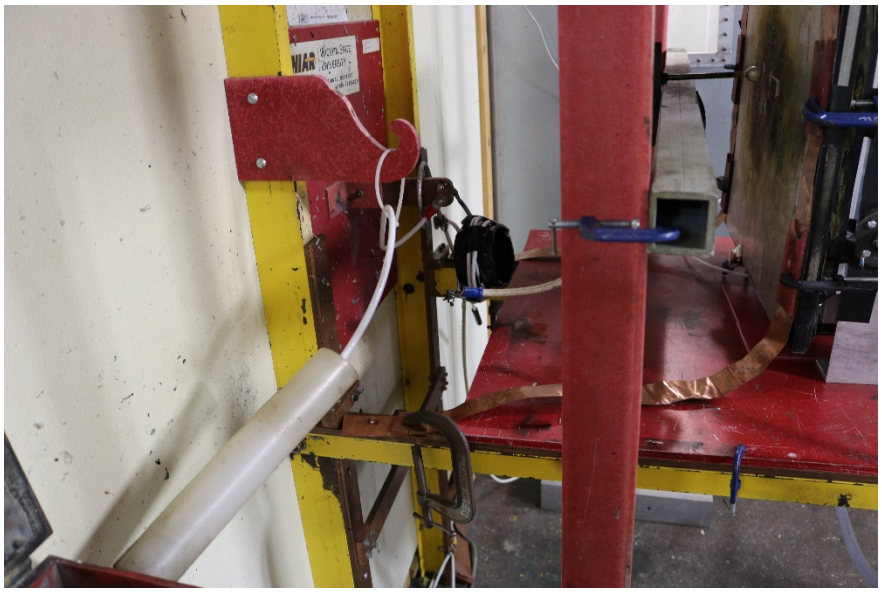


Figure 4: Arc Entry Test -General Test Setup-3

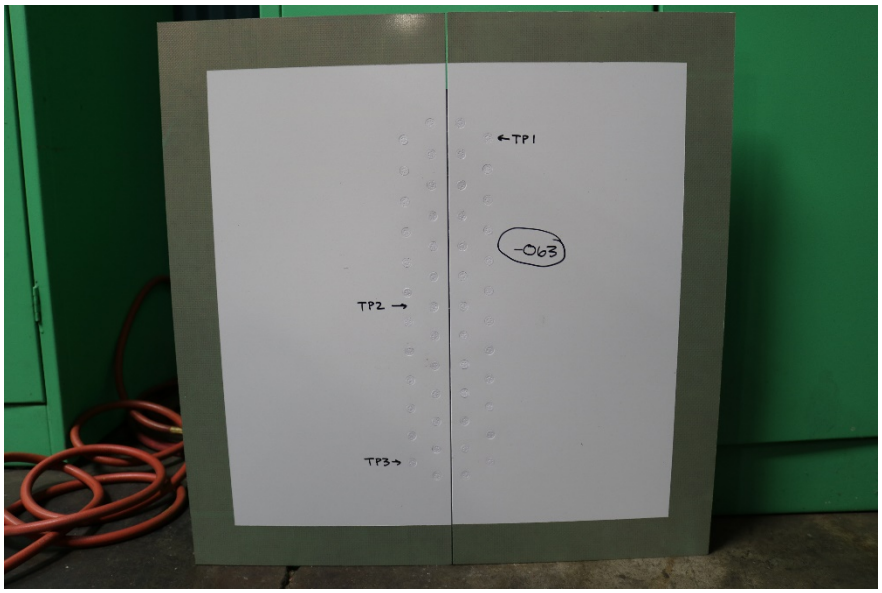


Figure 5: Arc Entry Test -Z3C5700-63-Check In-Pre-Test-Front

Figure 6: Arc Entry Test -Z3C5700-63-Check In-Pre-Test-Back

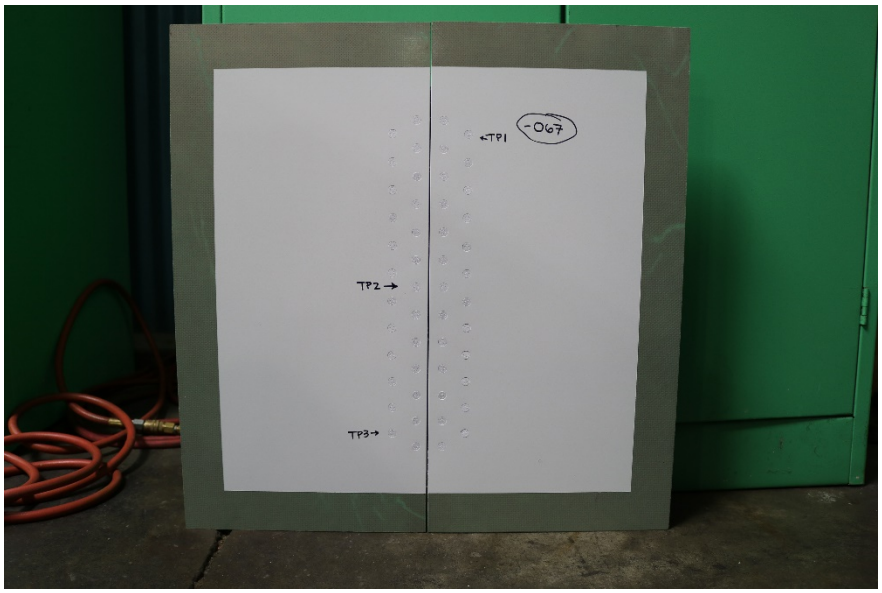


Figure 7: Arc Entry Test -Z3C5700-67-Check In-Pre-Test-Front -Incorrect Fastener

Figure 8: Arc Entry Test -Z3C5700-67-Check In-Pre-Test-Back-Incorrect Fastener

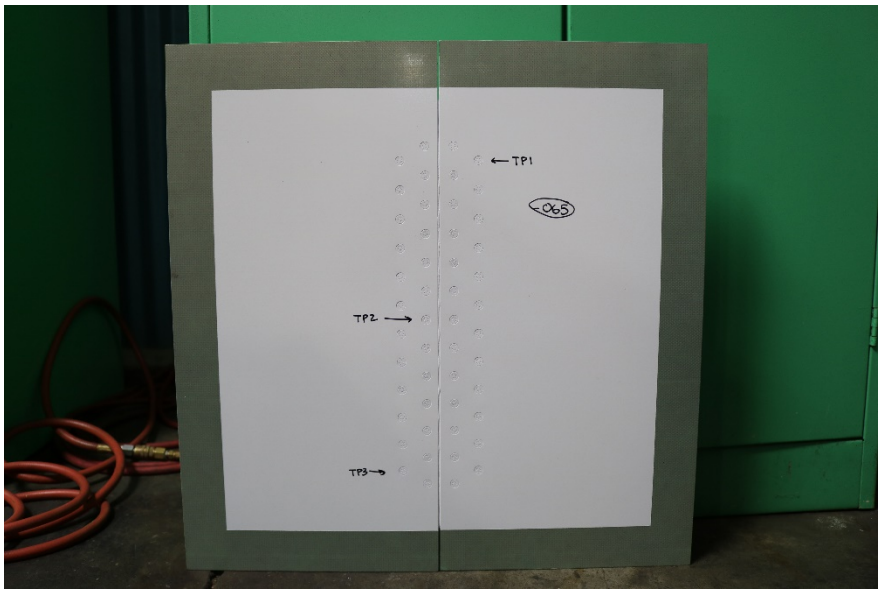


Figure 9: Arc Entry Test -Z3C5700-65-Check In-Pre-Test-Front

Figure 10: Arc Entry Test -Z3C5700-65-Check In-Pre-Test-Back

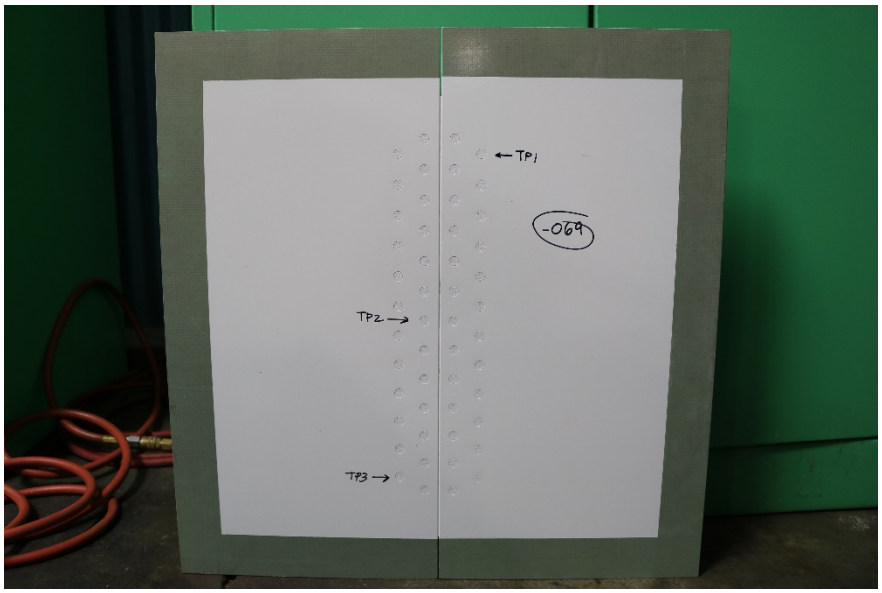


Figure 11: Arc Entry Test -Z3C5700-69-Check In-Pre-Test-Front

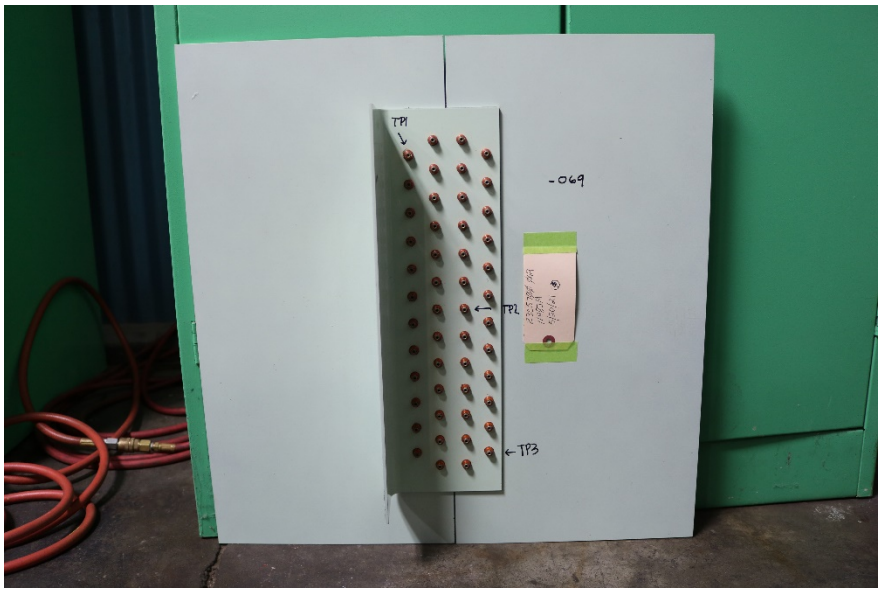


Figure 12: Arc Entry Test -Z3C5700-69-Check In-Pre-Test-Back

Figure 13: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP1-Pre-Test

Figure 14: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP1-Post-Test

