FINAL
TEST REPORT
Hexavalent Chrome Free Coatings for Electronics
Electromagnetic Interference (EMI)
Shielding Effectiveness (SE)

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NASA Technology Evaluation for Environmental Risk Mitigation

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CONSORTIUM PARTICIPATION

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Boeing
Rockwell Collins
Northrop Grumman
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Harris
BAE Systems
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1 Introduction

1.1 Background

The replacement of hexavalent chromium in the processing of aluminum for aviation and aerospace applications remains a goal of great significance within the aviation and aerospace community. Aluminum is the major manufacturing material of structures and components in both the aircraft (military and commercial) and space flight arena; consequently, the processing and maintenance of this material against degradation and corrosion is of prime importance. For years, hexavalent chromium has been a widely used element within applied coating systems because of its self-healing and corrosion resistant properties. Occupational Safety and Health Administration (OSHA) studies have concluded that hexavalent chromium (hex chrome) is carcinogenic and poses significant risk to human health. On May 5, 2011, amendments to the Defense Federal Acquisition Regulation Supplement (DFARS) were issued in the Federal Register. Subpart 223.73 prohibits contracts from requiring hexavalent chromium in deliverables unless certain exceptions apply. These exceptions include authorization from a general or flag officer and members of the Senior Executive Service from a Program Executive Office, and unmodified legacy systems. Otherwise, Subpart 252.223-7008 provides the contract clause prohibiting contractors from using or delivering hexavalent chromium in a concentration greater than 0.1 percent by weight for all new contracts and to be included down to subcontractors for supplies, maintenance and repair services, and construction materials. National Aeronautics and Space Administration (NASA), Department of Defense (DoD), and industry stakeholders continue to search for alternatives to hex chrome in coatings applications that meet their performance requirements in corrosion protection, cost, operability, and health and safety, while typically specifying that performance must be equal to or greater than existing systems.

1.2 Objective

The purpose of this testing is to determine the suitability of trivalent chromium conversion coatings that meet the requirements of MIL-DTL-5541, Type II, for use in applications where high-frequency electrical performance is important. The two applications to be evaluated are: the ability of conversion coated aluminum to form adequate EMI seals and provide adequate corrosion protection. Testing assesses performance of the trivalent chromium coatings against the known control hexavalent chromium MIL-DTL-5541 Type I Class 3 before and after they have been exposed to a set of environmental conditions.

Previous testing has been performed to down select trivalent formulations and processes that are capable of providing resistance to general corrosion, while maintaining low DC surface resistivity. These formulations were further evaluated for their high-frequency performance and compared against the baseline hexavalent chromium conversion coating per MIL-DTL-5541, Type I, class 3. No pass/fail criteria for the electrical properties were defined beforehand. A comparison of the EMI performance and contact electrical testing between the trivalent options and the hexavalent baseline is provided in this report.

1.3 Executive Summary

The test results for Salt Spray Resistance, Static Heat and Humidity and Marine Environment can be found in Sections 3.1.3.3, 3.1.4.3 and 3.1.5.3 respectively. In summary, both the Metalast TCP and SurTec 650 Type 2 conversion coatings perform very similar to the incumbent Type 1 conversion coating against both 6061 and 5052 aluminum under all three test conditions.

Significant prior work was performed to select the aluminum and conversion coating included within this test cycle; **Reference – NASA GSDO Program Hexavalent Chrome Alternatives Final Pretreatments Test Report Task Order: NNH12AA45D September 01, 2013**.

As illustrated in the data, the 6061 aluminum panels SLIGHTLY out-performed the 5052 aluminum panels. Individual shielding effectiveness graphs for each panel are included within Appendix C and D.

One other notable effect found during review of the data is that the Test Panels exposed to B117 Salt Fog reduced in shielding effectiveness significantly more than the Marine Environment Test Panels. The shielding effectiveness of the Marine Test Panels was approximately 20dB higher than the Test Panels that underwent B117 Salt Fog Exposure.

The intent of this evaluation was not to maximize shielding effectiveness values. The same Parker Chomerics Cho-Seal 6503 gasket material was used for all panels with aluminum and conversion coating variants. A typical EMI gasket design for corrosive environments would be done quite differently. The intent was to execute a test that would provide the best possible evaluation of different aluminum materials and conversion coatings in corrosive environments. The test program achieved this intent. The fact that the two aluminums and two Type II conversion coatings performed similar to the incumbent Type 1 conversion coating is a positive outcome. It was desired to have an outcome that further differentiation the performance of two aluminum types and two conversion coating types but this could not be extracted by the test results.

Further analysis of the test plates may be done by X-Ray Photoelectron Spectroscopy (XPS) or Electrochemical Impedance Spectroscopy (EIS). Feasibility of this is under review.

2 Test Articles

This section outlines the preparation of the test panels from alloy selection through non-chrome conversion coating application.

2.1 Alloys

The alloys selected for this project have been selected because of their common use in avionics and electronics housing applications. All aluminum materials were procured mill finished without mill markings. Mill finish is as supplied from the mill (raw material manufacturer), is not polished and most likely has a dull matte appearance. The following alloys have been selected for this project:

- 5052-H32
- 6061-T6

2.2 Non-Chrome Conversion Coatings

The non-chrome conversion coatings evaluated for this project are listed in Table 1. The hexavalent chrome free conversion coatings selected for this project were selected based on previous studies conducted by the project stakeholders.

Table 1 - Conversion Coating Systems

Conversion Coating Systems	Processing Location
Hexavalent Chrome Baseline	AOTCO Metal Finishing, Inc.
Metalast TCP	AOTCO Metal Finishing, Inc.
SurTec 650	AMZ Manufacturing Corp.

2.3 Test Panels

Test panels were used for Contact Electrical Resistance and Surface Resistance Testing. The test panels were 3”x10”x0.32” and procured mill finished without mill markings. Test panel size is called out in the test description sections.

2.4 Test Plate Sets

Test specimen configuration was provided by Parker Chomerics. The EMI gasket used in this project was Cho-Seal 6503E. Black oxide alloy steel socket head bolts were used to hold the plates together. Non-conductive spacers were used to control the amount of compression on the gaskets.

The following test fixture specifications were provided by Parker Chomerics. The CHO-TP09 test plate sets selected for this project consist of two aluminum plates manufactured to the specifications detailed in CHO-TP09. The first plate, referred to as the test frame is illustrated in Figure 1. The test frame is designed with a cutout in the center and two alternating bolt patterns. One pattern is used to bolt the test frame to the corresponding test cover plate (
Figure 2) forming a test plate set. The second pattern accepts the hardware used to mount the fully assembled test plate set to the main adapter plate (
Figure 3).

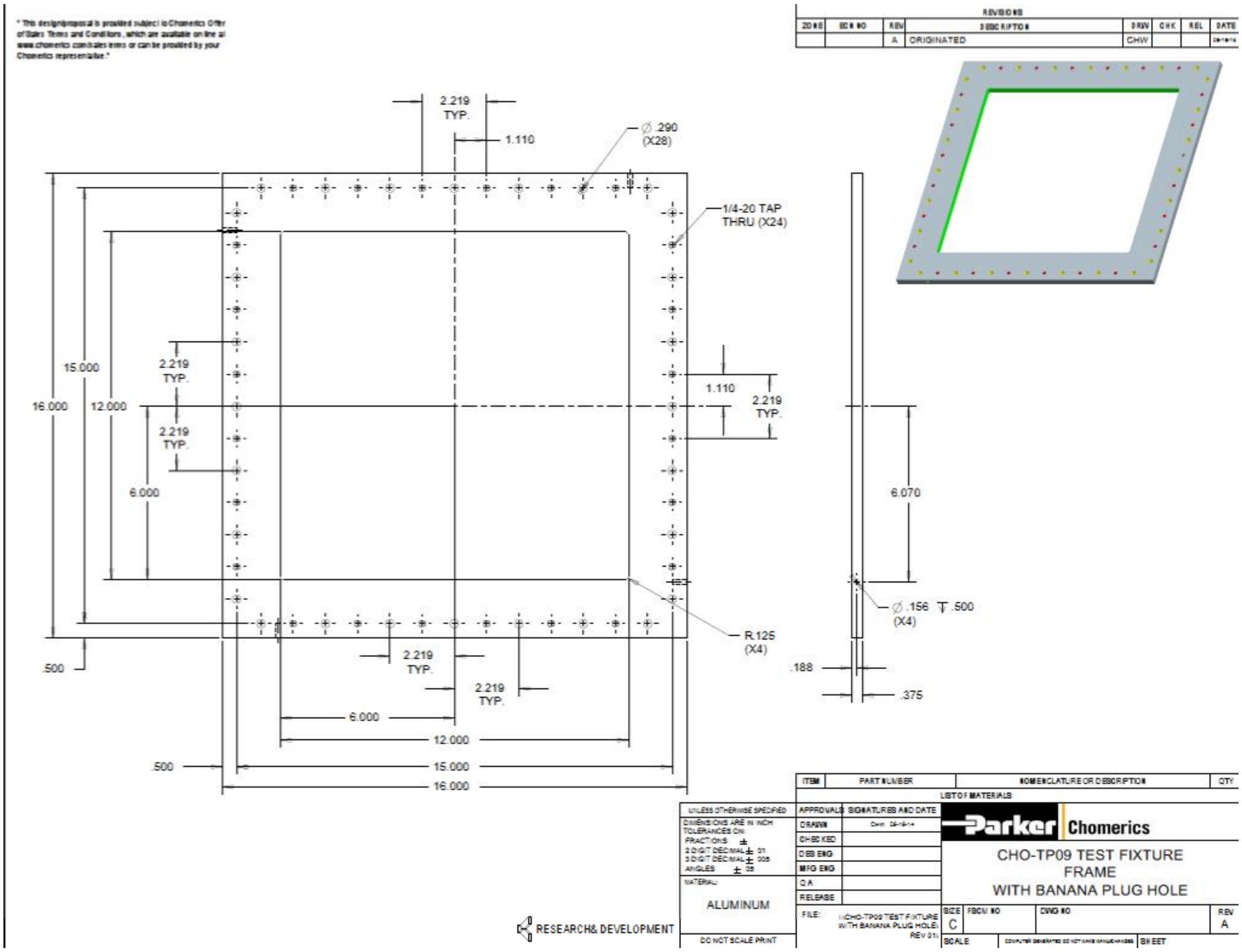


Figure 1 - CHO-TP09 Test Frame

The test cover plate (
Figure 2) is also made from aluminum and has the identical bolt hole configuration as the test frame described above.

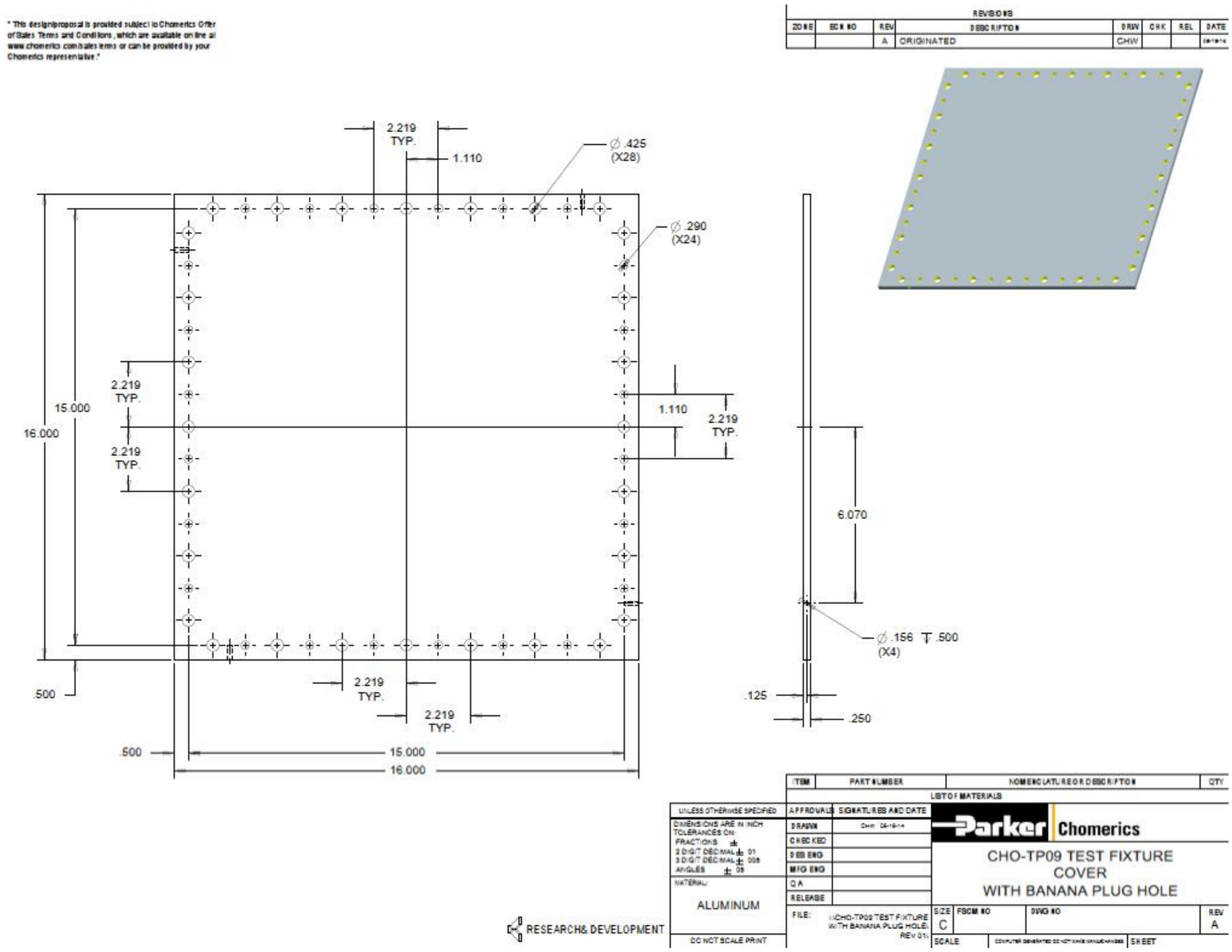


Figure 2 - CHO-TP09 Test Cover Plate

In order to monitor changes with the gasket interface between the test frame and cover plate, through resistance readings were recorded three times during the project; following initial plate set assembly, after thermal cycle preconditioning, and prior to test set disassembly after all testing is complete. Holes were drilled into the edge of the test frames and cover plates to accommodate through resistance readings.

A 0.500-inch thick aluminum main adapter plate illustrated in
Figure 3 is used to mount the test plate sets to the shielded room wall. The outer bolt pattern detailed in
Figure 3 is used to mate the adapter plate to the wall of the shielded room. The inner bolt pattern accepts the Test Plate set.