Figure 15: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP3-Pre-Test

Figure 16: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP3-Post-Test-1

Figure 17: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP3-Post-Test-2

Figure 18: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP3-Post-Test-3

Figure 19: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP4-Pre-Test

Figure 20: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP4-Post-Test

Figure 21: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP5-Pre-Test

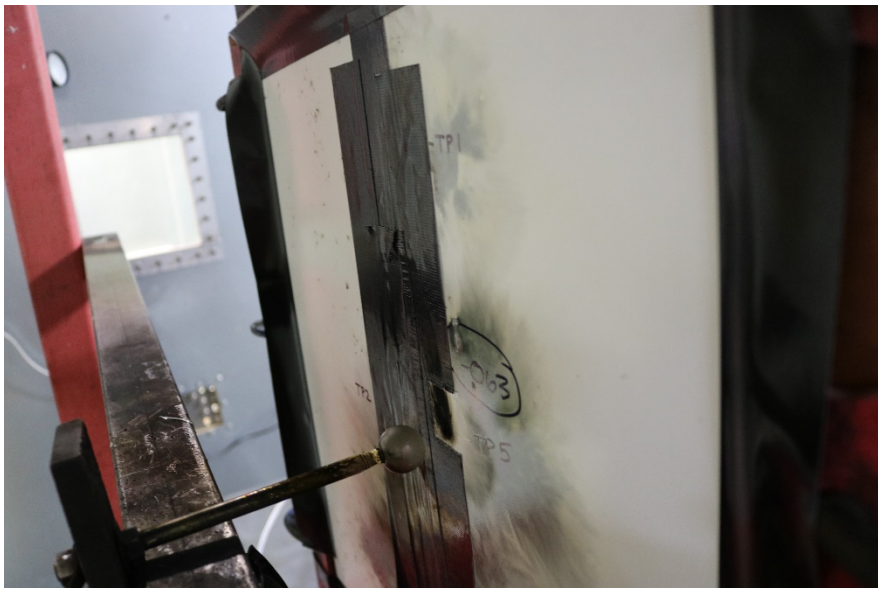


Figure 22: Arc Entry Test -Z3C5700-63-Installation-Zone 3-TP5-Post-Test

Figure 23: Arc Entry Test -Z3C5700-63-Zone 3-Post-Test-Front

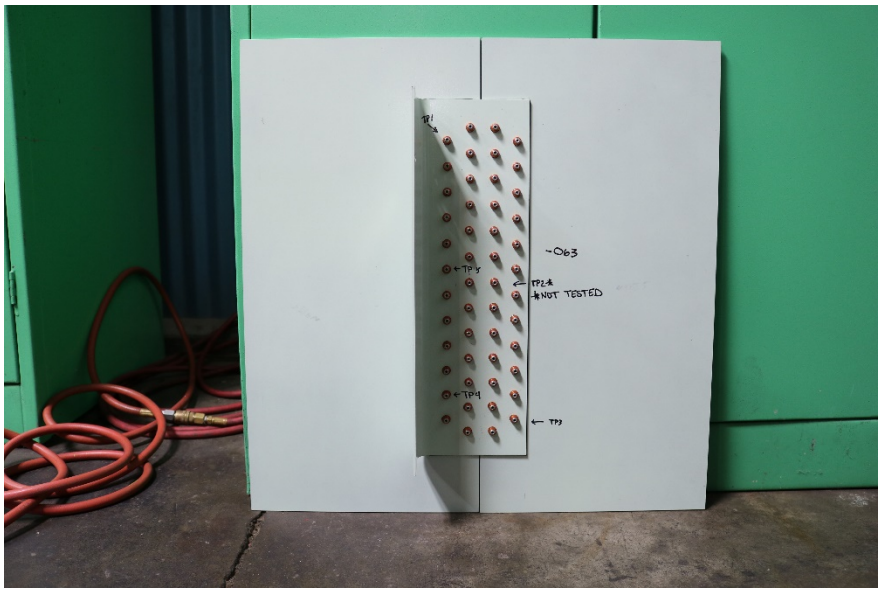


Figure 24: Arc Entry Test -Z3C5700-63-Zone 3-Post-Test-Back

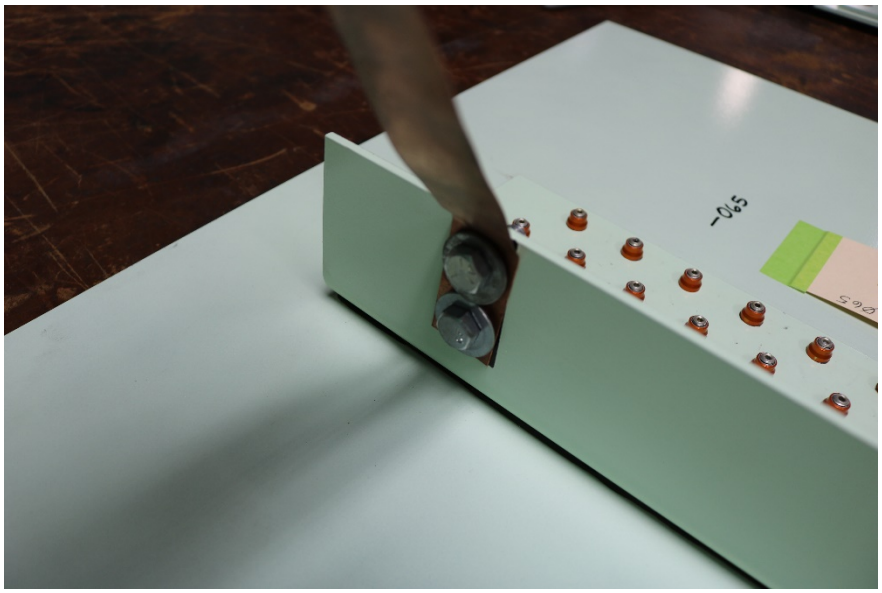


Figure 25: Arc Entry Test -General Test Setup-L bracket Bonding-1

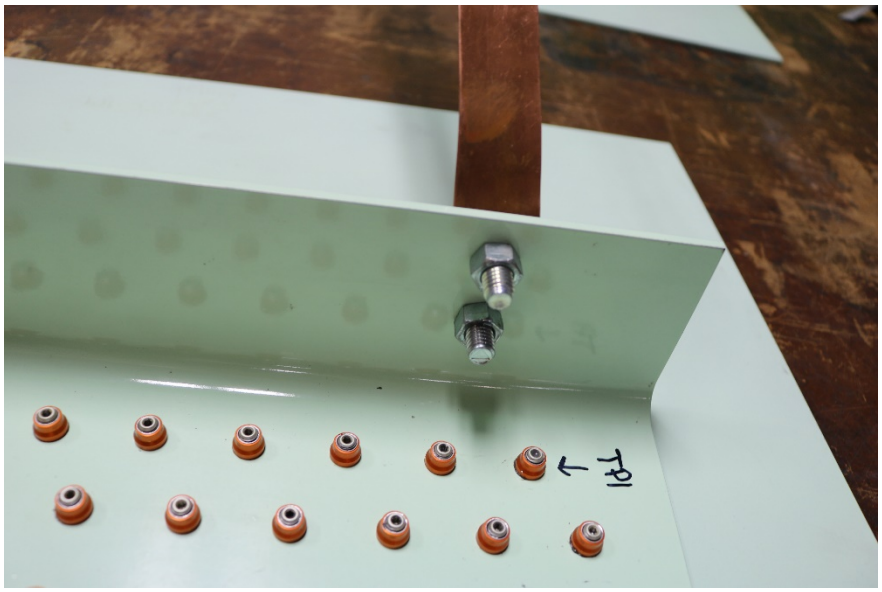


Figure 26: Arc Entry Test -General Test Setup-L bracket Bonding-2