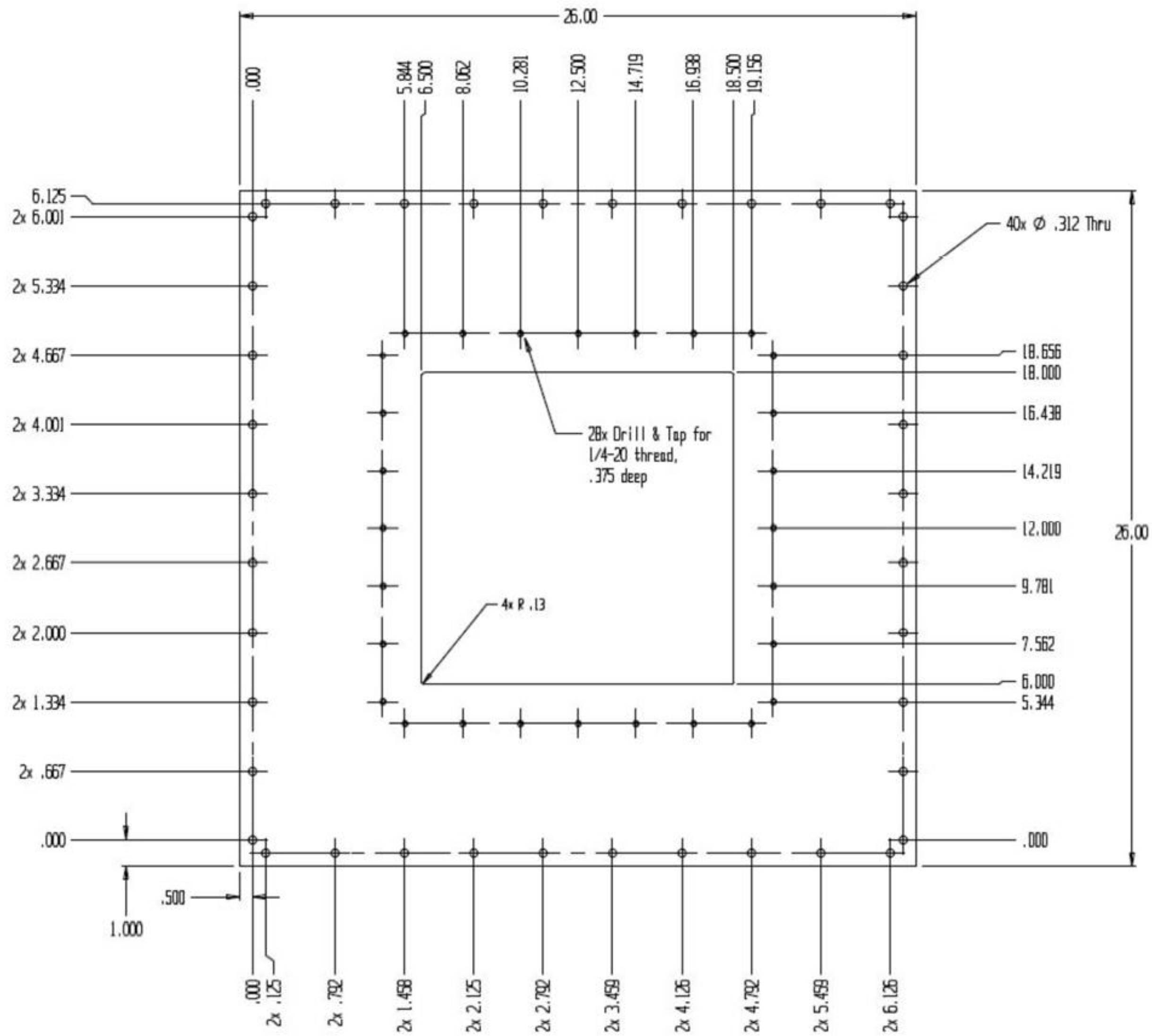


Figure 3 - Main Adapter Plate for Mounting Test Plate Sets to Wall of Shielded Enclosure

2.4.1 Fixture Hardware

Specifications regarding test fixture hardware have been provided by Parker Chomerics. In addition to the test plates, non-conductive washers were used as compression stops to target a nominal gasket deflection of 13.1%. The washers on the plate sets prevent uneven deflection in regions adjacent to the bolts. Twenty four washers are used per Test Plate set. Washers are to be 0.750-inch outside diameter by 0.257-inch inside diameter and 0.148-inch thick. Black oxide alloy steel socket head cap screws are used to bolt the Test Plate Covers and Frames together and to bolt the plate sets to the shielded room wall.

2.4.2 EMI Gasket Specifications

In order to select the right gasket material Parker Chomerics completed an extensive in-house corrosion evaluation in accordance with Parker Chomerics Test Method CHO-TM-101. This test method evaluates the corrosion resistance of EMI gasket materials by examination of galvanic weight loss and dimensional changes of an EMI gasket after 504 hours of salt fog exposure. The testing was performed on five different EMI gasket materials, two aluminum alloys (6061-T6 and 5052-H32), and two different conversion coatings (SurTec 650 and Metalast TCP). The purpose was to determine which gasket was best to recommend. Based on the test data, Cho-Seal 6503E EMI gasket material exhibited superior galvanic weight loss and dimensional change after 504 hours of salt fog exposure. The NASA Shielding Effectiveness project stakeholders agreed to use Cho-Seal 6503E EMI gasket material for the NASA Shielding Effectiveness Project.

2.5 Test Plate Set Assembly

The following equipment was used to assemble the test plate sets:

- Mitutoyo Model ID-C125TB Height Gage
- Cordless Drill

The hardware required to assemble plate sets are contained in Table 2.

Table 2 - CHO-TP09 Test Plate Set Hardware

Hardware Description	Qty. per Plate Set	Total Qty. (36) Plate Sets
CHO-TP09 Test Plate Frame	1	**36**
CHO-TP09 Test Plate Cover	1	**36**
CHO-TP09 Gasket Test Window Washers	24	**864**
0.25 inch diameter by 3.00 inch long set pins	24	**24 – reused on each plate set**
0.75 Inch long, 1/4 – 20 thread black oxide alloy steel socket head cap screws	24	**864**

2.5.1 Test Plate Set Assembly Procedure

The following assembly procedure was provided by Parker Chomerics. Using a height gage, height measurements were taken at six inch intervals for every test gasket sample. Based on the mean height of the sample population, the washer thickness was selected to achieve a nominal deflection of 13.1% when the test plate set was fully assembled. The selected washer thickness was also verified at the extreme minimum and maximum height measurements within the sample population to ensure that the deflection would be no less than 8.2% and no greater than 16.7% at any point along the gasket.

Prior to assembly, all surfaces of the Test Plate sets were wiped down with an isopropyl alcohol soaked rag and allowed to air dry for five minutes. Once dry, the test plate sets were assembled by laying the frame on a flat surface and installing the washers using 24 set pins to keep each washer in place. The set pins were placed in the same holes the black oxide alloy steel socket head screws are inserted. With the washers in place, the gasket was installed with the flat side seated on the surface of the frame. The gasket configuration was a square "picture frame" with outside dimensions adequate to fit inside the bolt pattern of the cover plate while maintaining separation from the compression stops (washers). Regardless of material grade (molded and extruded), the gaskets were assembled by butting the complimentary 45 degree ends of the parts together producing in a square "picture frame" gasket held firmly in place by the force of friction. An example of a CHO-TP09 Test Plate set mid-assembly can be found in Figure 4 below. In this picture, a continuous strip length of gasket is used and butted together or overlapped at the end. For this project, the gaskets were spliced at the four corners as described above and not as shown in the picture. The picture also shows "strip" compression stops when in fact the stops were washers around each bolt for this project. A picture was not taken of the spliced gasket and compression stop washer assembly. Figure 4 is included as a general pictorial. The test plate cover was then screwed to the test plate frame using 24 socket head cap screws referenced in Table 2 above. In using washers as compression stops, the set pins were removed one by one and the steel socket head screws inserted to ensure the washers stayed in position. The screws were tightened as much as possible to the compression stop without stripping, stretching or breaking. The set pins were then removed and the fixture "Test Set" was ready for testing.

The Test Sets were not disassembled until all environmental and shielding effectiveness testing was complete.

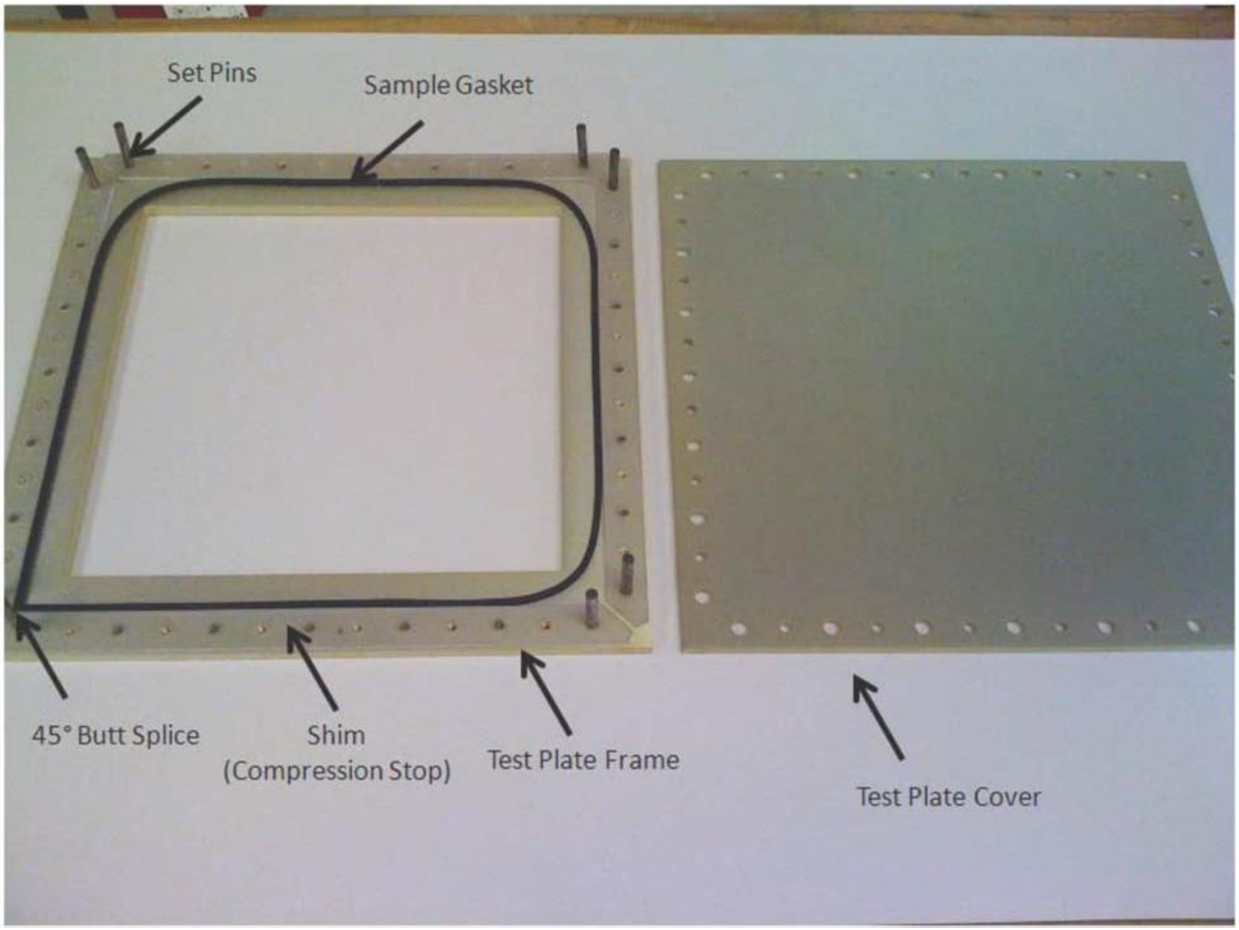


Figure 4 - Example of CHO-TP09 Test Plate Set

3 Testing

Testing was conducted at Parker Chomerics, KSC Corrosion Technology Laboratory and Beachside Corrosion Laboratory, Raytheon, and UTC Aerospace Systems. The testing was divided into two separate sections based on test article; Plate Sets and Test Panels.

3.1 Plate Sets – Shielding Effectiveness Testing

Table 3 – EMI Testing Overview

Test	Test Method	Duration	Evaluation Criteria	Location
Through Resistance	N/A	N/A	Record Data	Parker Chomerics
Thermal Preconditioning	0ºC to 100ºC	100 Cycles	N/A	Raytheon
EMI Testing	IEEE-STD-299	N/A	Record Data	Parker Chomerics
Salt Spray Resistance	ASTM B 117	1,000 Hours	MIL-DTL-5541	KSC Corrosion Lab
Static Heat and Humidity	85°C +/- 1°C and 85% RH +/- 5% RH	1,000 Hours	MIL-DTL-5541	KSC Corrosion Lab
Marine Environment	ASTM D 1014	12 Months	NASA-STD-4003	KSC Corrosion Lab

There were 2 replicate plate sets per alloy (2) per non-chrome conversion coating type (3) per environmental test (3) requiring 36 total plate sets; 12 salt spray, 12 static heat and humidity, and 12 Marine Environment. A total of 108 EMI measurements were taken; 36 initial, 36 as “baseline” after preconditioning and 36 once environmental testing was complete.

Table 4 - Testing Overview, EMI Plate Set Count per Test

Test	Alloy	Conversion coating	Quantity
SE Testing {Initial}	6061-T6	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
	5052-H32	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
Thermal Preconditioning	6061-T6	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
	5052-H32	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
SE Testing {Baseline}	6061-T6	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
	5052-H32	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
Salt Spray Resistance	6061-T6	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
	5052-H32	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
Static Heat and Humidity	6061-T6	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
	5052-H32	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
Marine Environment	6061-T6	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
	5052-H32	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
SE Testing {Final}	6061-T6	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
	5052-H32	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6

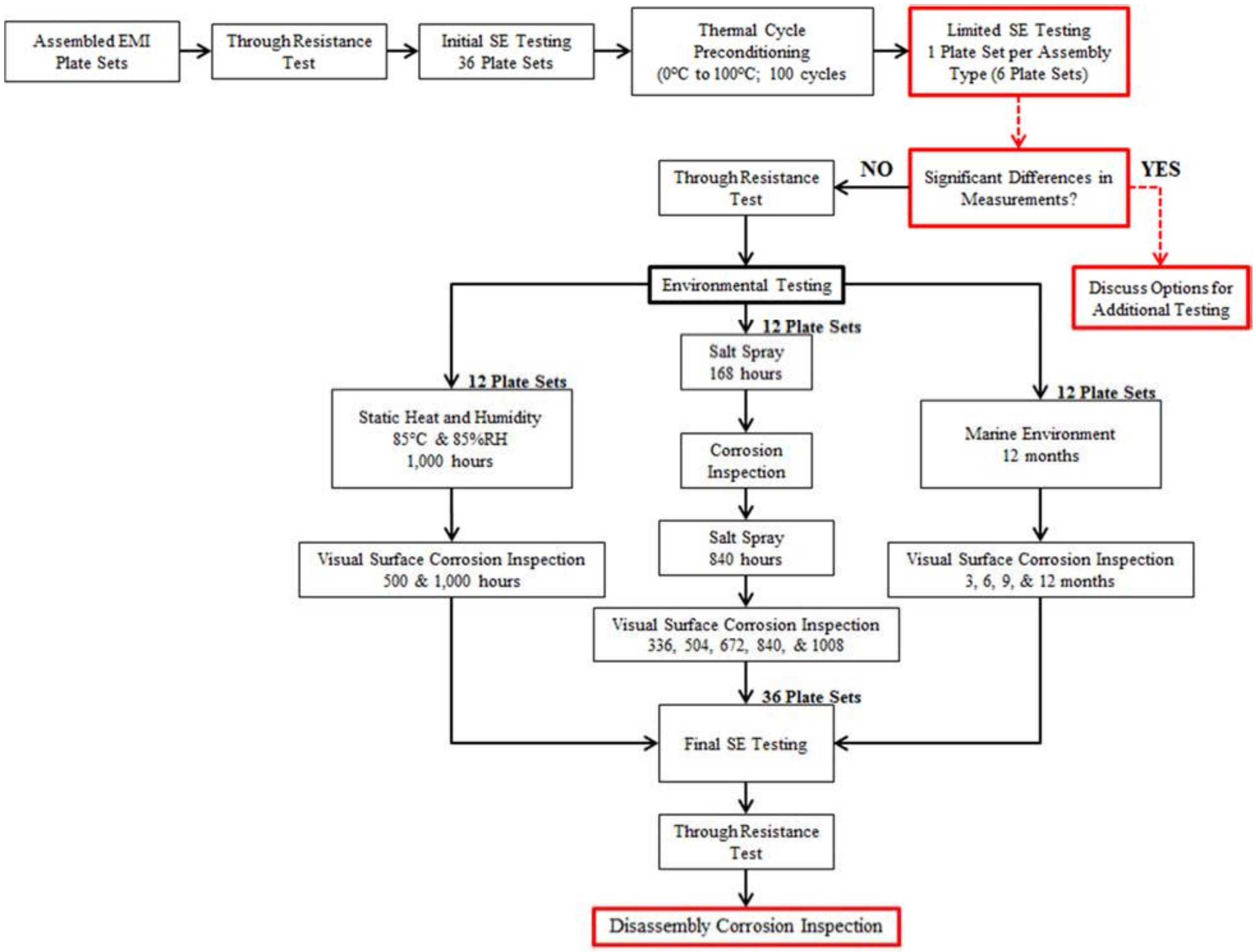


Figure 5 – Plate Set Testing Project Flow

3.1.1 Thermal Preconditioning

This procedure was selected by the stakeholders to replicate storage conditions that products could see in their life cycle prior to being fielded.

3.1.1.1 Test Procedure

Plate sets were subjected to 0ºC to 100ºC for 100 cycles.

The chamber was purged with GN_2 throughout the 100 cycles set to approximately 3 chamber workspace volumes per hour.