Figure 27: Arc Entry Test -General Test Setup-L bracket Bonding-3

Figure 28: Arc Entry Test -General Test Setup-L bracket Bonding-4

Figure 29: Arc Entry Test -Z3C5700-65-Installation-Zone 3-TP3-Pre-Test

Figure 30: Arc Entry Test -Z3C5700-65-Installation-Zone 3-TP3-Post-Test

Figure 31: Arc Entry Test -Z3C5700-65-Installation-Zone 3-TP2-Pre-Test

Figure 32: Arc Entry Test -Z3C5700-65-Installation-Zone 3-TP2-Post-Test

Figure 33: Arc Entry Test -Z3C5700-65-Installation-Zone 3-TP1-Pre-Test

Figure 34: Arc Entry Test -Z3C5700-65-Installation-Zone 3-TP1-Post-Test

Figure 35: Arc Entry Test -General Test Setup-L bracket Bonding-5

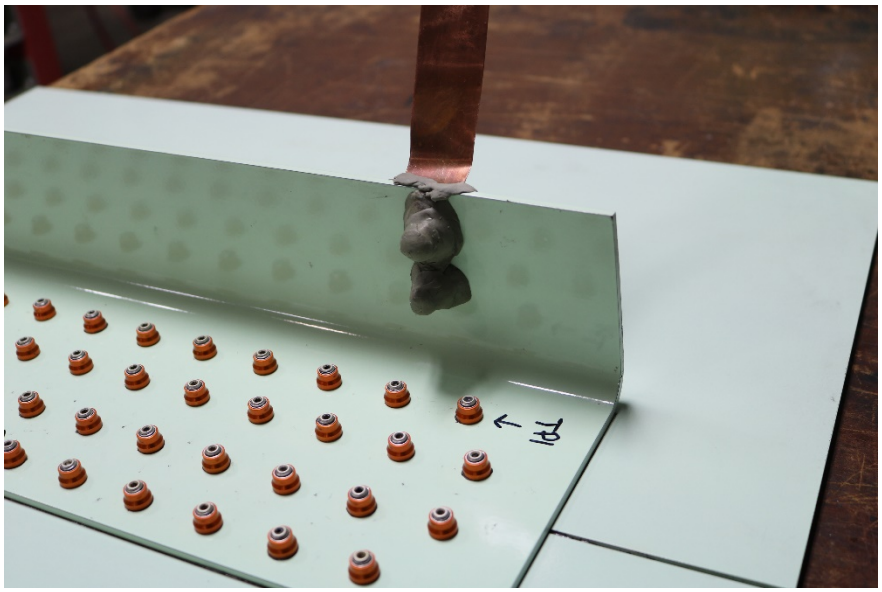


Figure 36: Arc Entry Test -General Test Setup-L bracket Bonding-6

Figure 37: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP3-Pre-Test

Figure 38: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP3-Post-Test

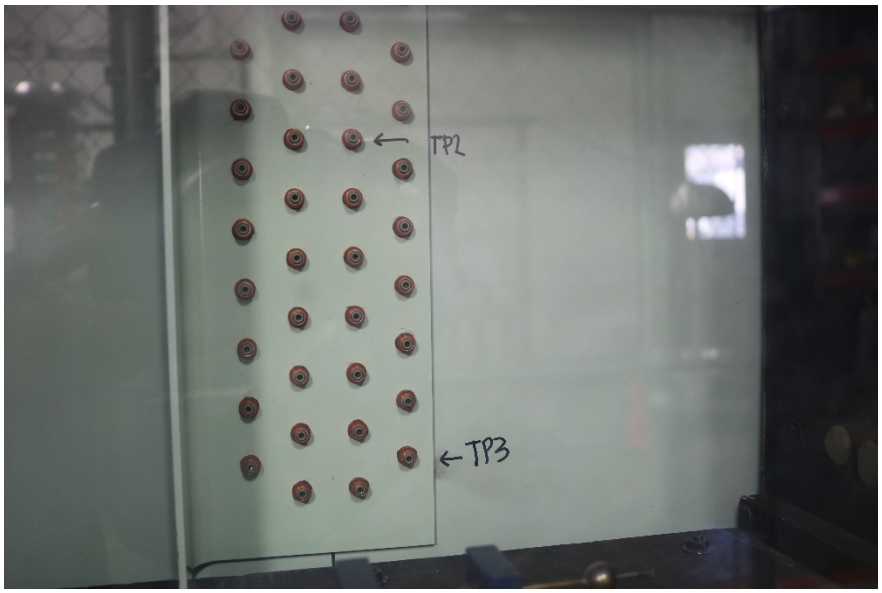


Figure 39: Arc Entry Test -Z3C5701-68-Installation-Zone 4-TP3-Post-Test-Backside scorching