The guaranteed soak feature of the chamber was set for 5C. Dwell times were 30 minutes with the chamber at least as cold as -5C and at least as hot as +105C. The chamber air dwell temperature ranged between -5C to -10C and +105C to +110C mostly trending towards -10C and +110C. The chamber air temperature transition rate was 10C/minute.

Given the load of approximately 30lBs, the chamber was able to attain: 10C/minute from -10C to +80C and require an additional 5 minutes to get to +105C (minimum dwell starting temperature) 10C/minute from +110C to +2C and required an additional 6 minutes to get to –C (minimum dwell starting temperature).

To expedite the test panel response and to reduce dwell times, the chamber air set points were set to -10C and -110C. The transition time (rate) between -10C and +110C was programmed for 12 minutes (10C/minute). The test panels attained a temperature range between -5C to 0C and +100C to +105C.

3.1.2 Shielding Effectiveness (SE) Testing

This testing evaluated the Shielding Effectiveness (SE) performance of the test panels before and after environmental exposure. The SE testing was conducted in accordance with IEEE-STD-299.

3.1.2.1 Test Method

One antenna polarization was required due to the symmetrical nature of the Test Plate Sets. Although it is true that other aspects of the test setup affect the test data (room dimensions) with the antenna at the opposite polarization, from Parker Chomerics' experience, it has been determined that the extra test time and cost to test both polarizations is not a benefit.

The antenna polarization used was the same for both Open Reference measurements and final shielding effectiveness measurements. The transmit and receive antenna polarizations were identical. The transmitting and receiving antennas were directed at each other, the distance between antennas, measured from antenna tip to antenna tip, was 5 feet (+/- 2.0-inches) if possible.

Open reference measurements were made using two methods as defined in Section 3.1.2.2. First, Open Reference measurements were made with the antennas in free space in accordance with IEE-STD-299. A second Open Reference measurement was taken by transmitting the signal through the open aperture on the shielded room wall where the Test Set was positioned/mounted.

The antennas and frequency range were as follows:

Table 5 – Antenna and Frequency Ranges

Test Frequency Range	Transmit Antenna	Receive Antenna
50MHz to 1GHz	EMCO 3106 Dual Ridge Guide	EMCO 3106 Dual Ridge Guide
1GHz to 18GHz	EMCO 3115 Horn Antenna	EMCO 3115 Horn Antenna

The EMCO 3106 Dual Ridge Guide antenna(s) can be substituted with an EMCO 3143 Log Periodic antenna(s) or a similar linearly polarized substitute.

The instrumentation was stepped through the test frequencies, and the received signal strength for each test frequency and antenna polarization was recorded for each test area (or test point) and configuration.

The transmit signal was controlled through automation using ETS-Lindgren TILE software. Measurements were recorded manually. Frequency stepping was interrupted as necessary to perform antenna/amplifier/signal generation changes.

For each test area or test point, shielding effectiveness measurements were made at the following test frequencies: 50, 100, 250, 300, 400, 500, 600, 700, 800, 900, 1000 MHz for electric field and 2, 4, 6, 8, 10, 12, 14, 16 and 18GHz for plane wave shielding effectiveness measurements.

The shielding effectiveness was calculated by taking the power level recorded during the open reference measurement(s), and subtracting it from the power level recorded from the final SE measurement(s). Below is a sample calculation.

Shielding Effectiveness = Open Reference Level – Final Measurement
= +10dBm – (-120dBm)
= 130dBm

Two Shielding Effectiveness values were calculated. One using the “free space” open references (IEEE-STD-299) and one using the “thru-hole” reference measurement to allow for both the shielded and aperture effects to be analyzed.

Identical antennas, equipment, cables and equipment settings (except internal attenuator settings) were used in the reference and measurement setups.

The reference level data for each test frequency was compared with the noise floor in the test chamber for the frequency under test and the dynamic range determined by subtracting the noise floor from the reference level and recorded.

3.1.2.2 Calibration Procedure

Parker Chomerics conducted "thru-hole" open reference measurements with only the adapter frame from Figure 3 mounted to the shielded room. This procedure was conducted in the SE chamber. The transmit and receive antennas were directed at each other through the open aperture, the distance between antennas, measured from antenna tip to antenna tip, was 5 feet (+/- 2.0-inches) if possible. The transmit antenna in the transmit room was placed 1-foot from the thru-hole opening and the receive antenna in the receive room placed 4 feet from the thru-hole opening. The Thru-hole Reference measurement test setup is illustrated in **Error! Reference source not found.**.

In addition, "Free Space" Open Reference Measurements for all test frequencies were performed per Figure 3(a) and 3(b) of IEEE-STD 299-1997. This procedure was conducted outside the SE chamber. The transmit and receive antennas spacing and arrangement for free space open reference were identical to the thru-hole open reference procedure stated above. The Free Space Open Reference measurement test setup is illustrated in Figure 7 Free Space Open Reference Measurements can be conducted at any time in the process.

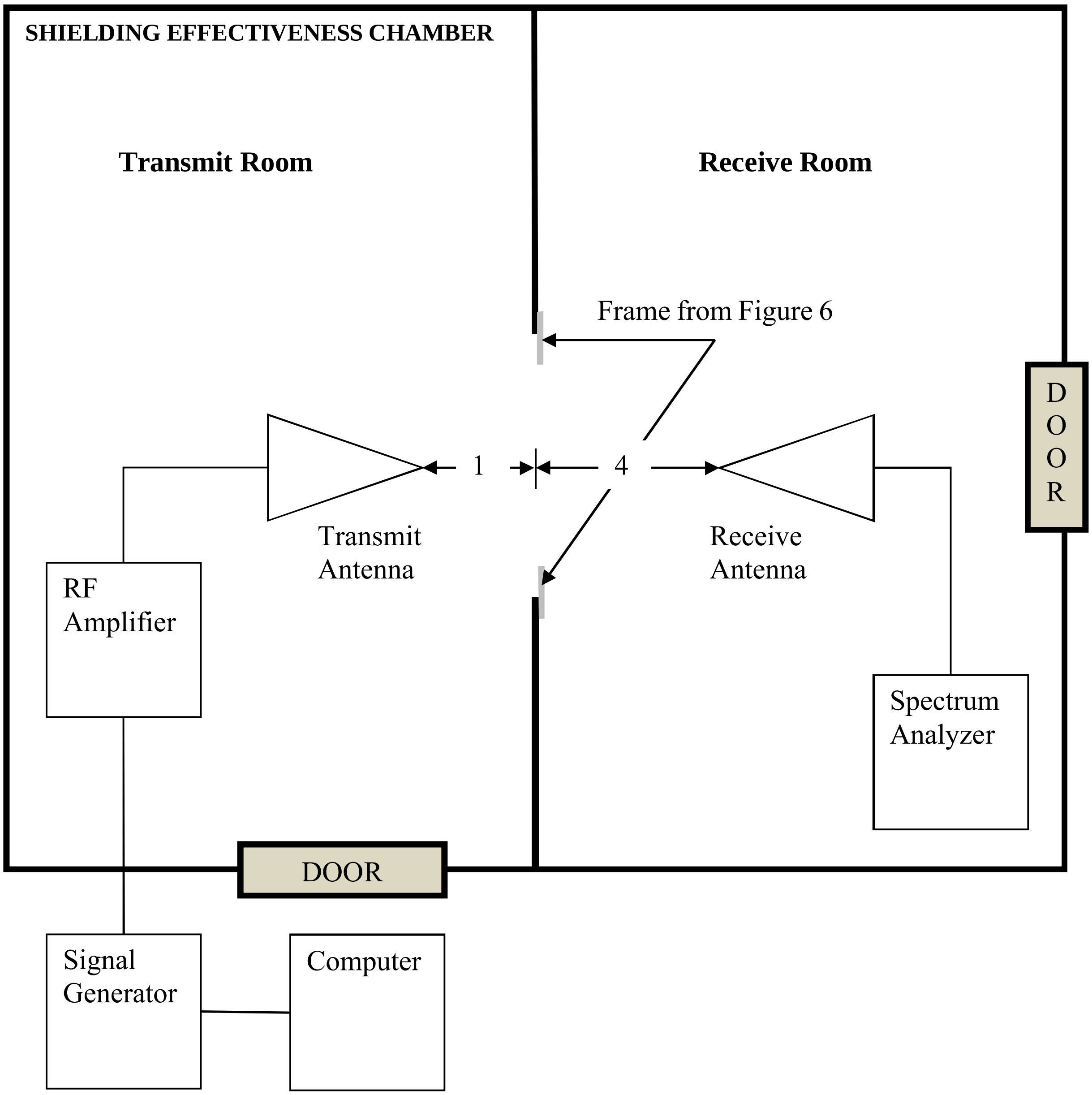
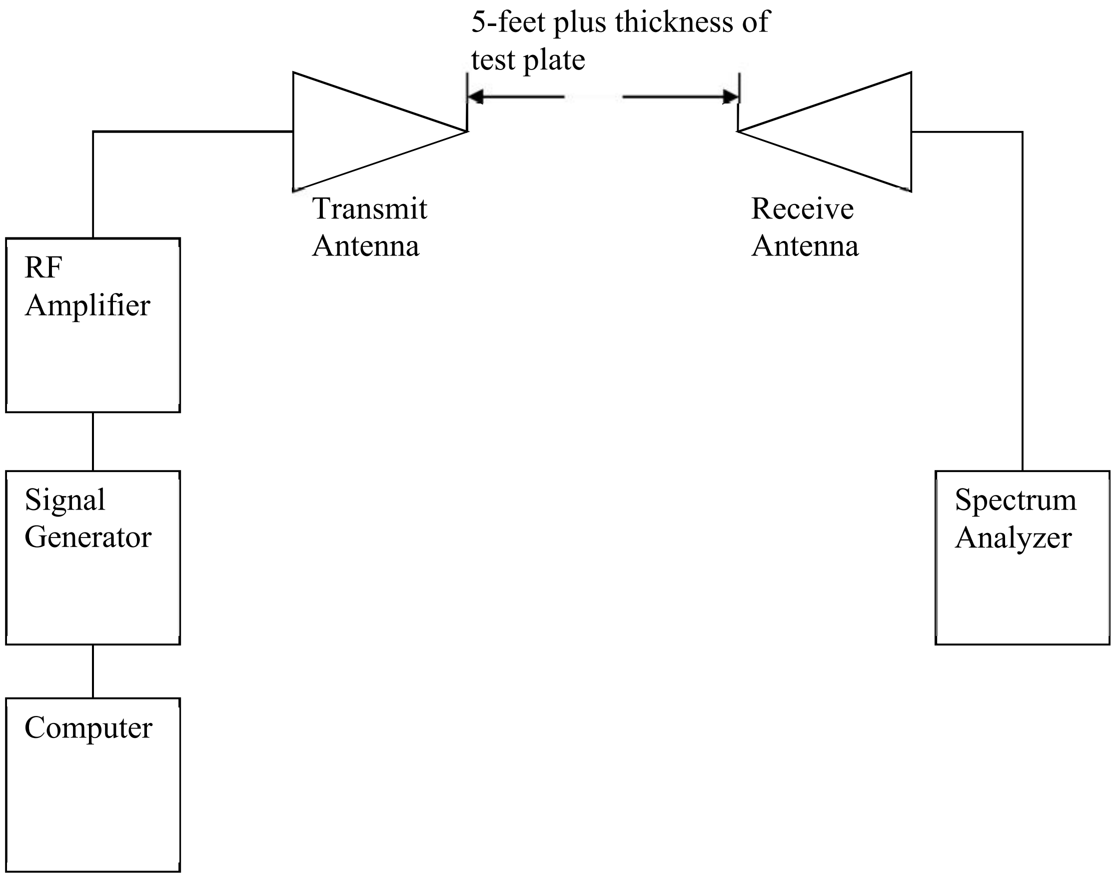


Figure 6 - Thru-Hole Open Reference Measurements



According to IEEE STD 299

Figure 7 - Free Space Open Reference Measurements

Panels were marked with the orientation of how they were mounted on the wall so the same position was used throughout the test.

3.1.2.3 Test Sequence

The testing sequence for the Test Sets was as follows:

1. Free Space Open Reference Measurements. Free space measurements may be done at any time in the process. Repeated prior to each separate test.
2. Thru-hole Open Reference measurements with only Frame fixture (Figure 3) mounted to SE chamber aperture. Only required for one fixture. Repeated prior to each separate test.
3. 1st SE test. All assembled panels (36 Test Sets). (Initial Tests)
4. Preconditioning Tests
5. 2nd SE test. All assembled panels (36 Test Sets) (Baseline tests after preconditioning)
6. Static Heat and Humidity –12 Plate Sets
7. Salt Fog Testing – 12 Plate Sets
8. Marine Environment – 12 Plate Sets
9. 3rd SE test. All assembled panels (36 Test Sets)

3.1.2.4 Test Equipment

Table 6 – Test Equipment

Test Equipment	Asset #	Serial #	Cal Date
HP 83620B Signal Generator	625	3844A00955	NCR
AR Amplifier 30W1000M7 30 Watts 25 - 1000MHz	480	15657	NCR
Logimetrics A300/S-08 2-4GHz Amplifier	133	3016	NCR
Logimetrics A300/C-08 4-8GHz Amplifier	132	3012	NCR
Logimetrics A300/IJ 8-18GHz Amplifier	134	3094	NCR
Agilent E4440A Spectrum Analyzer	704	US41421236	CAL
EMCO 3115 Ridge Guide Horn Antenna	376	2796	CAL
EMCO 3115 Ridge Guide Horn Antenna	377	2175	CAL
EMCO 3106 Ridge Guide Horn Antenna	117	2213	CAL
EMCO 3106 Ridge Guide Horn Antenna	120	2212	CAL
ETS-Lindgren TILE! EMC Software Version 4.0.A.9	N/A	N/A	NCR
Dell PC Computer	N/A	N/A	NCR
Valhalla Digital Ohm Meter 4100 ATC	158	2-2818	CAL
Parker Chomerics Cho-probe	N/A	N/A	NCR

All pieces of test equipment identified by CAL in the Cal Date column of the table were in calibration at the time of test. Since this test effort was over a period of a year and a half the actual calibration dates have not been included in this test reports. Calibration certificates can be provide by Parker Chomerics if requested.

3.1.2.5 Shielding Effectiveness (SE) Test Results

3.1.2.5.1 Shielding Effectiveness (SE) Results pre Thermal Preconditioning

Prior to thermal preconditioning, the test plates were subjected to shielding effectiveness testing in accordance with IEEE-STD-299. The shielding effectiveness readings are in Appendix C and Appendix D.

3.1.2.5.2 Shielding Effectiveness (SE) Results post Thermal Preconditioning

Following thermal preconditioning, the test plates were subjected to shielding effectiveness testing in accordance with IEEE-STD-299. The initial plan was to only select and test a few of the test plates for shielding effectiveness after preconditioning. If it was determined that there was a change in shielding effectiveness values for the few test plates selected all plates would be measured. There was in fact a change in shielding effectiveness which mandated that all panels were tested after preconditioning. (Appendix C and Appendix D).

3.1.2.5.3 Shielding Effectiveness (SE) Results post Environmental Exposure

Following environmental exposure, the test plates were subjected to shielding effectiveness testing in accordance with IEEE-STD-299. There was a change, drop, in the shielding effectiveness readings (Appendix C and Appendix D).

3.1.2.6 DC Thru Resistance Test Results of Plate Sets

All test plates were fabricated with banana jack holes for DC meter probes. This allowed for each test set to be measure for DC resistance between the two aluminum plates after full assembly.

Test results for the DC resistance measurements are included in TABLE 7.