Figure 40: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP2-Pre-Test

Figure 41: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP2-Post-Test

Figure 42: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP1-Pre-Test

Figure 43: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP1-Post-Test

Figure 44: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP4-Pre-Test

Figure 45: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP4-Post-Test

Figure 46: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP5-Pre-Test

Figure 47: Arc Entry Test -Z3C5700-69-Installation-Zone 3-TP5-Post-Test

Figure 48: Arc Entry Test -Z3C5700-69-Zone 3-Post-Test-Front

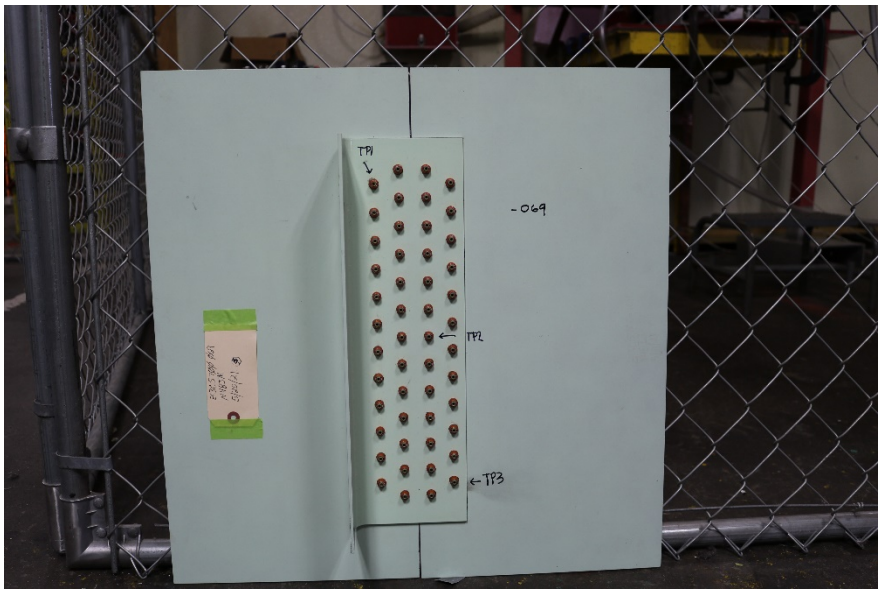


Figure 49: Arc Entry Test -Z3C5700-69-Zone 3-Post-Test-Back

Figure 50: Arc Entry Test -Z3C5700-65-Zone 3-Post-Test-Front

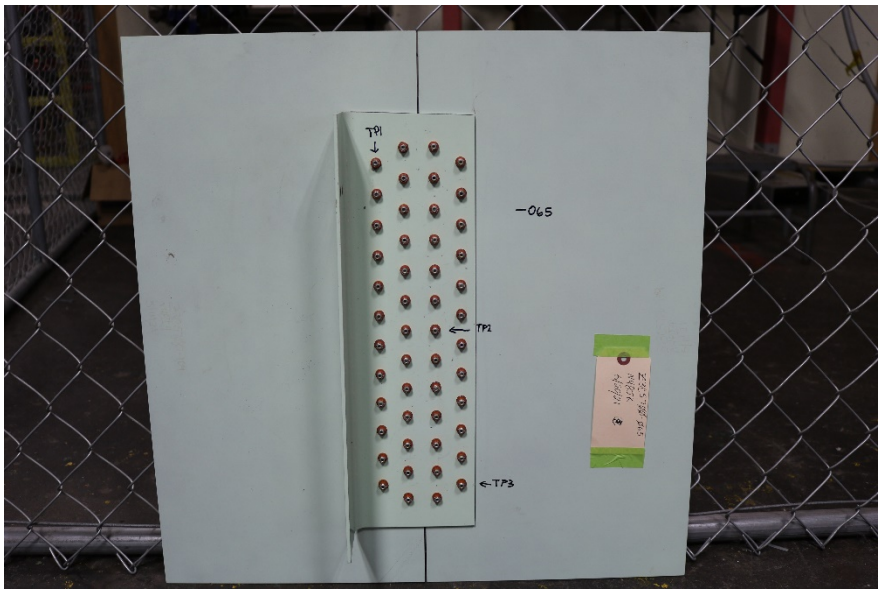


Figure 51: Arc Entry Test -Z3C5700-65-Zone 3-Post-Test-Back

Figure 52: Arc Entry Test -Z3C5700-67-Check In-Pre-Test-Front

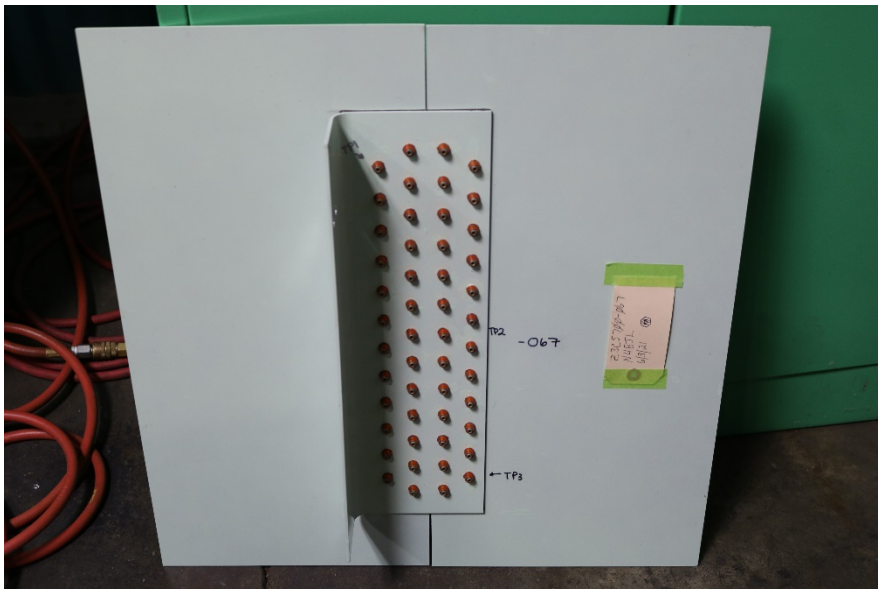


Figure 53: Arc Entry Test -Z3C5700-67-Check In-Pre-Test-Back

Figure 54: Arc Entry Test -Z3C5700-67-Installation-Zone 3-TP3-Pre-Test

Figure 55: Arc Entry Test -Z3C5700-67-Installation-Zone 3-TP3-Post-Test

Figure 56: Arc Entry Test -Z3C5700-67-Installation-Zone 3-TP2-Pre-Test

Figure 57: Arc Entry Test -General Test Setup-4

Figure 58: Arc Entry Test -Z3C5700-67-Installation-Zone 3-TP2-Post-Test

Figure 59: Arc Entry Test -Z3C5700-67-Installation-Zone 3-TP1-Pre-Test

Figure 60: Arc Entry Test -Z3C5700-67-Installation-Zone 3-TP1-Post-Test

Figure 61: Arc Entry Test -Z3C5700-67-Zone 3-Post-Test-Front

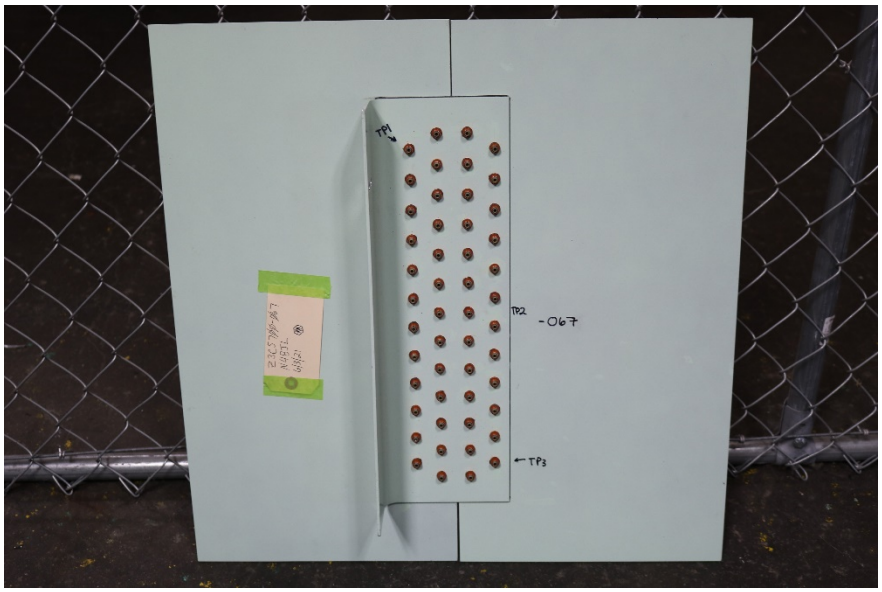


Figure 62: Arc Entry Test -Z3C5700-67-Zone 3-Post-Test-Back

Appendix C - Test Logs

Figure 1: Lightning Direct Effects Test Log

Customer	KART								
Part Number	Multiple								
Serial Number	Multiple								
Test Section	Lightning Direct Effects								
Tested By	Alyssa Gonzalez, Rebeka Khajehpour								
Test Witness	N/A								
Start Date	6/8/2021								
End Date	6/9/2021								
Lab Conditions	**Date**	**Temp**	**Humidity**	**Date**	**Temp**	**Humidity**	**Date**	**Temp**	**Humidity**
	6/8/21	69.4	72.5						
	6/14/21	71.8	62.4						

Test Log Data

Date	Time	Notes
6/8/2021	8:00AM	Arrive to begin testing.
	8:30AM	Completed flammable gas calibration with 9 consecutive ignitions between 162 and 171 µJ. Hydrogen concentration is 7% with a 14.6 SLPM flow rate. Air flow rate is 194 SLPM. Capacitor is set to 9.76 pF.
	9:30AM	Generator waveform verification for Zone 3 direct attachment waveform Components A/5, B, and C* into aluminum panel. Generator is in D bank configuration (6 caps, ½ wall resistor, inductor on output), with B spark gap set to 0.5", and a 24+28 gauge copper fuse for C*. **Shot #** / **Charge Voltage, kV A bank:** / **Charge Voltage, kV B bank:** / **Peak I, kA (±10%)** / **Action Integral, kAAs (±20%)** / **B Charge Transfer, C (±10%)** / **C* Charge Transfer, C (±20%)** **Target 40 kA**: 26.7 / 5.51 / 40 / 80 / 10 / 18 **Actual**: / / 43.47 / 99.48 / 10.78 / 18.14 Bonding aluminum cal plate to ground: 0.507 mΩ All waveforms are within specification.
	11:00AM	Panel -063 TP1 **Shot #** / **Charge Voltage, kV A bank:** / **Charge Voltage, kV B bank:** / **Peak I, kA (±10%)** / **Action Integral, kAAs (±20%)** / **B Charge Transfer, C (±10%)** / **C* Charge Transfer, C (±20%)** / **Notes**

Test Log Data

Date	Time	Notes

40 kA	26.7	5.51	42.6	94.81	N/A	21.04	B bank did not fire, test is invalid for this reason

No ignition during test. Post-test ignition was successful at 166uJ.

Due to evident conditioning, we are moving to test point 3 next, because it looks more pristine than TP 2. TP2 will not be tested because it shows damage resulting from the TP1 test.