Table 7 - NASA DC Resistance Test Results of Test Sets

FIGURE 7 - DC Resistance of NASA Test Plates					
	Initial 11/24/14	1/6/2015	3/25/2015	3/25/2015	2/5/2016
Plate #	Initial Resistance (Ω)	After Preconditioning (Ω)	After 1000 Hours 85/85 (Ω)	After 1000 Hours Salt Fog (Ω)	After 12 Months Beach Front (Ω)
5S06	0.00009	0.00084			0.00204
5S05	0.00010	0.00094			0.00305
5S04	0.00011	0.00141	0.0047		
5S03	0.00012	0.00119	0.00411		
5S02	0.00008	0.00123		0.00313	
5S01	0.00009	0.00107		0.00215	
6S06	0.00006	0.00015			0.00041
6S05	0.00006	0.00016			0.00030
6S04	0.00005	0.00014	0.00023		
6S03	0.00005	0.00016	0.00018		
6S02	0.00007	0.00032		0.00352	
6S01	0.00005	0.00013		0.00315	
6A06	0.00007	0.00017			0.00038
6A05	0.00007	0.00023			0.00051
6A04	0.00005	0.00011	0.00015		
6A03	0.00004	0.00012	0.00014		
6A02	0.00007	0.00023		0.0026	
6A01	0.00008	0.00028		0.00414	
5A06	0.00008	0.00061			0.00196
5A05	0.00006	0.00078			0.00237
5A04	0.00011	0.00122	0.00376		
5A03	0.00011	0.00164	0.00496		
5A02	0.00011	0.00129		0.00329	
5A01	0.00014	0.00143		0.00359	
5M06	0.00007	0.00057			0.00161
5M05	0.00007	0.00048			0.00138
5M04	0.00010	0.00077	0.00189		
5M03	0.00012	0.00084	0.00255		
5M02	0.00008	0.00049		0.00099	
5M01	0.00008	0.00073		0.00147	
6M06	0.00005	0.00014			0.00026
6M05	0.00008	0.00024			0.00065
6M04	0.00007	0.00022	0.00028		
6M03	0.00008	0.00026	0.00038		
6M02	0.00006	0.00017		0.00138	
6M01	0.00008	0.00028		0.00296	

It’s important to note that these DC resistance values were recorded as simply a piece of information. It’s widely known that DC resistance is not a good indicator of shielding effectiveness.

3.1.3 Salt Spray Resistance

This test is used to rapidly evaluate the performance of a coating or coating system and how well it prevents corrosion. Salt Spray Resistance is a requirement MIL-DTL-5541.

3.1.3.1 Test Procedure

Plate sets were subjected to a 5 percent NaCl salt spray, pH-adjusted to a range of 6.5 – 7.2, in accordance with ASTM B 117 (Standard Practice for Operating a Salt Spray (Fog) Apparatus). The plate sets were placed into the salt spray chamber diagonally (see Figure **8**) to prevent moisture from pooling on the gasket.

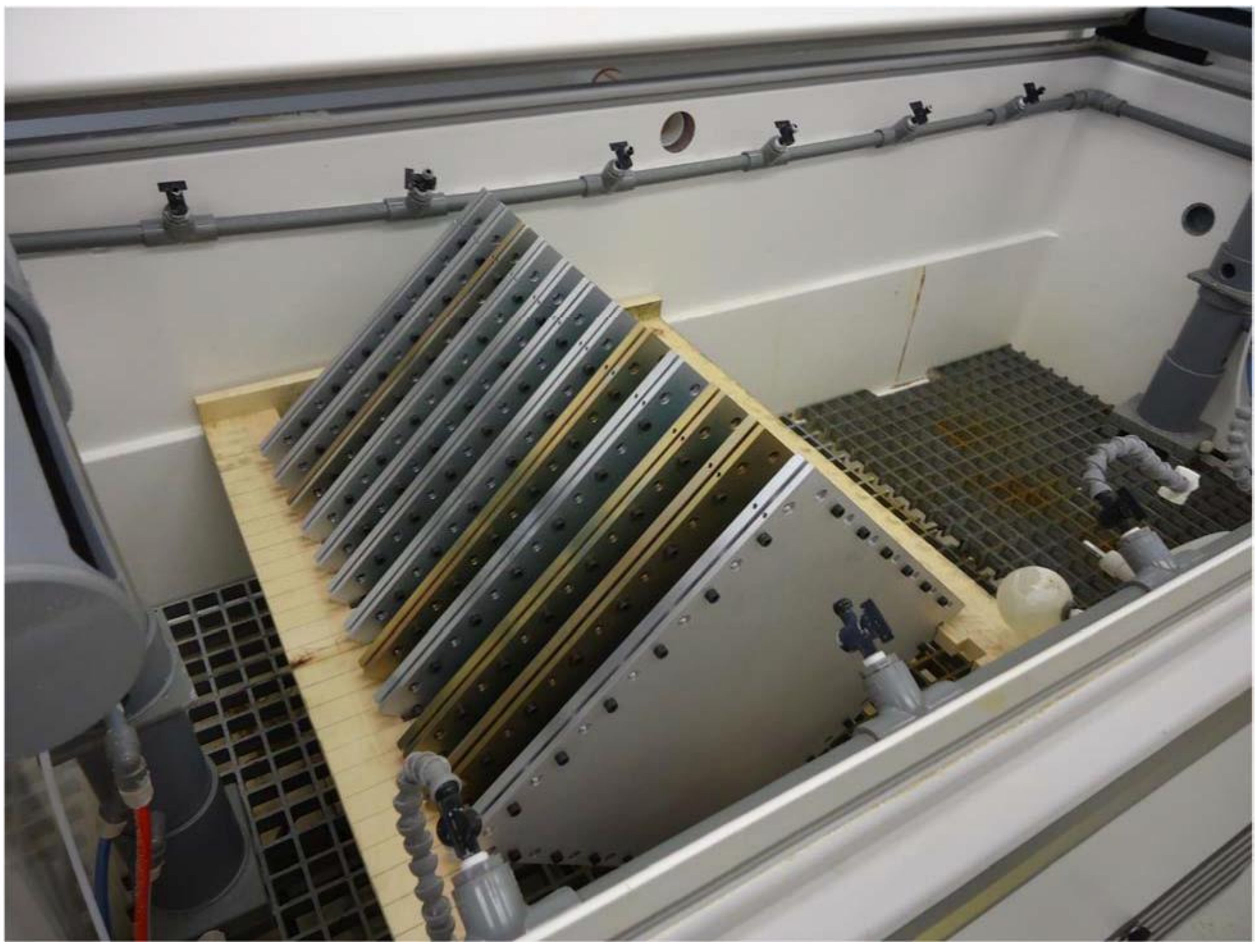


Figure 8 – ASTM B 117 Salt Spray Setup

3.1.3.2 Evaluation Procedure

Plate set evaluations took place at 168 hour intervals. During plate set evaluation, photos were taken for each plate set. Following inspection, the panels were rotated a quarter turn when placed back into the salt spray chamber.

3.1.3.3 Salt Spray Resistance Test Results

During salt spray testing, the black oxide alloy steel socket head cap screws used to assemble the test plates corroded. The corrosion products from the socket head cap screws created streaked across the surface of the test plates. As testing continued and the test plates were rotated in the salt spray chamber, the streaking covered a majority of the test plate surface making it difficult to analyze the surface of the test plates for the presence of corrosion. Areas of the test plates that were not covered in streaking showed no signs of corrosion or pitting on the surface of the test plates.

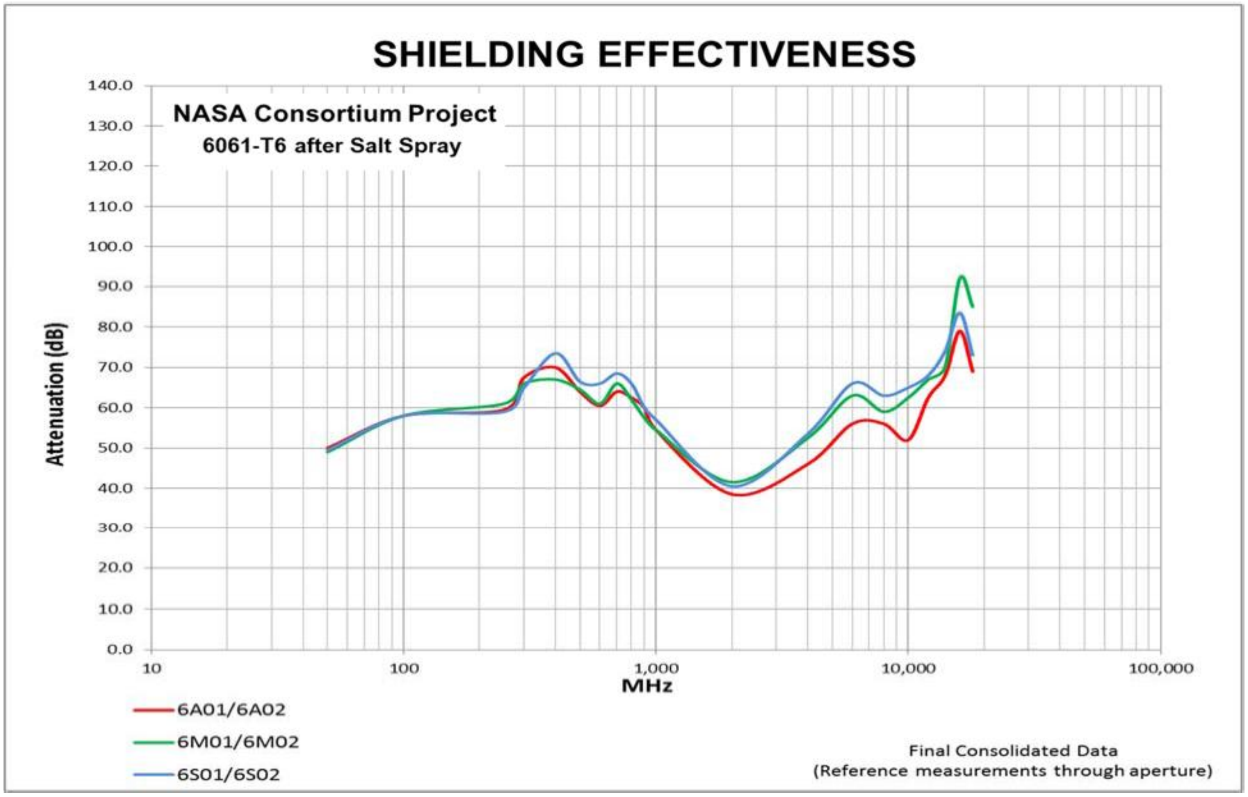
As expected, shielding effectiveness values were reduced after exposure to Salt Spray conditions. However, there was little (if any) differentiation to the SE data taken from the different types of aluminum and/or conversion coating. The graphs below compare the SE data for all three conversion coatings against 6061 aluminum and 5052 aluminum respectively. Individual shielding effectiveness graphs for each panel are included within Appendix C and D.

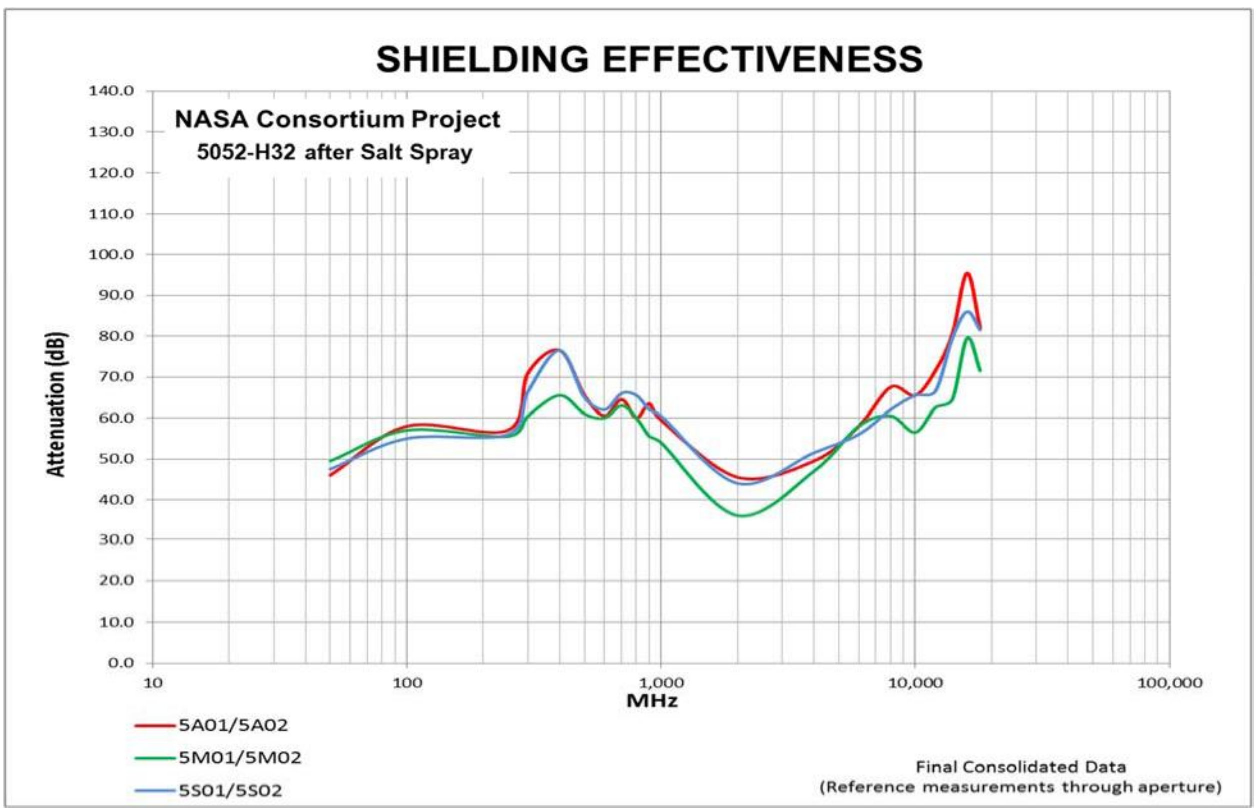
Statistical data analysis to differentiate the test data was not successful due to the close similarity of all data and the small sample size of 3 sets of each type.

Significant prior work was performed to select the aluminum and conversion coating included within this test cycle **Reference – NASA GSDO Program Hexavalent Chrome Alternatives Final Pretreatments Test Report Task Order: NNH12AA45D September 01, 2013**.

From review of the test data, the Type 2 conversion coatings perform very similar to the incumbent Type 1 conversion coating against both 6061 and 5052 aluminum under these test conditions.

All graphs included in this Test Report were created from SE measurements with the "Open Reference" taken through the open aperture and not in "Free Space" (see Section 3.1.2.1) for simplicity. All test data exists and can be graphed in many ways.


SHIELDING EFFECTIVENESS
NASA Consortium Project
6061-T6 after Salt Spray
Attenuation (dB)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10
100
1,000
10,000
100,000
MHz
6A01/6A02
6M01/6M02
6S01/6S02
Final Consolidated Data
(Reference measurements through aperture)


SHIELDING EFFECTIVENESS
NASA Consortium Project
5052-H32 after Salt Spray
Attenuation (dB)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10
100
1,000
10,000
100,000
MHz
5A01/5A02
5M01/5M02
5S01/5S02
Final Consolidated Data
(Reference measurements through aperture)

3.1.4 Static Heat and Humidity

Plate sets were subjected to high heat and humidity for 1,000 hours.