12:00PM

Panel -063 TP3

Pretest bond measurement from panel ECF to ground = 3.430 mΩ

Shot #	Charge Voltage, kV A bank:	Charge Voltage, kV B bank:	Peak I, kA (±10%)	Action Integral, kAAs (±20%)	B Charge Transfer, C (±10%)	C* Charge Transfer, C (±20%)	Notes
40 kA	26.7	5.51	43.87	90.01	10.52	21.83	

No ignition during test. Post-test ignition was successful at 162uJ.

Next test point is TP 4.

2:15PM

Panel -063 TP4

Shot #	Charge Voltage, kV A bank:	Charge Voltage, kV B bank:	Peak I, kA (±10%)	Action Integral, kAAs (±20%)	B Charge Transfer, C (±10%)	C* Charge Transfer, C (±20%)	Notes
40 kA	26.7	5.51	43.3	90.38	10.68	19.34	

No ignition during test. Post-test ignition was successful at 181uJ.

Next test point is TP 5. We are doing a fourth shot on this test article since the first one was invalid without B component firing.

2:40PM

Panel -063 TP5

Shot #	Charge Voltage, kV A bank:	Charge Voltage, kV B bank:	Peak I, kA (±10%)	Action Integral, kAAs (±20%)	B Charge Transfer, C (±10%)	C* Charge Transfer, C (±20%)	Notes
40 kA	26.7	5.51	42.6	88.65	10.69	20.26	

No ignition during test. Post-test ignition was successful at 157uJ.

3:30PM

Panel -065 TP3

Pretest bond measurement from copper strap to ground = 0.617mΩ

Test Log Data

Date	Time	Notes
		Shot # | **Charge Voltage, kV A bank:** | **Charge Voltage, kV B bank:** | **Peak I, kA (±10%)** | **Action Integral, kAAs (±20%)** | **B Charge Transfer, C (±10%)** | **C* Charge Transfer, C (±20%)** | **Notes** **40 kA** | 26.7 | 5.51 | 2.67 | 88.07 | 10.62 | 20.3 | Post-test spark energy not captured No ignition during test. Post-test ignition was successful with spark of unknown energy below 200 uJ. Test is valid as gas was ignitable and sufficiently sensitive.
	3:45PM	Panel -065 TP2 **Shot #** | **Charge Voltage, kV A bank:** | **Charge Voltage, kV B bank:** | **Peak I, kA (±10%)** | **Action Integral, kAAs (±20%)** | **B Charge Transfer, C (±10%)** | **C* Charge Transfer, C (±20%)** | **Notes** **40 kA** | 26.7 | 5.51 | 42.47 | 86.26 | 10.64 | 23.55 | No ignition during test. Post-test ignition was successful at 162uJ.
	4:00PM	Panel -065 TP1 **Shot #** | **Charge Voltage, kV A bank:** | **Charge Voltage, kV B bank:** | **Peak I, kA (±10%)** | **Action Integral, kAAs (±20%)** | **B Charge Transfer, C (±10%)** | **C* Charge Transfer, C (±20%)** | **Notes** **40 kA** | 26.7 | 5.51 | 42.33 | 86.56 | 10.61 | 20.01 | Ignition during test. Will inspect for location of any damage after removing from fixture.
	4:15PM	Finish testing for the day.
6/9/2021	8:00AM	Arrive to begin testing.
	9:15AM	Panel -069 TP3 Pretest bond measurement from panel ECF to ground = 3.957 mΩ **Shot #** | **Charge Voltage, kV A bank:** | **Charge Voltage, kV B bank:** | **Peak I, kA (±10%)** | **Action Integral, kAAs (±20%)** | **B Charge Transfer, C (±10%)** | **C* Charge Transfer, C (±20%)** | **Notes** **40 kA** | 26.7 | 5.51 | 42.6 | 87.09 | 10.6 | 19.3 | Scorching evident on backside of panel near TP3,

Test Log Data

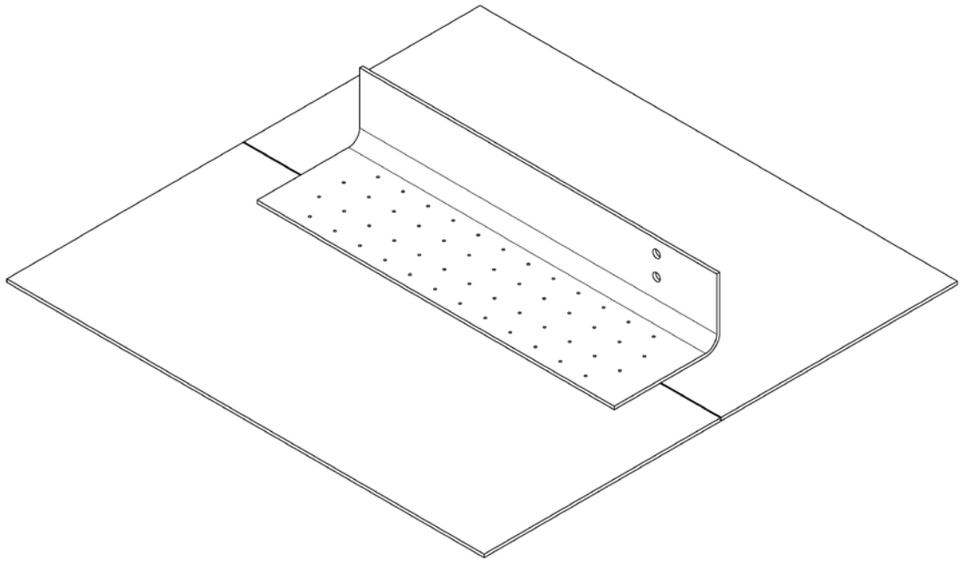
Date	Time	Notes
		<table><tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>but no ignition was noted</td></tr></table> No ignition during test. Post-test ignition was successful at 162uJ.
	9:45AM	Panel -069 TP2 <table><tr><th>Shot #</th><th>Charge Voltage, kV A bank:</th><th>Charge Voltage, kV B bank:</th><th>Peak I, kA (±10%)</th><th>Action Integral, kAAs (±20%)</th><th>B Charge Transfer, C (±10%)</th><th>C* Charge Transfer, C (±20%)</th><th>Notes</th></tr><tr><td>40 kA</td><td>26.7</td><td>5.51</td><td>42.0</td><td>80.921</td><td>10.24</td><td>11.24</td><td></td></tr></table> No ignition during test. Post-test ignition was successful at 166uJ. C component was short with low charge transfer. Fuse did not blow. We will do a 4th test point to obtain all correct waveforms.
	10:00AM	Panel -069 TP1 <table><tr><th>Shot #</th><th>Charge Voltage, kV A bank:</th><th>Charge Voltage, kV B bank:</th><th>Peak I, kA (±10%)</th><th>Action Integral, kAAs (±20%)</th><th>B Charge Transfer, C (±10%)</th><th>C* Charge Transfer, C (±20%)</th><th>Notes</th></tr><tr><td>40 kA</td><td>26.7</td><td>5.51</td><td>37.53</td><td>54.43</td><td>10.25</td><td>21.59</td><td>Action integral low.</td></tr></table> No ignition during test. Post-test ignition was successful at 171uJ. Action integral was low. This shot will be repeated (at a new test point) to obtain all required waveforms.
	10:15AM	Panel -069 TP4 <table><tr><th>Shot #</th><th>Charge Voltage, kV A bank:</th><th>Charge Voltage, kV B bank:</th><th>Peak I, kA (±10%)</th><th>Action Integral, kAAs (±20%)</th><th>B Charge Transfer, C (±10%)</th><th>C* Charge Transfer, C (±20%)</th><th>Notes</th></tr><tr><td>40 kA</td><td>26.7</td><td>5.51</td><td>41.4</td><td>74.65</td><td>10.32</td><td>24.46</td><td></td></tr></table> No ignition during test. Post-test ignition was successful at 176uJ.
	10:40AM	Panel -069 TP5 <table><tr><th>Shot #</th><th>Charge Voltage, kV</th><th>Charge Voltage, kV</th><th>Peak I, kA (±10%)</th><th>Action Integral</th><th>B Charge Transfe</th><th>C* Charge</th><th>Notes</th></tr></table>