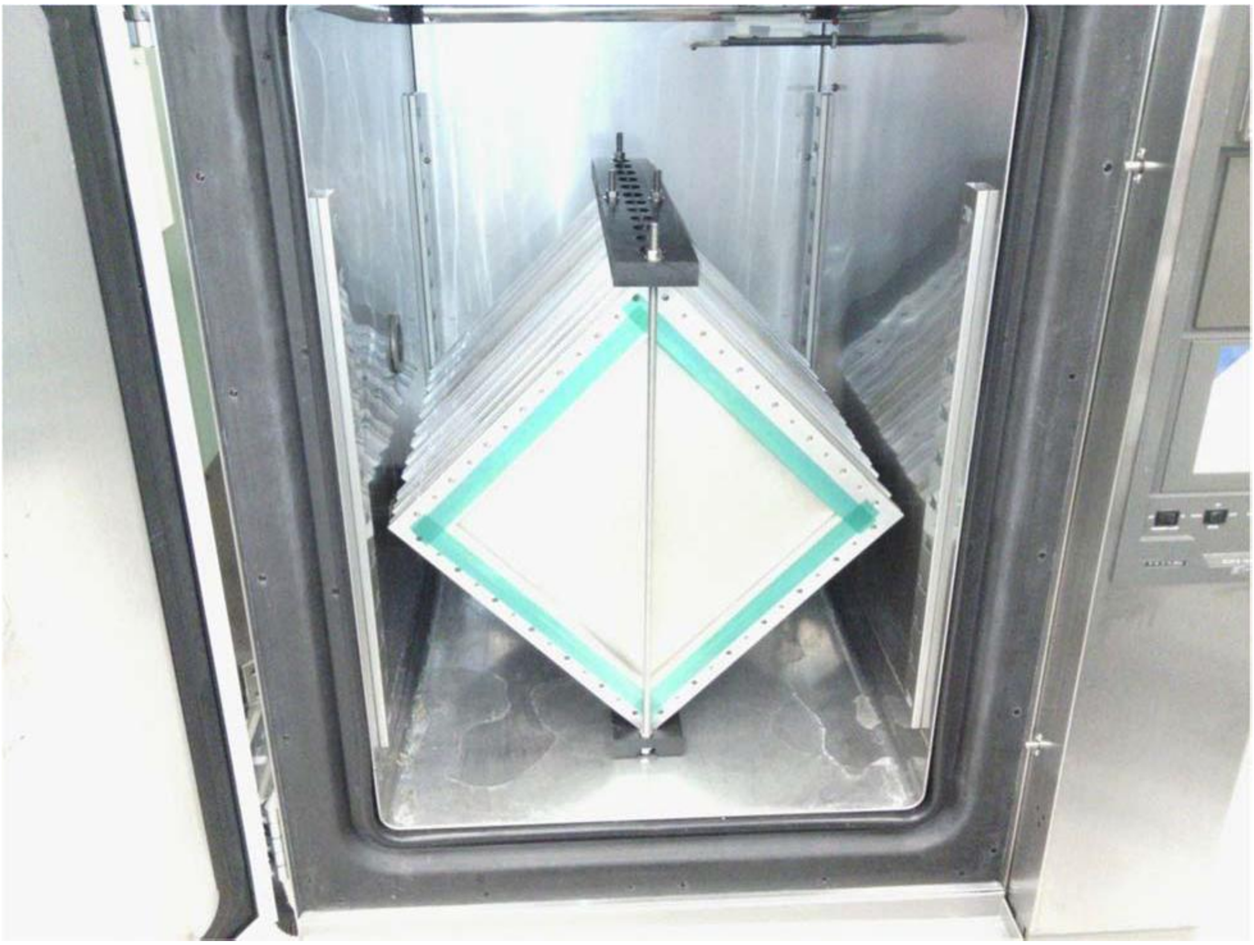


Figure 9 – Static Heat and Humidity Test Setup

3.1.4.1 Test Procedure

Plate sets were subjected to an 85 Degrees C and 85% RH for a period of 1000 Hours. The plate sets were placed into the Temp/Humidity chamber diagonally (see Figure **8**) to prevent moisture from pooling on the gasket.

3.1.4.2 Evaluation Procedure

Following 1,000 hours of testing, the plate sets were evaluated. Signs of corrosion that appear on the test articles were circled with a felt tip pen (Sharpie or equivalent) and photos were taken for each plate set.

3.1.4.3 Static Heat and Humidity Test Results

Following the completion of testing all of the test plates were reviewed for the presence of corrosion. No signs of corrosion or pitting were observed on the surface of the test plates. The only corrosion observed was from the black oxide alloy steel socket head cap screws used to assemble the test plates. Test plates near the humidity input show signs of extensive corrosion on the socket head cap screws. The corrosion from these particular socket head cap screws was blown along the edge of the test plates. Test plates away from the humidity input did not have an issue with the socket head cap screws.

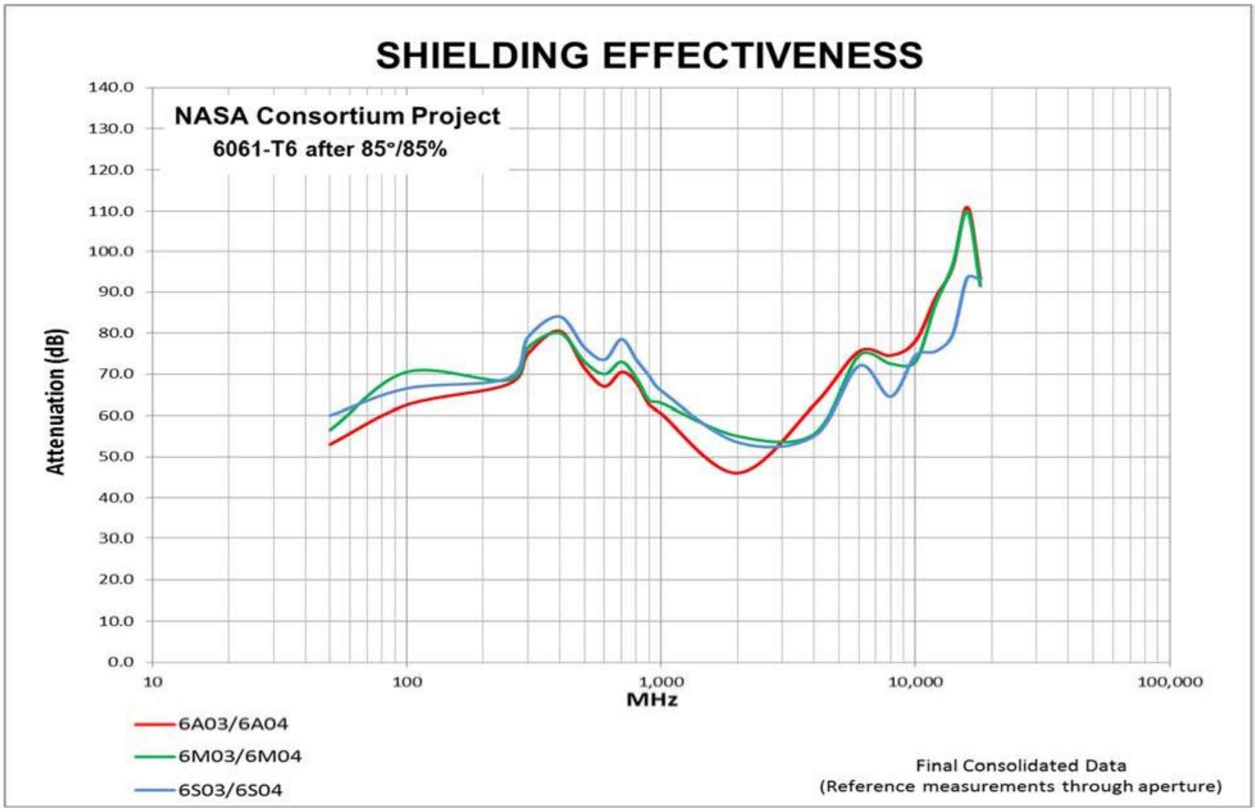
As expected, shielding effectiveness values were reduced after exposure to Static Heat and Humidity conditions. However, there was little (if any) differentiation to the SE data taken from the different types of aluminum and/or conversion coating. The graphs below compare the SE data for all three conversion coatings against 6061 aluminum and 5052 aluminum respectively. Individual shielding effectiveness graphs for each panel are included within Appendix C and D.

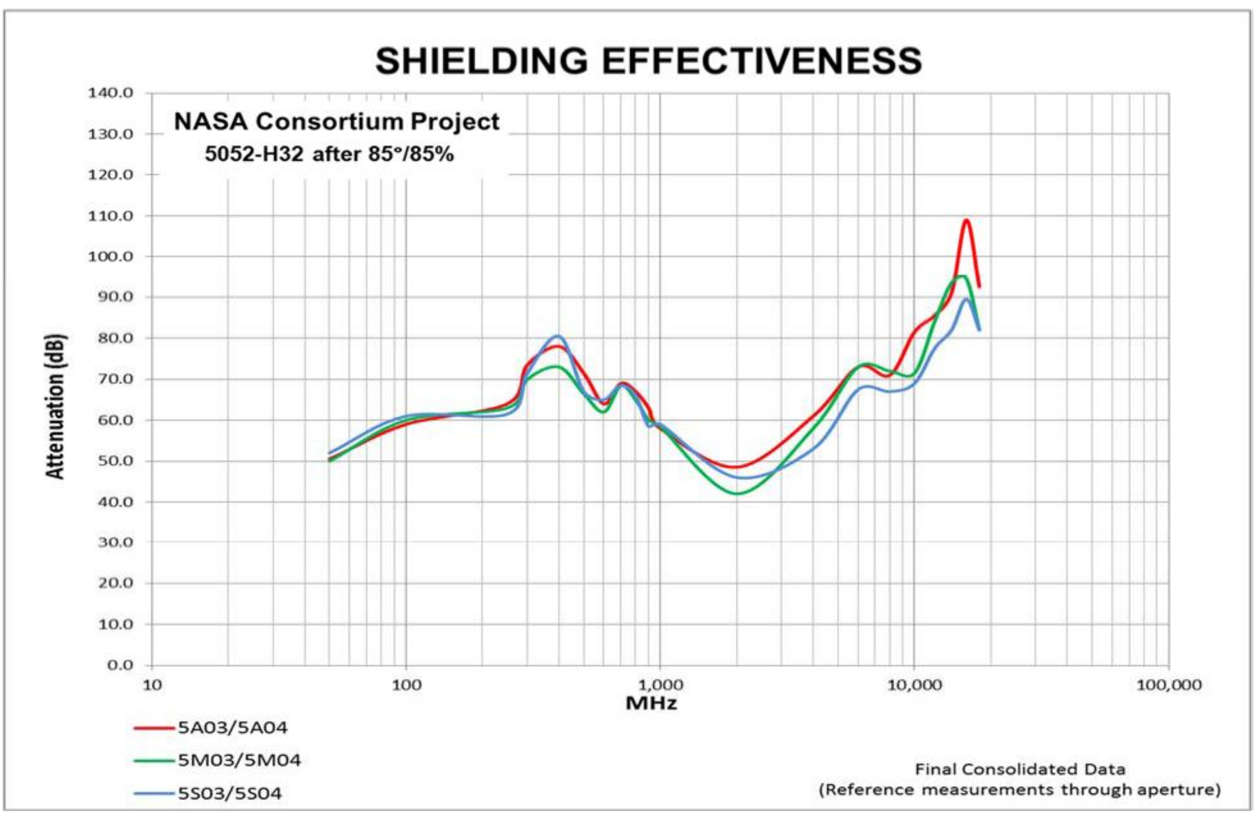
Statistical data analysis to differentiate the test data was not successful due to the close similarity of all data and the small sample size of 3 sets of each type.

Significant prior work was performed to select the aluminum and conversion coating included within this test cycle **Reference – NASA GSDO Program Hexavalent Chrome Alternatives Final Pretreatments Test Report Task Order: NNH12AA45D September 01, 2013**.

From review of the test data, the Type 2 conversion coatings perform very similar to the incumbent Type 1 conversion coating against both 6061 and 5052 aluminum under these test conditions.

All graphs included in this Test Report were created from SE measurements with the "Open Reference" taken through the open aperture and not in "Free Space" (see Section 3.1.2.1) for simplicity. All test data exists and can be graphed in many ways.


SHIELDING EFFECTIVENESS
NASA Consortium Project
6061-T6 after 85°/85%
Attenuation (dB)
MHz
6A03/6A04
6M03/6M04
6S03/6S04
Final Consolidated Data
(Reference measurements through aperture)


SHIELDING EFFECTIVENESS
NASA Consortium Project
5052-H32 after 85°/85%
Attenuation (dB)
MHz
5A03/5A04
5M03/5M04
5S03/5S04
Final Consolidated Data
(Reference measurements through aperture)

3.1.5 Marine Environment

This test evaluates the performance of the test and control coatings during outdoor exposure in a marine environment. Accelerated testing is useful for comparing the performance of coatings under accelerated conditions; however, correlations to actual service performance have been difficult due to different corrosion mechanisms prevalent in the two situations. Therefore, outdoor exposure in the environment of performance is a critical test necessary to determine the effect actual weather patterns and real-world exposure has on the coatings of interest. Comparing data collected from atmospheric and accelerated testing provides insight into anticipated performance of a coating system before being field tested.

3.1.5.1 Test Procedure

Atmospheric exposure testing follows ASTM D 1014 (Standard Practice for Conducting Exterior Exposure Tests of Paints and Coatings on Metal Substrates).

Test articles were installed diagonally (see
Figure **10**) at the KSC Beach Front Corrosion Lab, located at latitude 28.594°N, longitude -80.582°W, and approximately 100 feet (30 meters) from the high tide line.

Figure 10 – KSC Beachfront Testing

3.1.5.2 Evaluation Procedure

Plate set evaluations took place at every 3 months. During plate set evaluation, signs of corrosion that appear on the test articles were circled with a felt tip pen (Sharpie or equivalent) and photos were taken for each plate set.

3.1.5.3 Marine Environment Test Results

During Marine Environment testing, the black oxide alloy steel socket head cap screws used to assemble the test plates corroded. As a result, disassembly of these plates was very difficult and far worse than the Test Plates exposed in B117 Salt Fog conditions described above. Many of the bolts had to be snapped to remove. Areas of the test plates that were not covered in streaking showed no signs of corrosion or pitting on the surface of the test plates.

As expected, shielding effectiveness values were reduced after exposure to Marine Environment conditions. There was little (if any) differentiation to the SE data taken from the different types of conversion coating. However, significant differences were seen in the Shielding Effectiveness of 6061 aluminum compared to 5052 aluminum. The graphs below compare the SE data for all three conversion coatings against 6061 aluminum and 5052 aluminum respectively. As illustrated, the 6061 aluminum panels slightly out-performed the 5052 aluminum panels Individual shielding effectiveness graphs for each panel are included within Appendix C and D.

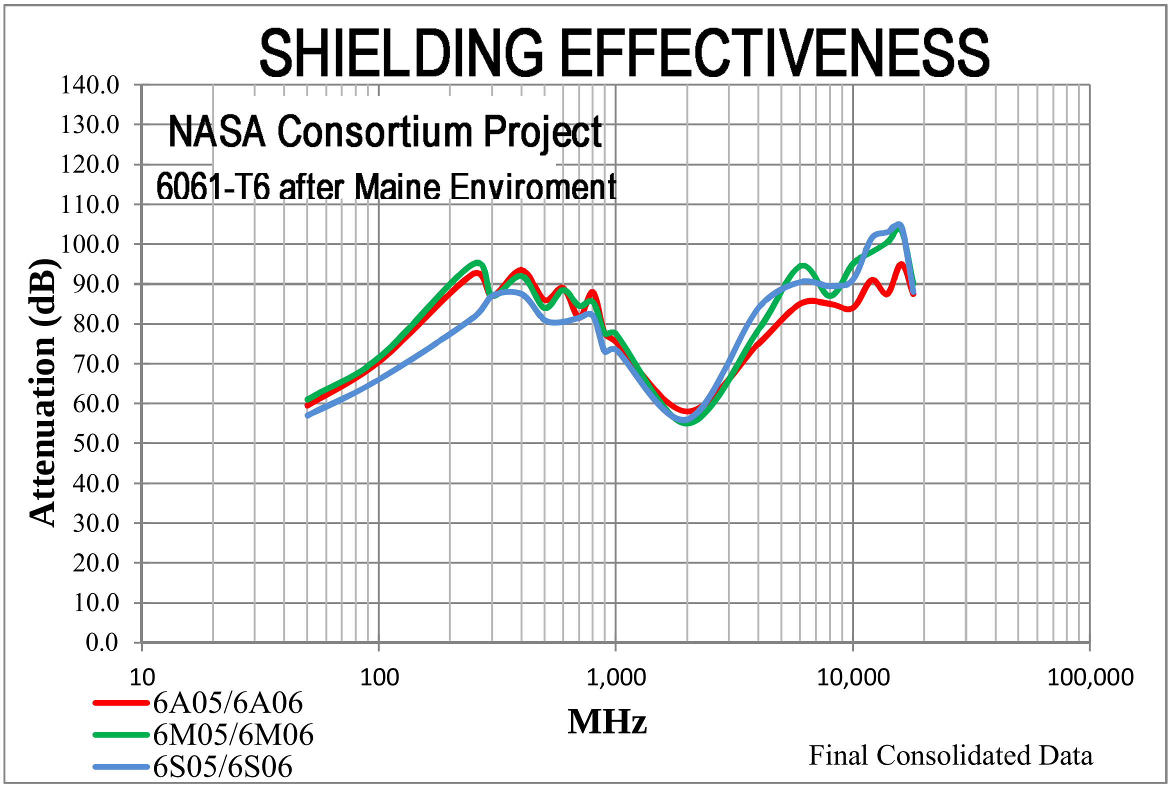
The other notable effect found during review of the data is that the Test Panels exposed to B117 Salt Fog reduced in shielding effectiveness significantly more than the Marine Environment Test Panels. The shielding effectiveness of the Marine Test Panels was approximately 20dB higher than the Test Panels that underwent B117 Salt Fog Exposure.