Test Log Data

Date	Time	Notes
		<table><tr><th></th><th>A bank:</th><th>B bank:</th><th></th><th>, kAAs (±20%)</th><th>r, C (±10%)</th><th>Transfer, C (±20%)</th><th></th></tr><tr><td>40 kA</td><td>26.7</td><td>5.51</td><td>50.07</td><td>69.91</td><td>10.4</td><td>20.96</td><td></td></tr></table> No ignition during test. Post-test ignition was successful at 176uJ.
	11:00AM	Finish testing for the day. Will resume when panels -067, -071, or -073 are received.
6/14/21	8:00AM	Arrive to begin testing.
		Panel -067 was received back after having been re-worked. The panel was originally received from the shop with the incorrect fasteners installed (BJ coating code rather than AG (hi-kote)) The BJ fasteners were removed, the AG fasteners were installed, the sealant was reapplied, and the test panel was recoated with topcoat.
	9:30AM	Panel -067 TP3 Pretest bond measurement from panel ECF to ground = 5.569 mΩ <table><tr><th>Shot #</th><th>Charge Voltage, kV A bank:</th><th>Charge Voltage, kV B bank:</th><th>Peak I, kA (±10%)</th><th>Action Integral, kAAs (±20%)</th><th>B Charge Transfer, C (±10%)</th><th>C* Charge Transfer, C (±20%)</th><th>Notes</th></tr><tr><td>40 kA</td><td>26.7</td><td>5.51</td><td>49.47</td><td>65.98</td><td>10.5</td><td>20.44</td><td></td></tr></table> No ignition during test. Post-test ignition was successful at 137uJ. Generator output inductor failed/fused out during this shot and needs to be replaced
	10:00AM	Panel -067 TP2 <table><tr><th>Shot #</th><th>Charge Voltage, kV A bank:</th><th>Charge Voltage, kV B bank:</th><th>Peak I, kA (±10%)</th><th>Action Integral, kAAs (±20%)</th><th>B Charge Transfer, C (±10%)</th><th>C* Charge Transfer, C (±20%)</th><th>Notes</th></tr><tr><td>40 kA</td><td>26.7</td><td>5.51</td><td>44.13</td><td>89.72</td><td>10.62</td><td>19.04</td><td>Ignition during test</td></tr></table> Gas ignited during this test. No post-test verification was necessary.
	10:30AM	Panel -067 TP1 <table><tr><th>Shot #</th><th>Charge Voltage, kV A bank:</th><th>Charge Voltage, kV B bank:</th><th>Peak I, kA (±10%)</th><th>Action Integral, kAAs (±20%)</th><th>B Charge Transfer, C (±10%)</th><th>C* Charge Transfer, C (±20%)</th><th>Notes</th></tr><tr><td>40 kA</td><td>26.7</td><td>5.51</td><td>44.27</td><td>90.73</td><td>10.6</td><td>18.92</td><td></td></tr></table> No ignition during test. Post-test ignition was successful at 148 uJ.

Test Log Data		
Date	**Time**	**Notes**
		Testing complete.

Appendix D – Test Article Engineering Drawings



ZONE 3 COMPOSITE ASSY

NOTES:

1. INTERPRET THIS DATASET PER ASME Y14. 100 - 2017
2. DIMENSIONS AND TOLERANCES PER ASME Y14.5 - 2018
3. MASK OFF INDICATED AREA BEFORE APPLYING ANY COATINGS.
4. WET INSTALL ALL FASTENERS PER PPG PR-1440 CLASS B FUEL TANK SEALANT TECHNICAL DATA SHEET. APPLY PR-1440 CLASS B FUEL TANK SEALANT TO THE SHANK AND UNDER THE HEAD OF THE FASTENER ENSURING FULL COVERAGE PRIOR TO INSTALLATION. THREADS MUST BE FREE OF SEALANT BEFORE AND AFTER INSTALLATION. IF TRACES ARE VISIBLE AFTER INSTALLATION, WIPE OFF WITH CLEAN DRY CLOTH. DO NOT USE SOLVENT. DURING INSTALLATION, A BEAD OF SEALANT MUST BE FORCED OUT FROM THE HEAD OF THE FASTENER. USE A DRY CLOTH TO WIPE OFF EXCESS SEALANT BEFORE CURE.
5. PREPARE HOLES FOR AND INSTALL HST11 FASTENERS PER HSTR_HLR-ISO1 DOCUMENT.
6. PREPARE HOLES FOR TRI-LOCK FASTENERS PER HSTR_HLR-ISO1 DOCUMENT.
7. FS = FASTENER MANUFACTURED HEAD FAR SIDE.
8. FINISH ONE MIL OF FUEL TANK PRIMER.
9. FINISH ALODINE PLUS ONE MIL OF FUEL TANK PRIMER.
10. FAY SEAL ALL MATING SURFACES. APPLY PR-1440 CLASS B SEALANT WITH A ROLLER TO ONE OR BOTH FAYING SURFACES. ENSURE ALL AREAS OF THE FAYING SURFACE HAVE A MINIMUM APPLIED FILM THICKNESS OF 0.005 INCH BEFORE ASSEMBLY. AFTER ASSEMBLY, A CONTINUOUS BEAD OF SEALANT MUST BE CLEARLY VISIBLE AT THE PERIFERY OF FAYING SURFACES AS EVIDENCE THAT THE JOINTS ARE FILLED. A CONTINUOUS BEAD OF SEALANT MUST REMAIN ALONG ALL EDGES. EXCESSIVE SEALANT SQUEEZE OUT MUST EITHER BE SMOOTHED INTO A FILLET SEAL OR CLEANED WITH A CLEAN DRY CLOTH.
11. POLYURETHANE TOPCOAT APPLIED ON FAR SIDE ONLY EXCEPT WHERE NOTED.
12. -109 CFRP/ECF PANEL FACE SHOWN. ENSURE ECF IS FACING DOWN BEFORE ASSEMBLY.
13. -111 CFRP/ECF/GRP PANEL FACE SHOWN. ENSURE ECF IS FACING DOWN BEFORE ASSEMBLY.
14. BREAK SHARP EDGES .005-.015

-073	-071	-069	-067	-065	-063	ITEM	PART NUMBER	DESCRIPTION	MATERIAL/SUPPLIER	THICKNESS	HOLE SIZE	FIT TYPE	TOTAL QUANTITY
QTY PER ASSY							PARTS LIST INFORMATION						
						19							
		50	50	50	50	18	HST79CY8						QTY = 200
						17							
						16							
50	50					15	PF AA7CC-08-05				∅.2495-.2505	CLEARANCE	QTY = 100
		50	50			14	HST11AG8-5				∅.2495-.2505	CLEARANCE	QTY = 100
				50	50	13	HST11BJ8-5				∅.2495-.2505	CLEARANCE	QTY = 100
						12							
	2		2		2	11	Z3C5700-111	CFRP/ECF/GRP PANEL	COMPOSITE/NIAR	.162			QTY = 6
2		2		2		10	Z3C5700-109	CFRP/ECF PANEL	COMPOSITE/NIAR	.158			QTY = 6
1		1		1		9	Z3C5700-107	CFRP ANGLE	COMPOSITE/NIAR	.150			QTY = 3
	1		1		1	8	Z3C5700-105	AL ANGLE	AL CLAD 2024-T3 (AMS-QQ-A-250/5)	.125			QTY = 3
						7							
						6	Z3C5700-073	TEST ARTICLE ASSY					ASSY QTY = 1
						5	Z3C5700-071	TEST ARTICLE ASSY					ASSY QTY = 1
						4	Z3C5700-069	TEST ARTICLE ASSY					ASSY QTY = 1
						3	ZC35700-067	TEST ARTICLE ASSY					ASSY QTY = 1
						2	Z3C5700-065	TEST ARTICLE ASSY					ASSY QTY = 1
						1	Z3C5700-063	TEST ARTICLE ASSY					ASSY QTY = 1

DRAWN CPARTEN 8/18/2020
CHECKED XXX XX/XX/XXXX
APPROVED XXX XX/XX/XXXX
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON
DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
ANGLES ±30'