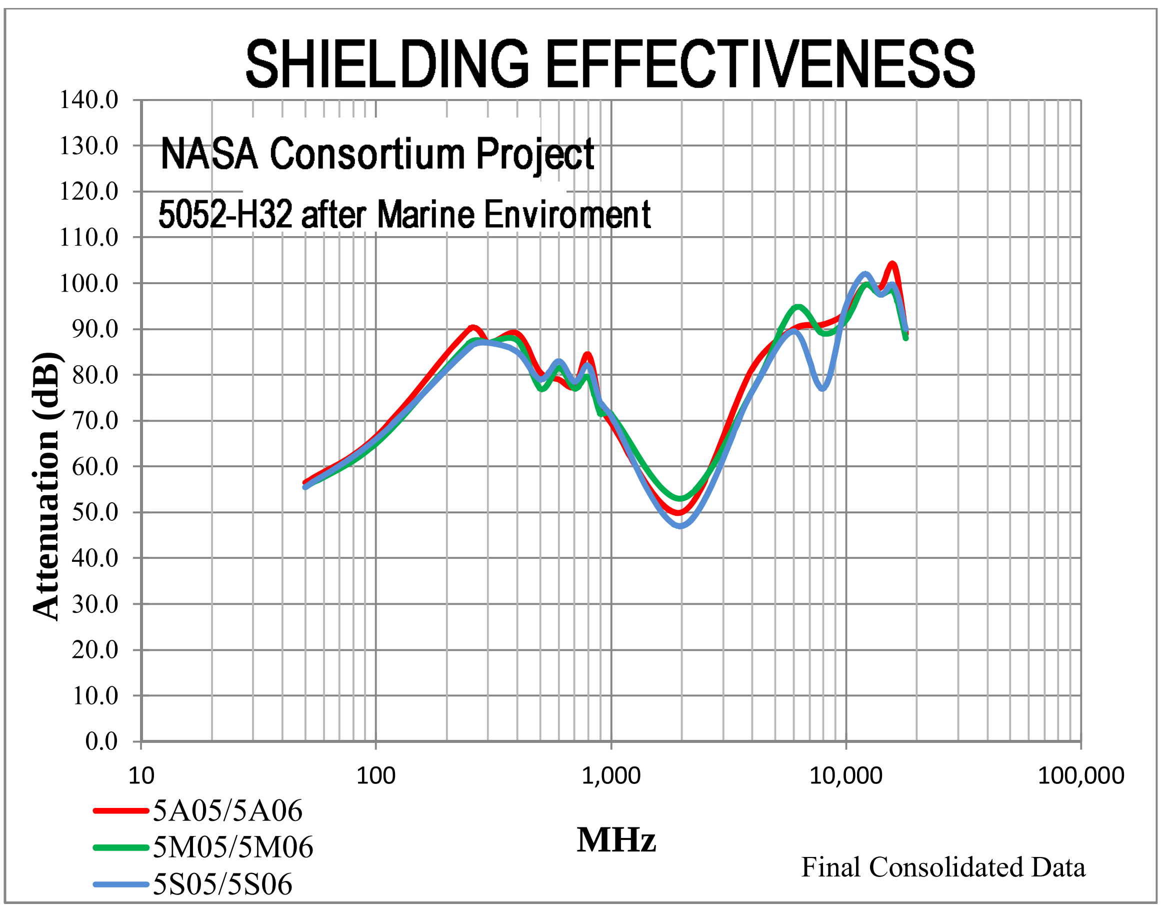
Statistical data analysis to differentiate the test data was not successful due to the close similarity of all data and the small sample size of 3 sets of each type.

Significant prior work was performed to select the aluminum and conversion coating included within this test cycle **Reference – NASA GSDO Program Hexavalent Chrome Alternatives Final Pretreatments Test Report Task Order: NNH12AA45D September 01, 2013**.

From review of the test data, the Type 2 conversion coatings perform very similar to the incumbent Type 1 conversion coating against both 6061 and 5052 aluminum under these test conditions.

All graphs included in this Test Report were created from SE measurements with the “Open Reference” taken through the open aperture and not in “Free Space” (see Section 3.1.2.1) for simplicity. All test data exists and can be graphed in many ways.


SHIELDING EFFECTIVENESS
NASA Consortium Project
6061-T6 after Maine Enviroment
Attenuation (dB)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10
100
1,000
10,000
100,000
MHz
6A05/6A06
6M05/6M06
6S05/6S06
Final Consolidated Data


SHIELDING EFFECTIVENESS
NASA Consortium Project
5052-H32 after Marine Enviroment
Attenuation (dB)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10
100
1,000
10,000
100,000
MHz
5A05/5A06
5M05/5M06
5S05/5S06
Final Consolidated Data

3.2 DC Resistance Testing – MIL-DTL-81706

3.2.1 Test Panel - Resistance Testing

For the following tests, 3”x10”x0.32” test panels were used in two alloy types; 6061-T6 and 5052-H32.

Table 8 – Resistance Testing Overview

Test	Test Method	Panel Count	Evaluation Criteria	Location
Contact Electrical Resistance	MIL DTL 81706	Set 1 = 30	not greater than 5,000 microhms	UTC Aerospace Systems
Surface Resistance Test	ASTM D 257	Set 1 = 30	Data collection	Raytheon
Salt Spray Resistance	ASTM B 117	168 Hours	MIL-DTL-5541	KSC Corrosion Lab
Contact Electrical Resistance	MIL DTL 81706	Set 2 = 30	not greater than 5,000 microhms	UTC Aerospace Systems
Surface Resistance Test	ASTM D 257	Set 1 = 30	Data collection	Raytheon

Table 9 – Resistance Testing, Test Panels Breakout

MIL-DTL-81706 Contact Resistance				
Numer of samples	Alloy	Conversion Coating	Set 1	Total Number of Test Panels
5	6061-T6	Hex Chrome	Before Salt Spray	15
5		SurTec	Before Salt Spray	
5		Metalast	Before Salt Spray	
Numer of samples	Alloy	Conversion Coating	Set 1	Total Number of Test Panels
5	5052-H32	Hex Chrome	Before Salt Spray	15
5		SurTec	Before Salt Spray	
5		Metalast	Before Salt Spray	
Numer of samples	Alloy	Conversion Coating	Set 2	Total Number of Test Panels
5	6061-T6	Hex Chrome	After Salt Spray	15
5		SurTec	After Salt Spray	
5		Metalast	After Salt Spray	
Numer of samples	Alloy	Conversion Coating	Set 2	Total Number of Test Panels
5	5052-H32	Hex Chrome	After Salt Spray	15
5		SurTec	After Salt Spray	
5		Metalast	After Salt Spray	
ASTM D 257 Surface Resistance				
Numer of samples	Alloy	Conversion Coating	Set 1	Total Number of Test Panels
5	6061-T6	Hex Chrome	Before& After Salt Spray	15
5		SurTec	Before& After Salt Spray	
5		Metalast	Before& After Salt Spray	
Numer of samples	Alloy	Conversion Coating	Set 1	Total Number of Test Panels
5	5052-H32	Hex Chrome	Before& After Salt Spray	15
5		SurTec	Before& After Salt Spray	
5		Metalast	Before& After Salt Spray	

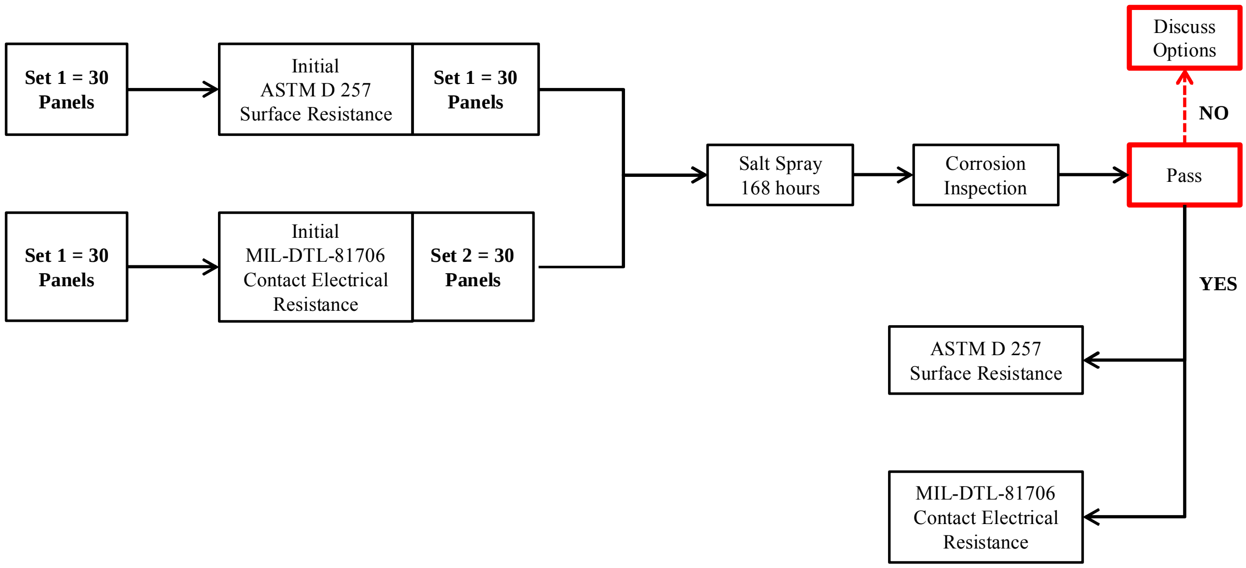


Figure 11 – Resistance Testing Project Flow

3.2.2 Contact Electrical Resistance

Low contact electrical resistance properties are a qualification requirement of MIL-DTL-81706B. Readings were taken prior to and following ASTM B 117 salt spray testing. A total of 60 test panels underwent testing; five (5) replicates, (2) alloys, (3) conversion coatings, (2) panel sets; set 1 was used for electrical resistance readings prior to salt spray testing. Set 1 was not subjected to spray testing. Set 2 was subjected to salt spray testing (168 hours) and then electrical resistance readings were taken.

3.2.2.1 Test Procedure

The test was conducted similar to the test set-up in
Figure **12**. The applied load was within one percent of the calculated 200 pounds per square inch (psi) applied pressure. The contacting electrodes were copper with a finish not rougher than that obtained by the use of 000 metallographic abrasive paper. The electrodes were flat enough so that when the load was applied without a specimen between them, light was not visible through the contacting surface. The area of the upper electrode was one square inch (25 square mm) and the area of the lower electrodes was larger. Ten measurements were made on each panel in the areas shown on
Figure **13**.

1. Two copper rods a minimum of 1-inch thick with the end surfaces polished to a mirror finish. One electrode 1" diameter and the other 1.5" diameter.
2. The panels were double rinsed with clean, running, lukewarm DI water (less than 100°F) for approximately 30 seconds. The panels were blown dry with nitrogen and wrapped in clean paper towels to protect them from scratching each other. The clean panels were allowed to air dry for 24 hours at room temperature prior to testing.
3. Before taking readings on each panel, baseline electrical resistance readings of the copper rods alone were taken. These values were subtracted from the panel electrical resistance values.

The copper electrical resistance values were observed to look for any increase in baseline resistance, which would indicate a need to re-polish the electrodes.

4. The larger diameter copper rod was positioned in the middle of the lower Instron compression plate. The test panel was positioned on top of the larger diameter copper rod and then the smaller diameter copper rod centered over the lower (reference Figure 3.) 200 pounds of force were applied using the Instron. The electrical resistance compression test method automatically stopped the compressive loading at approximately 200 pounds. When approximately 200 pounds of force was achieved, electrical resistance readings were taken. The HP Agilent HP 4338B electrical meter was used for readings using 16143B probes. The probes were pushed against the side of the copper rods and the meter reading recorded. Ten electrical resistance readings were taken on each panel, evenly distributed over the panel. After each panel, the copper rod was cleaned using a dry, lint free, non-abrasive cloth.
5. Using the HP 4338B Agilent Meter: The four connection mating cables were plugged into the front of the meter, matching the LCUR, LPOT, HPOT and HCUR designations on the connector and meter. The Auto Meas light lit up green and the screen read, "R:-29.9 kΩ LVL: Auto AVG: 1". Pushing down on the probe tips caused the sheath to make contact and a reading was displayed on the meter. The reading may be continuously changing on the last decimal place; in this case, an average reading was recorded.
6. The electrical resistance readings were averaged and the baseline copper plate electrical resistance subtracted from the average, and then this value divided by two to give the coating electrical resistance value. These values were tabulated and reported.
7. The copper plates were re-polished to a mirror finish after each testing day.

3.2.2.2 Evaluation Procedure

The contact electrical resistance of aluminum alloy panels treated with class 3 materials under an applied electrode pressure of 200 pounds psi is not supposed to be greater than 5,000 microhms psi as applied and 10,000 microhms psi after salt spray exposure. Individual readings not greater than 20 percent in excess of the specified maximums are acceptable, provided that the average of all readings does not exceed the specified maximum resistance.

Figure 12 - Contact Electrical Resistance Testing

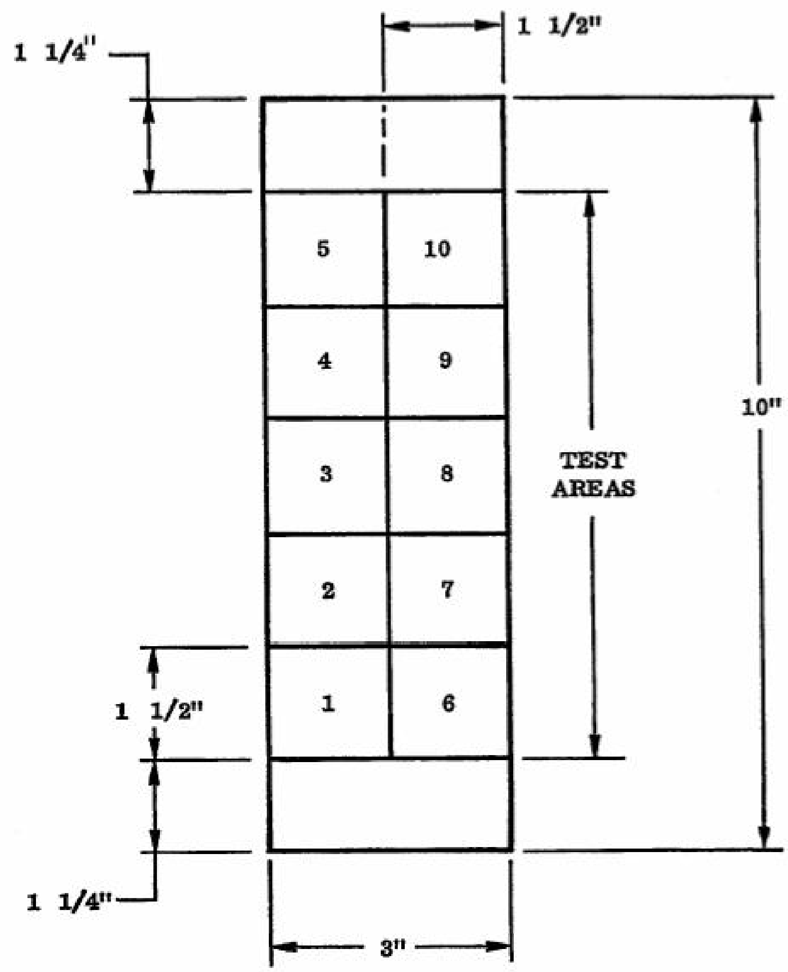


Figure 13 - Contact Electrical Resistance Test Pattern

3.2.2.3 Contact Electrical Resistance Test Results

Following the completion of the contact electrical resistance testing, it was determined that all test panels did not meet the qualification requirements of MIL-DTL-81706B; alloy panels treated with class 3 materials under an applied electrode pressure of 200 pounds psi shall not be greater than 5 milliohms psi as applied before salt spray testing and 10 milliohms psi as applied following salt spray testing. Previous studies have yielded similar high readings for test panels that have been stored for weeks prior to contact electrical resistance testing. The reason for why storing test panels prior to testing has this effect is not fully understood at this time. The following tables contain the results from contact electrical resistance testing.