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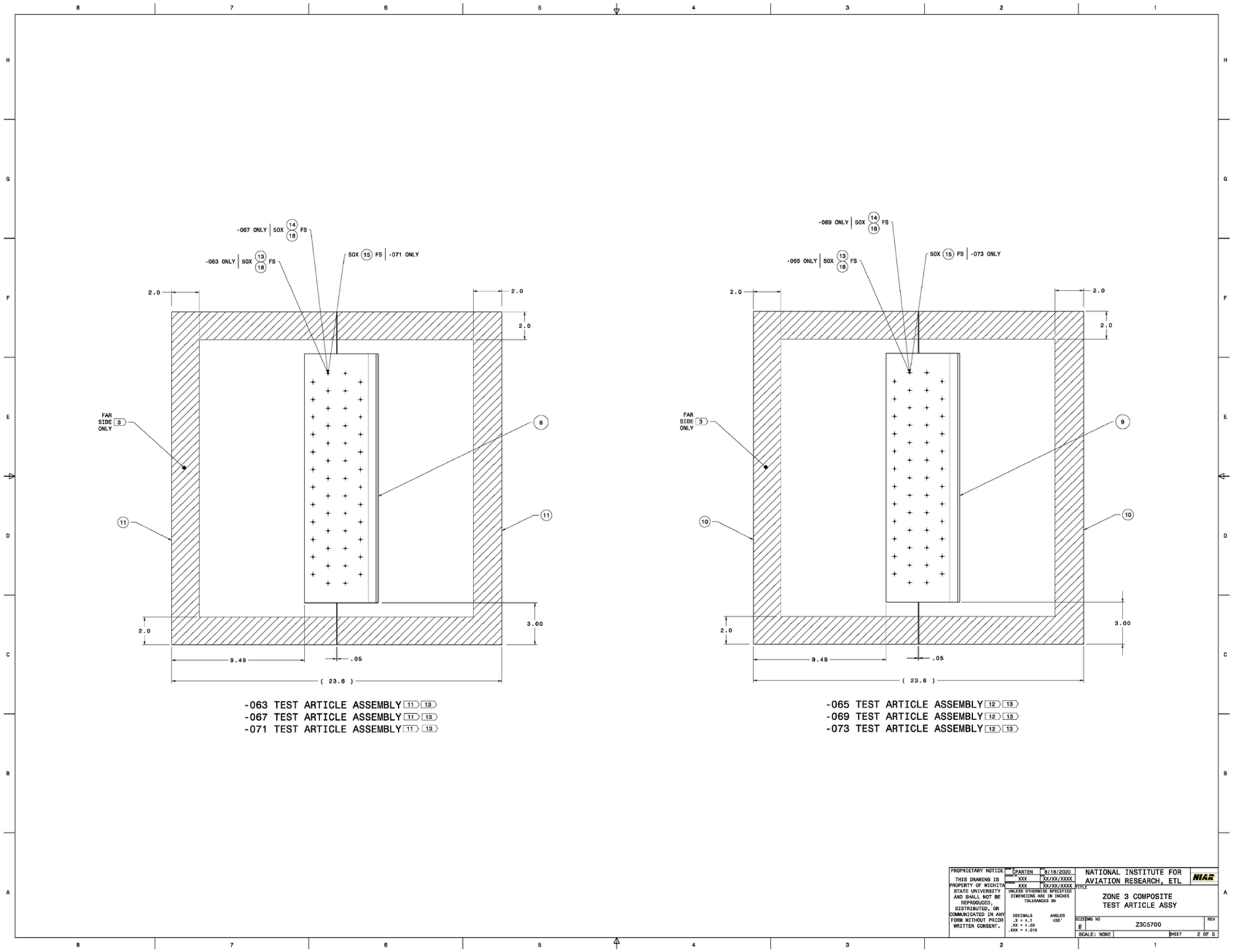
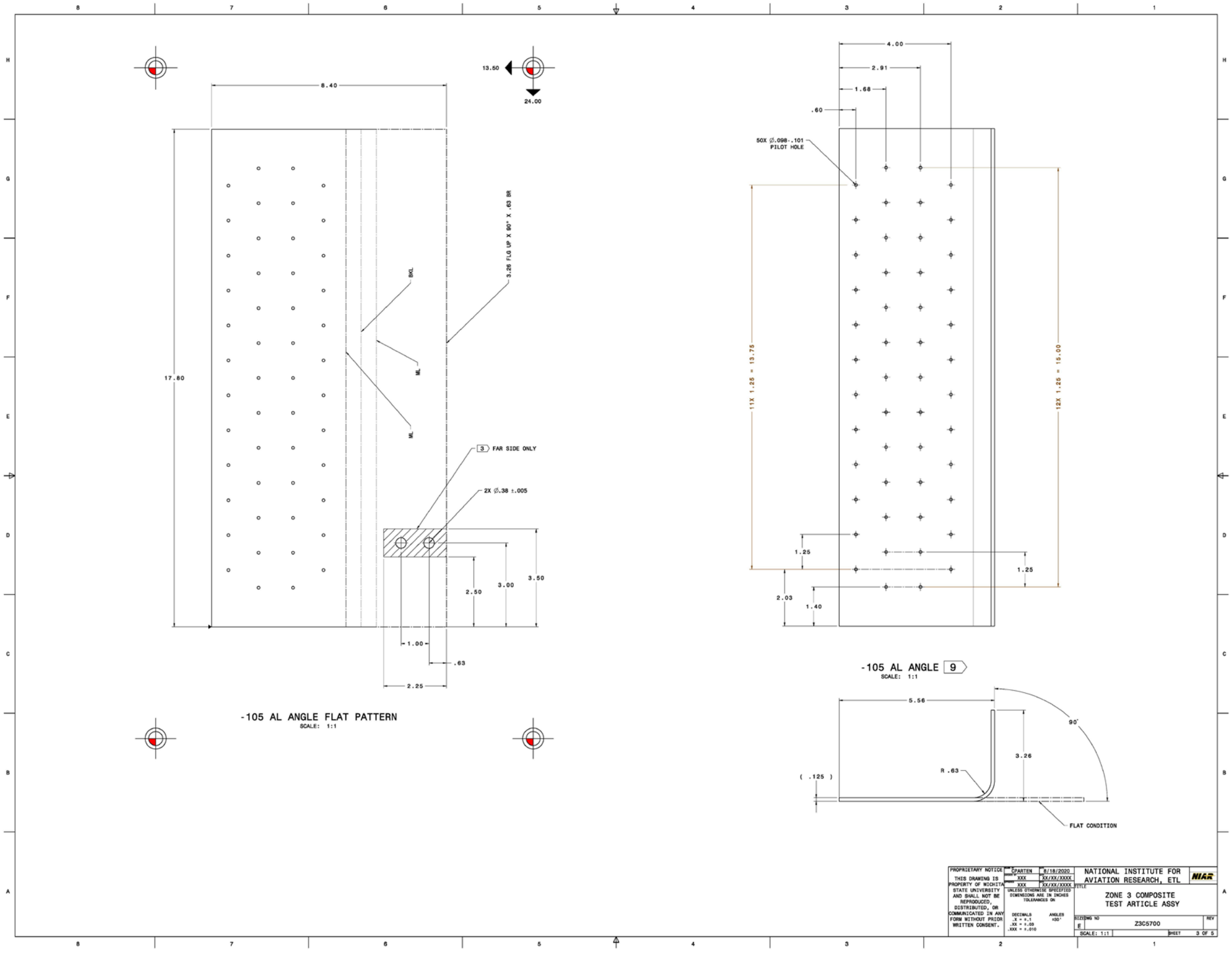
TITLE: ZONE 3 COMPOSITE TEST ARTICLE ASSY

SIZE E | DWG NO Z3C5700 | REV
SCALE: NONE | SHEET 1 OF 5



-063 TEST ARTICLE ASSEMBLY (11) (13)
-067 TEST ARTICLE ASSEMBLY (11) (13)
-071 TEST ARTICLE ASSEMBLY (11) (13)

-065 TEST ARTICLE ASSEMBLY (12) (13)
-069 TEST ARTICLE ASSEMBLY (12) (13)
-073 TEST ARTICLE ASSEMBLY (12) (13)


8.40
13.50
24.00
17.80
BKL
ML
ML
3.26 FLG UP X 90° X .63 BR
3 FAR SIDE ONLY
2X Ø.38 ±.005
3.50
3.00
2.50
1.00
.63
2.25
-105 AL ANGLE FLAT PATTERN
SCALE: 1:1
4.00
2.91
1.68
.60
50X Ø.098-.101 PILOT HOLE
11X 1.25 = 13.75
12X 1.25 = 15.00
1.25
1.25
2.03
1.40
-105 AL ANGLE 9
SCALE: 1:1
5.56
90°
3.26
R .63
(.125)
FLAT CONDITION
PROPRIETARY NOTICE
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8/18/2020
XXX
XX/XX/XXXX
XXX
XX/XX/XXXX
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON
DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
ANGLES ±30'
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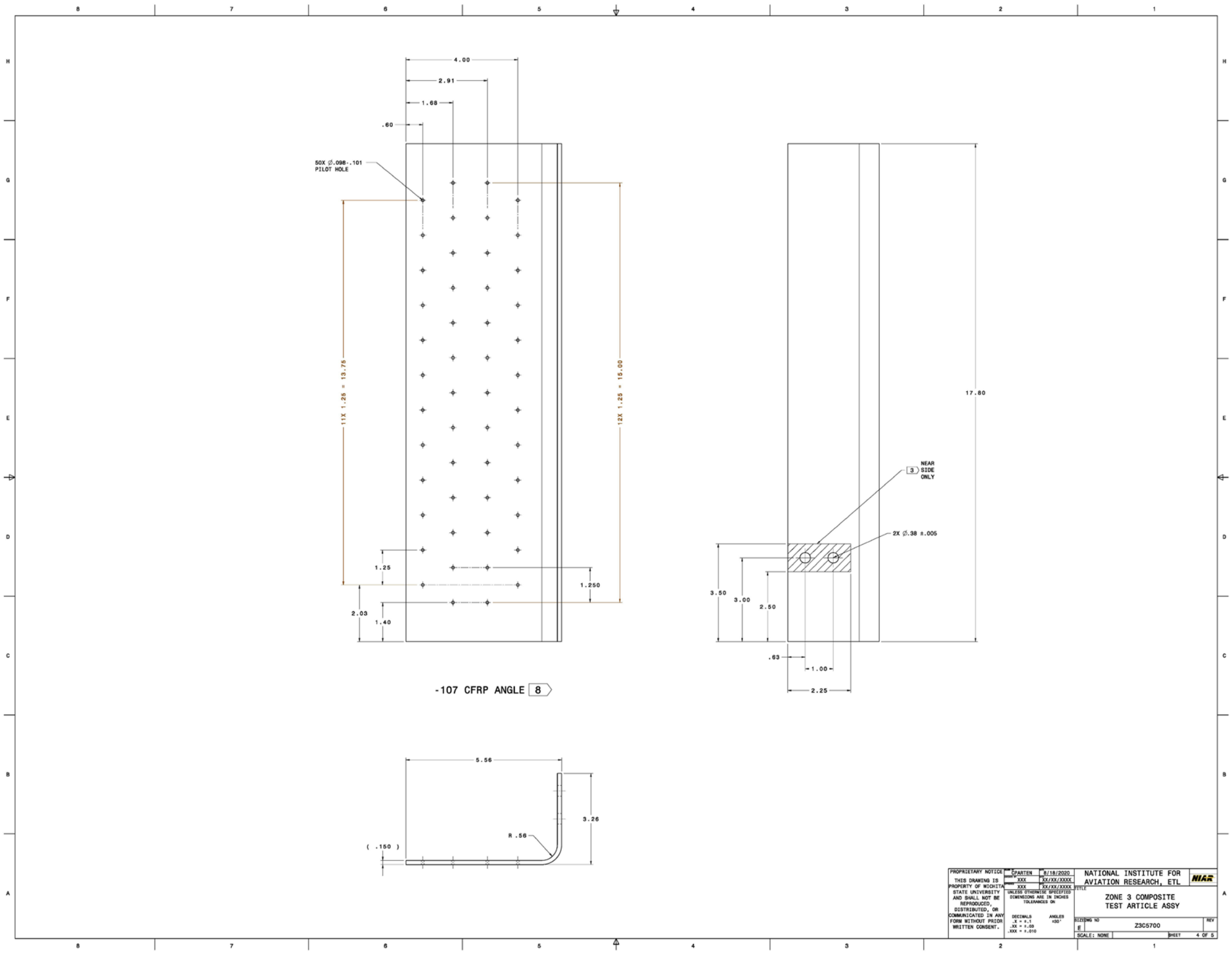
TITLE
ZONE 3 COMPOSITE TEST ARTICLE ASSY
SIZE E
DRAWING NO Z3C5700
REV
SCALE: 1:1
SHEET 3 OF 5


4.00
2.91
1.68
.60
50X Ø.098-.101
PILOT HOLE
11X 1.25 = 13.75
12X 1.25 = 15.00
1.25
1.250
2.03
1.40
17.80
NEAR SIDE ONLY
3
2X Ø.38 ±.005
3.50
3.00
2.50
.63
1.00
2.25
-107 CFRP ANGLE 8
5.56
3.26
R .56
(.150)
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8/18/2020
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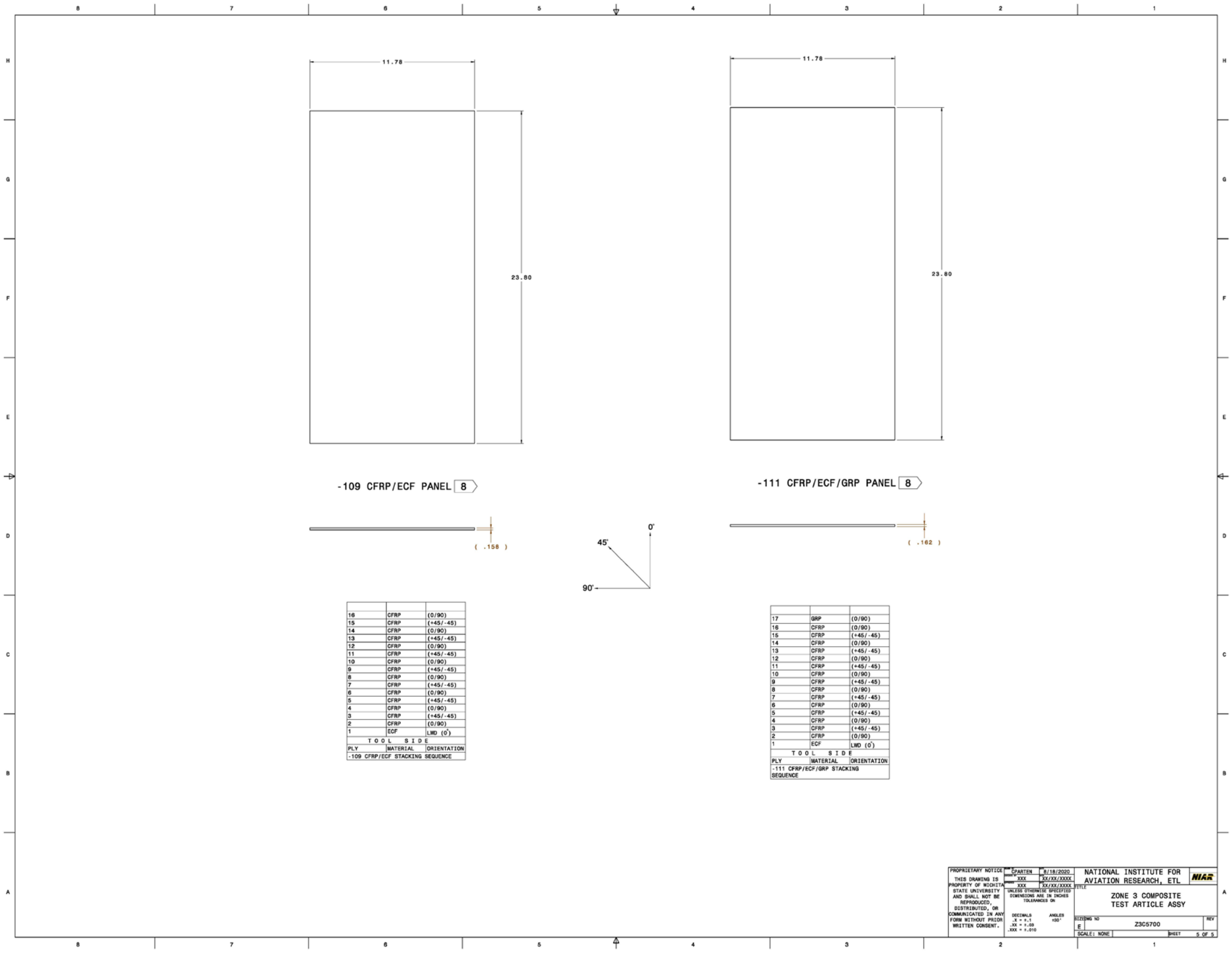
DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
ANGLES ±30'
NATIONAL INSTITUTE FOR AVIATION RESEARCH, ETL
TITLE
ZONE 3 COMPOSITE TEST ARTICLE ASSY
SIZE E
DWG NO Z3C5700
REV
SCALE: NONE
SHEET 4 OF 5



16	CFRP	(0/90)
15	CFRP	(+45/-45)
14	CFRP	(0/90)
13	CFRP	(+45/-45)
12	CFRP	(0/90)
11	CFRP	(+45/-45)
10	CFRP	(0/90)
9	CFRP	(+45/-45)
8	CFRP	(0/90)
7	CFRP	(+45/-45)
6	CFRP	(0/90)
5	CFRP	(+45/-45)
4	CFRP	(0/90)
3	CFRP	(+45/-45)
2	CFRP	(0/90)
1	ECF	LWD (0°)
TOOL SIDE		
PLY	MATERIAL	ORIENTATION

-109 CFRP/ECF STACKING SEQUENCE

17	GRP	(0/90)
16	CFRP	(0/90)
15	CFRP	(+45/-45)
14	CFRP	(0/90)
13	CFRP	(+45/-45)
12	CFRP	(0/90)
11	CFRP	(+45/-45)
10	CFRP	(0/90)
9	CFRP	(+45/-45)
8	CFRP	(0/90)
7	CFRP	(+45/-45)
6	CFRP	(0/90)
5	CFRP	(+45/-45)
4	CFRP	(0/90)
3	CFRP	(+45/-45)
2	CFRP	(0/90)
1	ECF	LWD (0°)
TOOL SIDE		
PLY	MATERIAL	ORIENTATION

-111 CFRP/ECF/GRP STACKING SEQUENCE

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SPARTEN 8/18/2020
XXX XX/XX/XXXX
XXX XX/XX/XXXX

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DECIMALS .X = ±.1 .XX = ±.03 .XXX = ±.010
ANGLES ±30'

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ZONE 3 COMPOSITE TEST ARTICLE ASSY

SIZE E | DWG NO Z3C5700 | REV
SCALE: NONE | SHEET 5 OF 5