Table 10 – Resistance Values in Milliohms before Salt Spray Testing

Alloy	Conversion Coat	Test Panel	Location on Test Panel										Mean	Median	Standard	Copper Electrode to
		ID	1	2	3	4	5	6	7	8	9	10			Deviation	Electrode Resistance
6061	Alodine 1200S	1	80	11	9.4	36.5	210	60	78	164	73	143	86.49	75.5	66.32781	0.31
		2	75	72	62	163	141	19.5	180	120	190	250	127.25	130.5	70.67738	0.48
		3	84	240	26	81	15	21	7.6	41	48	31	59.46	36	68.48183	0.3
		4	127	40	108	157	69	33	186	14	192	88	101.4	98	63.65916	0.85
		5	187	15	120	33	81	115	99	76	160	247	113.3	107	70.14754	1.2
6061	SurTec 650	6	51	1900	34	4.2	7.6	62	22	18	113	380	259.18	42.5	587.264	0.49
		7	326	295	72	64	163	54	120	53	1020	78	224.5	99	296.6023	0.81
		8	560	456	59	526	600	11	24	29	35	128	242.8	93.5	256.3248	0.37
		9	92	65	570	36	50	200	64	23	22	139	126.1	64.5	165.5975	0.69
		10	97	28	140	10	48	8.4	76	45	15	76	54.34	46.5	42.87087	0.35
6061	Metalast TCP-HF	11	153	403	20	228	460	33	158	153	327	228	216.3	193	145.419	3
		12	338	321	111	400	344	1180	2600	8700	61	296	1435.1	341	2663.468	1.6
		13	17	1200	1130	58	1.4	12	48	6.6	15	2.7	249.07	16	483.3816	0.45
		14	61	2800	6.6	4.8	2.6	3.4	3	28	323	113	334.54	17.3	871.9408	0.27
		15	42	15	18	480	110	8	4.9	28	331	17.7	105.46	23	164.7696	0.74

Alloy	Conversion Coat	Test Panel	Location on Test Panel										Mean	Median	Standard	Copper Electrode to
		ID	1	2	3	4	5	6	7	8	9	10			Deviation	Electrode Resistance
5052	Alodine 1200S	1	32	60	15	15	4.2	36	43	24	23	79	33.12	28	22.64042	2
		2	18	21	6.6	14	94	74	44	26	54	81	43.26	35	31.07569	1.2
		3	33	8.8	19	39	99	24	112	55	73	43	50.58	41	34.30108	1.6
		4	7.8	18	42	40	65	19	92	90	75	75	52.38	53.5	31.11305	2.1
		5	23	35	30	64	37	35	11	60	60	59	41.4	36	18.27688	0.69
5052	SurTec 650	6	27	43	240	140	65	48	19	45	25	41	69.3	44	69.10065	1.2
		7	19	141	25	110	16	18	48	14	5.2	3.8	40	18.5	47.24461	0.17
		8	9.6	4.9	4.8	20	12	11	41	11	62	45	22.13	11.5	19.93835	0.93
		9	14	38	14	13	30	11	16	29	26	33	22.4	21	9.834181	1.8
		10	10	19	15	7.5	18	9	34	31	31	16	19.05	17	9.730964	1
5052	Metalast TCP-HF	11	95	37	52	49	300	18	15	70	460	15	111.1	50.5	148.8254	0.74
		12	170	49	110	30	29	81	71	170	50	45	80.5	60.5	53.08955	0.14
		13	110	270	9	63	18	290	130	31	46	11	97.8	54.5	104.3092	0.79
		14	68	180	32	4.1	53	17	8.4	6.5	18	42	42.9	25	52.66194	0.85
		15	74	44	47	140	92	18	18	5.2	80	35	55.32	45.5	41.34142	0.2

Requirement = 5 milliohms, maximum

Table 11 - Resistance Values in Milliohms after Salt Spray Testing

Alloy	Conversion Coat	Test Panel ID	Location on Test Panel										Mean	Median	Standard Deviation	Copper Electrode to Electrode Resistance
			1	2	3	4	5	6	7	8	9	10				
6061	Alodine 1200S	16	290	208	320	140	120	160	160	140	520	120	217.8	160	126.9276	0.69
		17	180	280	81	62	74	140	140	140	140	140	137.7	140	62.4216	0.79
		18	140	60	130	180	55	106	82	94	36	110	99.3	100	43.60441	2.6
		19	190	55	130	36	88	12	150	310	250	84	130.5	109	96.06855	3.6
		20	75	110	75	15	38	76	7.1	140	16	220	77.21	75	66.23826	2.1
6061	SurTec 650	21	510	107	83	1200	120	360	2800	620	105	110	601.5	240	849.3096	2.2
		22	23	15	12	21	36	160	105	90	150	260	87.2	63	82.61127	0.83
		23	27	30	43	170	190	11	100	330	23	220	114.4	71.5	108.2971	1.8
		24	560	30	86	160	31	140	250	650	130	33	207	135	221.7496	0.79
		25	14	170	74	130	160	11	180	1060	54	65	191.8	102	311.3522	1.3
6061	Metalast TCP-HF	26	52	79	67	350	120	33	210	19	93	530	155.3	86	164.7396	2.3
		27	53	310	22	350	33	320	320	280	330	320	233.8	315	137.7831	3.5
		28	500	320	16	36	1	15	150	390	3.4	29	146.04	32.5	187.4844	1.5
		29	1500	86	120	540	170	130	55	150	28	25	280.4	125	453.3687	0.54
		30	43	40	54	14	31	11	110	87	270	50	71	46.5	76.2321	0.55

Alloy	Conversion Coat	Test Panel ID	Location on Test Panel										Mean	Median	Standard Deviation	Copper Electrode to Electrode Resistance
			1	2	3	4	5	6	7	8	9	10				
5052	Alodine 1200S	16	24	19	30	102	14	31	35	49	97	60	46.1	33	31.23549	0.77
		17	11	53	110	17	29	2.6	67	79	26	51	44.56	40	33.8589	0.45
		18	51	32	10	5.4	49	69	71	11	77	61	43.64	50	27.25123	2.1
		19	40	28	30	19	38	108	39	53	14	32	40.1	35	26.29512	0.53
		20	22	71	30	56	34	11	16	85	37	33	39.5	33.5	23.978	0.79
5052	SurTec 650	21	34	14	6.6	33	45	14	16	46	18	56	28.26	25.5	16.83675	1.5
		22	9.3	26	10	8.3	33	32	6.5	23	7	11	16.61	10.5	10.68077	0.97
		23	15	9.8	6	34	6.4	14	5.3	11	35	14	15.05	12.5	10.82725	1.1
		24	71	59	5.6	4.9	4.9	26	9.3	11	24	9.8	22.55	10.4	23.73906	1.4
		25	11	91	7.1	7.4	6.9	38	5.4	8.4	7.9	10	19.31	8.15	26.94057	1.4
5052	Metalast TCP-HF	26	170	120	46	25	17	8.2	13	14	140	110	66.32	35.5	61.89491	0.79
		27	44	110	20	17	120	28	32	9	37	27	44.4	30	38.58382	1.9
		28	5.5	7.2	32	15	330	110	100	25	85	74	78.37	53	96.74624	0.78
		29	39	4.9	11	75	210	130	200	250	6	74	99.99	74.5	92.08873	2
		30	85	130	3.8	15	20	26	14	11	45	33	38.28	23	39.74622	2.2
Requirement = 10 milliohms, maximum																

3.2.3 Surface Resistance Test

Stakeholders expressed interest in having this test for comparison with the contact electrical resistance test. A major difference in the ASTM D 257 procedure is the greatly reduced applied pressure on the electrodes. Readings were taken prior to and following ASTM B 117 salt spray testing. A total of 30 test panels undergo testing; five (5) replicates, (2) alloys, (3) conversion coatings. Only a single set of panels was used for surface resistance testing. Surface resistance readings were taken prior to salt spray testing and again, using the same test panels, following 168 hours of salt spray testing.

3.2.3.1 Test Procedure

The following Surface Resistance Test procedure was provided by Raytheon:

1. Use the ASTM D257 Certified Probe made by Electro-Tech Systems (Model 803B)
2. Connect probe to Agilent 34401A multimeter with 4 point hook up and set to 4 point resistance measurements (
3. Figure 14):
   a. Connect black and red leads on probe to the black and red leads on multimeter
   b. Connect green lead to probe case (not color coded) and black terminal of multimeter Input
   c. Set multimeter to 4W resistance mode

Figure 14 – Surface Resistance Test Set-Up

4. Inspect the panel visually for any evidence of surface contamination. Solvent clean the panel using isopropyl alcohol and wipe, with a lint free towel when necessary.
5. Place probe on surface making full contact with coupon and apply medium pressure (less than 20 pounds of pressure with a new probe) in center of probe from above until resistance measurement stabilizes, for at least 15 seconds.

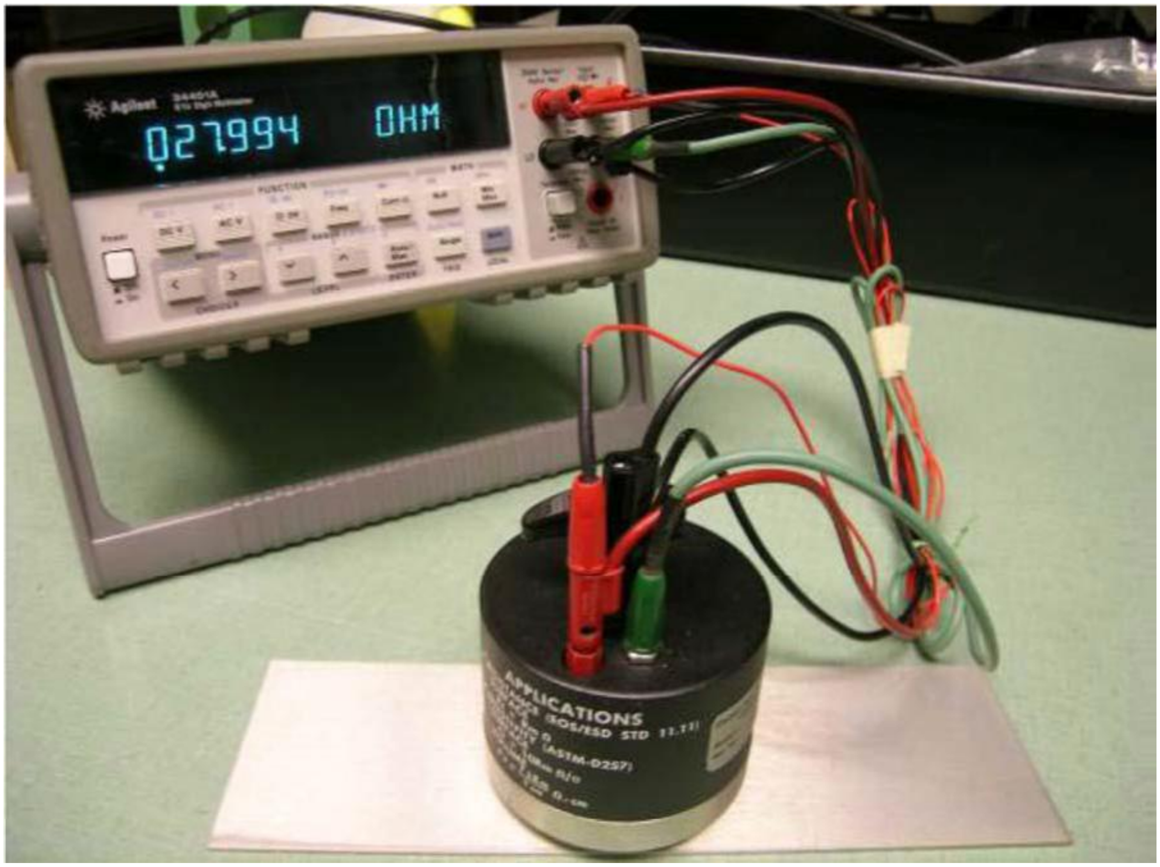


Figure 15 - Surface Resistance Testing

6. Use equation on side of probe to determine that the surface resistance in ohms per square is equal to measured resistance times 10.
7. Record surface resistance value. If required, determine if the test pass or fail in accordance with the criteria established.
8. Depending on size of coupon repeat up to 10 times per coupon testing each side 5 times, less times if coupon is smaller (standard coupon size is roughly 3.5" x 8").

3.2.3.2 Evaluation Procedure

The intent of this testing is to collect the data for each test specimen before and after environmental testing. The surface electrical resistance of the test panels was measured and documented for additional data analysis.

3.2.3.3 Surface Resistance Test Results

Following the completion of the surface resistance testing, it was determined that all of the measurements were well below the 15 ohms per square requirement. There was a small measurable increase in the surface resistance for all combinations post salt spray testing. The Alodine 1200S pretreated test panels showed the lowest increase in surface resistance, followed by the Metalast TCP-HF, with the SurTec 650 test panels showing the greatest increase in surface resistance post salt spray testing. The 5052-H32 alloy test panels showed lower surface resistivity than the 6061-T6 alloy test panels. The following tables contain the results from surface resistance testing.

Table 12 – Surface Resistance Test Results; 5052-H32 Alloy Test Panels

5052-H32: Hex Cr Alodine 1200S																
Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	8.1	8.5	1	8.4	8.1	1	8.0	8.3	1	7.8	8.8	1	8.9	8.9		
2	8.2	8.7	2	8.1	8.4	2	8.0	8.2	2	7.3	8.2	2	8.7	8.1		
3	6.7	8.0	3	7.9	8.3	3	8.3	8.0	3	8.1	8.4	3	8.0	8.0		
4	8.5	8.3	4	7.7	8.3	4	8.2	8.4	4	7.8	8.5	4	7.9	7.9		
5	7.2	8.9	5	8.5	8.3	5	8.1	8.7	5	8.0	8.3	5	8.5	8.2	**Average of All Panels:**	
Average:	**7.7**	**8.5**	**Average:**	**8.1**	**8.3**	**Average:**	**8.1**	**8.3**	**Average:**	**7.8**	**8.4**	**Average:**	**8.4**	**8.2**	**8.0**	**8.3**
															Pre-Salt	**Post-Salt**
5052-H32: SurTec 650																
Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	6.5	7.9	1	6.3	7.7	1	6.6	7.8	1	6.2	8.0	1	6.7	7.9		
2	6.2	7.8	2	6.1	7.9	2	6.3	7.8	2	6.5	7.7	2	6.8	7.7		
3	6.4	7.7	3	6.1	8.0	3	6.6	7.9	3	6.0	7.6	3	6.9	7.9		
4	6.7	7.8	4	6.1	7.7	4	6.6	7.7	4	6.1	7.8	4	5.9	7.9		
5	6.0	7.9	5	6.5	7.7	5	6.8	7.9	5	6.3	7.9	5	6.4	7.6	**Average of All Panels:**	
Average:	**6.4**	**7.8**	**Average:**	**6.2**	**7.8**	**Average:**	**6.6**	**7.8**	**Average:**	**6.2**	**7.8**	**Average:**	**6.5**	**7.8**	**6.4**	**7.8**
															Pre-Salt	**Post-Salt**
5052-H32: Metalast-TCP-HF																
Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	6.1	7.0	1	5.9	7.3	1	6.0	6.9	1	6.3	7.4	1	6.0	6.9		
2	6.4	7.0	2	5.9	7.0	2	5.9	6.8	2	6.2	7.1	2	6.0	6.9		
3	6.3	7.2	3	6.4	7.1	3	6.1	6.9	3	6.3	7.0	3	6.1	6.8		
4	6.4	6.9	4	6.2	7.1	4	6.1	6.7	4	6.1	7.2	4	6.2	7.2		
5	5.9	7.3	5	6.3	7.1	5	6.0	7.2	5	6.3	6.9	5	6.1	7.0	**Average of All Panels:**	
Average:	**6.2**	**7.1**	**Average:**	**6.1**	**7.1**	**Average:**	**6.0**	**6.9**	**Average:**	**6.2**	**7.1**	**Average:**	**6.1**	**7.0**	**6.1**	**7.0**
															Pre-Salt	**Post-Salt**
ASTM D257 - Model 803B Probe																
****All Measurements are in Ohms/Square****																

Table 13 – Surface Resistance Test Results; 6061-T6 Alloy Test Panels

6061-T6: Hex Cr Alodine 1200S

Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	5.8	6.5	1	6.1	6.6	1	6.0	7.0	1	6.2	6.2	1	5.9	6.8		
2	6.0	6.7	2	6.8	6.7	2	6.1	6.5	2	6.1	6.5	2	5.9	6.7		
3	5.9	6.8	3	6.4	6.8	3	6.0	6.4	3	6.2	6.6	3	6.0	6.4		
4	6.1	6.6	4	6.2	6.8	4	6.0	6.8	4	6.3	6.7	4	5.8	6.2		
5	5.8	6.7	5	5.9	6.2	5	6.0	6.2	5	6.0	6.8	5	5.7	6.8	**Average of All Panels:**	
Average:	**5.9**	**6.7**	**Average:**	**6.3**	**6.6**	**Average:**	**6.0**	**6.6**	**Average:**	**6.2**	**6.6**	**Average:**	**5.9**	**6.6**	**6.0**	**6.6**
															Pre-Salt	**Post-Salt**

6061-T6: SurTec 650

Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	6.1	7.5	1	5.8	7.4	1	5.9	7.3	1	5.4	7.7	1	5.5	7.6		
2	5.8	7.4	2	5.1	7.2	2	6.0	7.4	2	5.4	7.4	2	5.3	7.5		
3	5.6	7.4	3	5.4	7.4	3	5.3	7.5	3	5.6	7.3	3	5.7	7.4		
4	5.7	7.3	4	5.6	7.2	4	6.1	7.4	4	5.6	7.5	4	6.1	7.5		
5	5.8	7.6	5	5.9	7.2	5	5.7	7.4	5	5.2	7.6	5	5.4	7.2	**Average of All Panels:**	
Average:	**5.8**	**7.4**	**Average:**	**5.6**	**7.3**	**Average:**	**5.8**	**7.4**	**Average:**	**5.4**	**7.5**	**Average:**	**5.6**	**7.4**	**5.6**	**7.4**
															Pre-Salt	**Post-Salt**

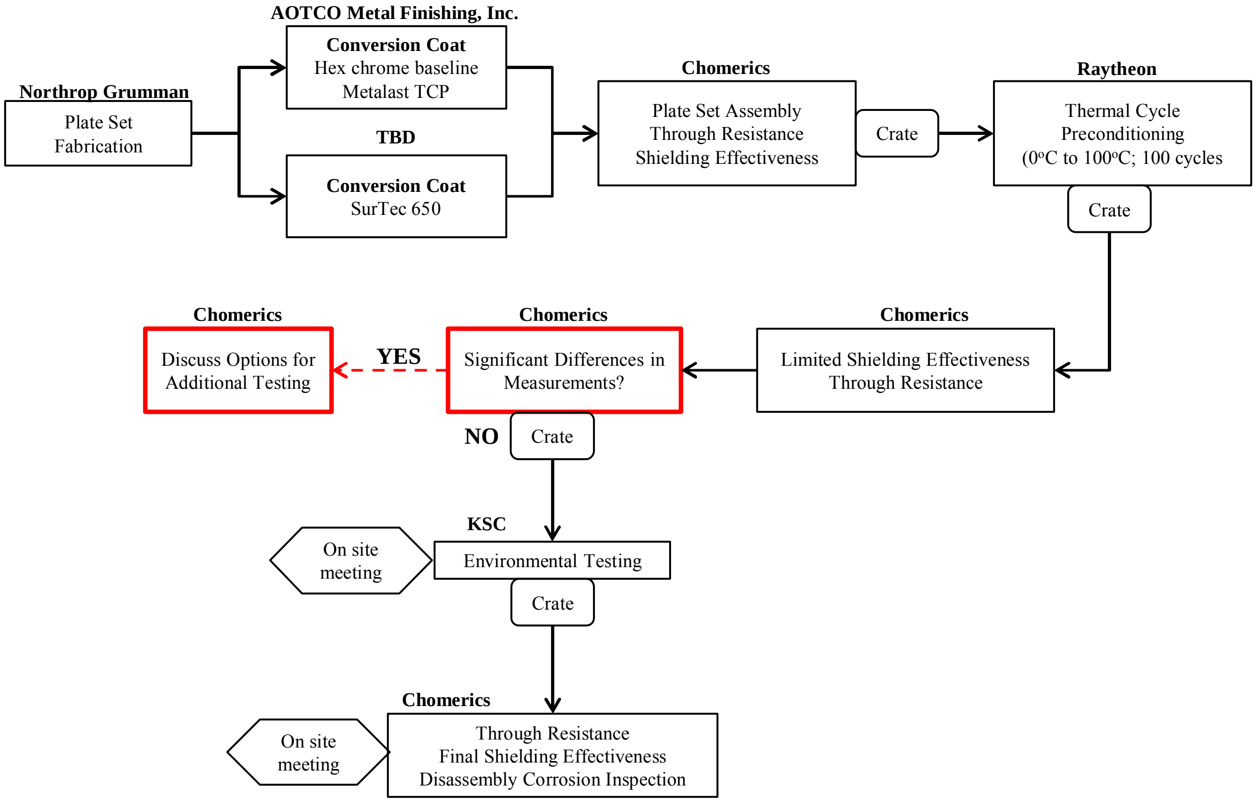
6061-T6: Metalast-TCP-HF

Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	5.4	7.0	1	5.1	6.5	1	4.9	6.9	1	4.9	6.2	1	5.6	6.1		
2	5.4	6.8	2	4.9	7.1	2	4.9	6.9	2	5.0	6.8	2	5.3	6.0		
3	5.2	7.2	3	5.3	6.7	3	5.0	6.8	3	4.8	6.9	3	5.2	6.3		
4	5.3	6.7	4	5.4	6.7	4	5.1	6.7	4	5.3	6.2	4	5.4	6.4		
5	5.1	7.3	5	5.6	7.2	5	5.0	6.6	5	5.4	7.1	5	5.1	6.2	**Average of All Panels:**	
Average:	**5.3**	**7.0**	**Average:**	**5.3**	**6.8**	**Average:**	**5.0**	**6.8**	**Average:**	**5.1**	**6.6**	**Average:**	**5.3**	**6.2**	**5.2**	**6.7**
															Pre-Salt	**Post-Salt**

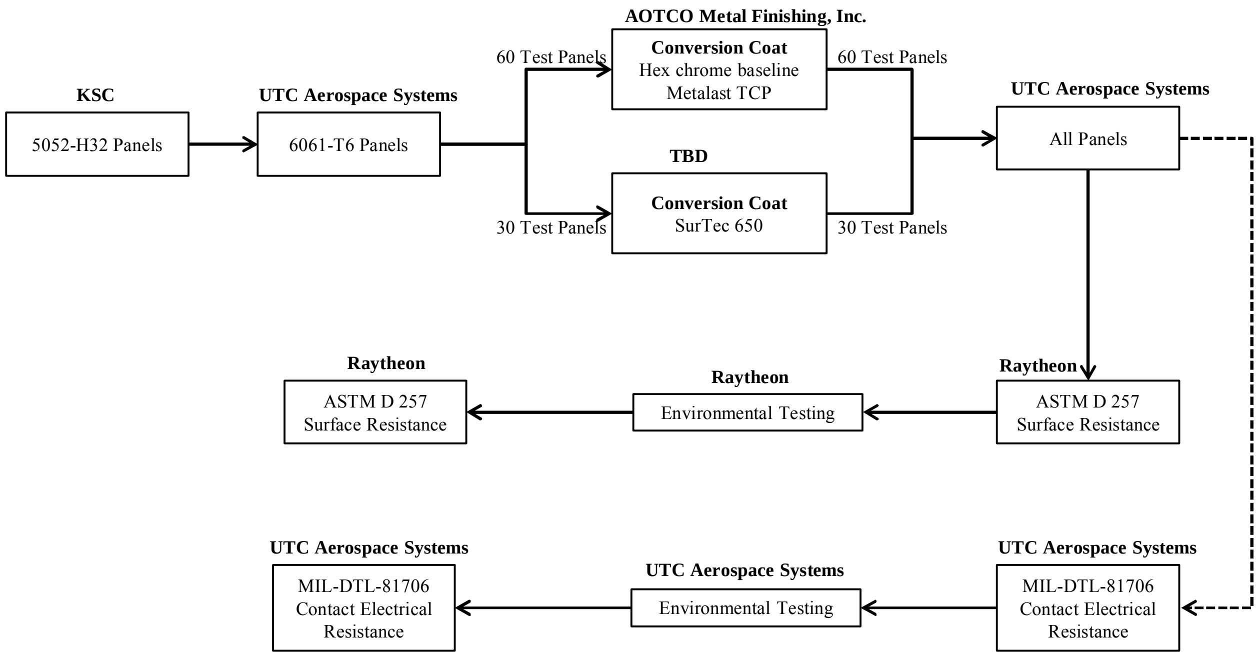
ASTM D257 - Model 803B Probe

****All Measurements are in Ohms/Square****

Appendix A – Plate Set Testing Task Flow

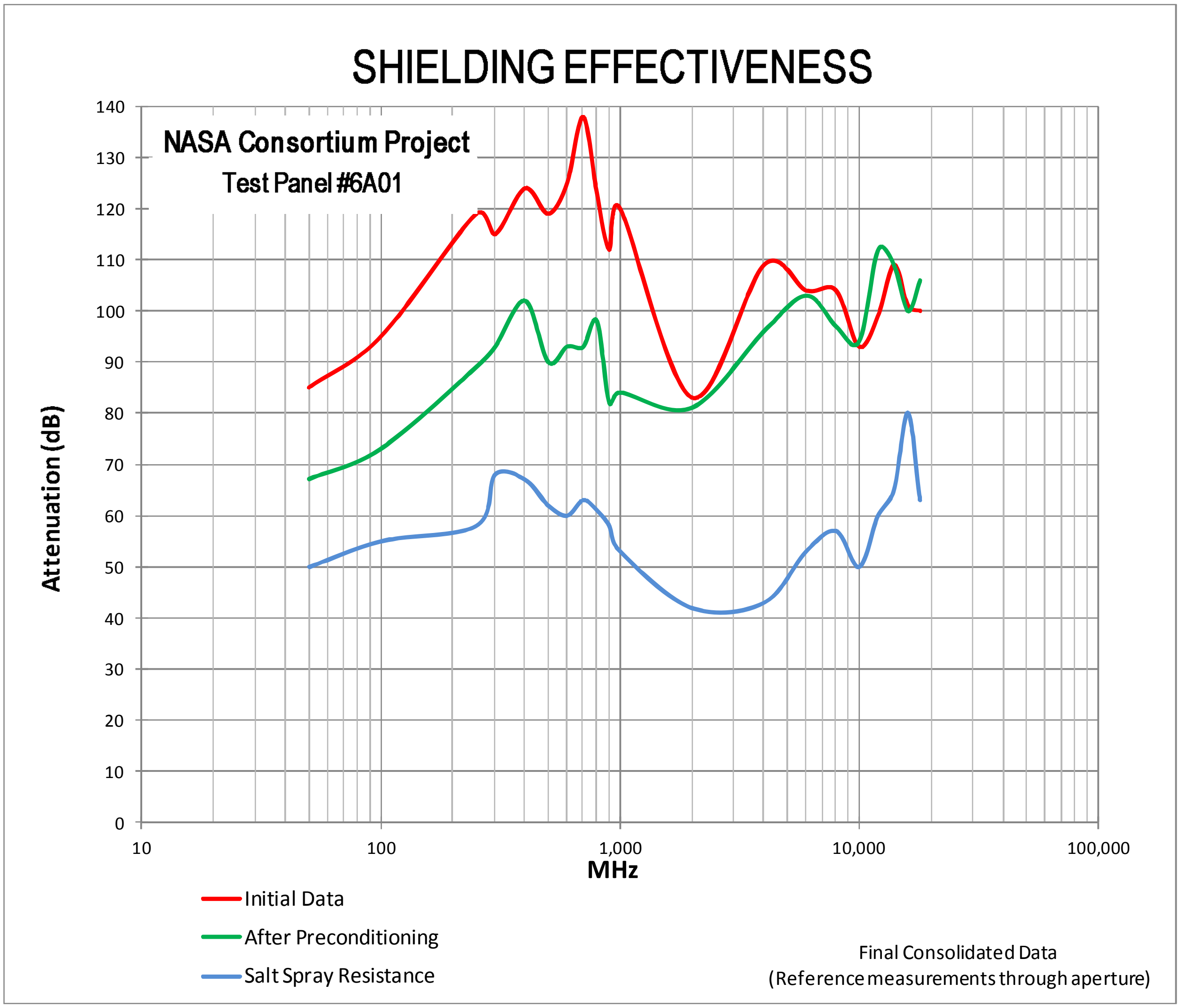


Appendix B – Test Panel Testing Task Flow

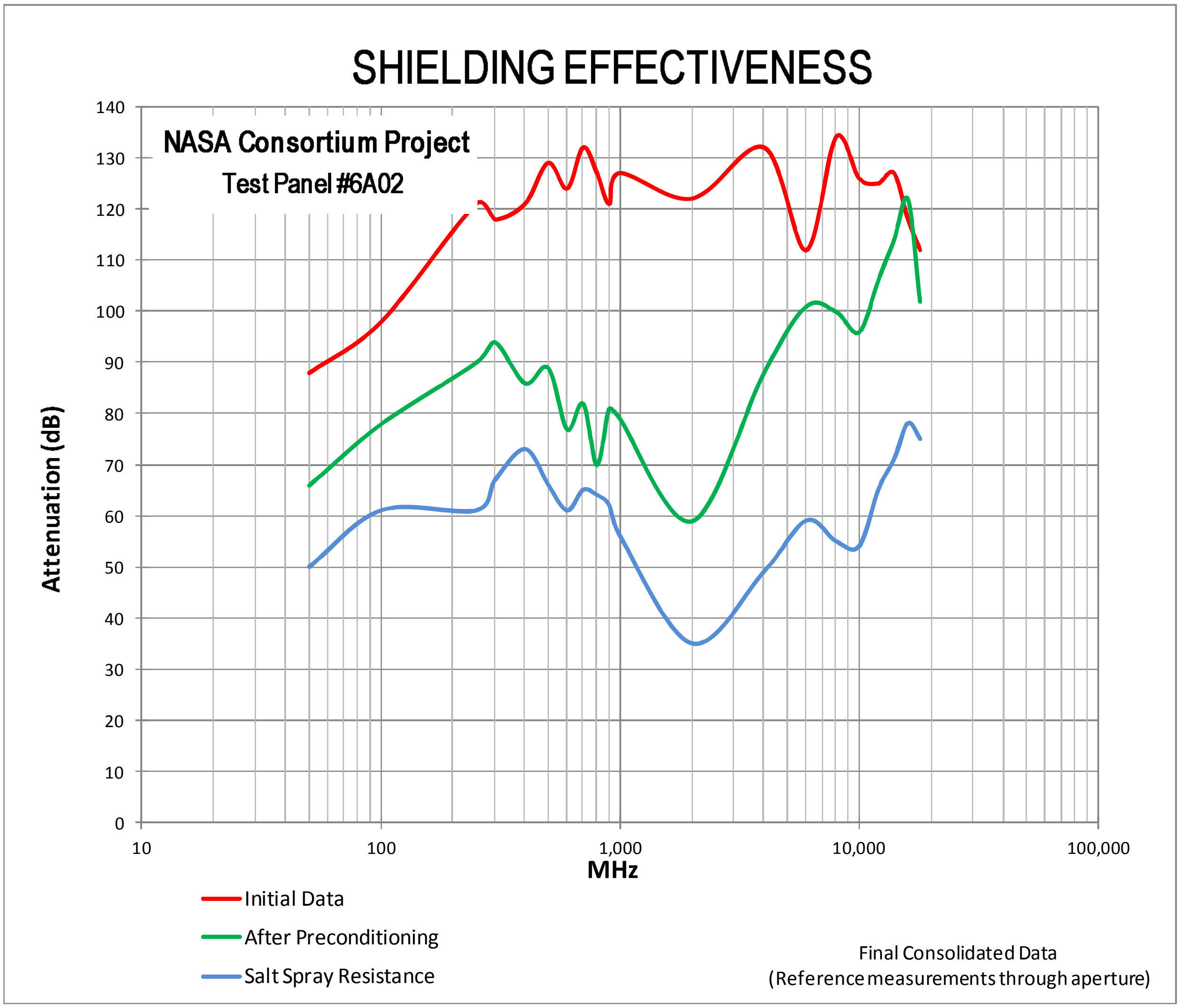


Appendix C – Shielding Effectiveness Results – Salt Spray Testing

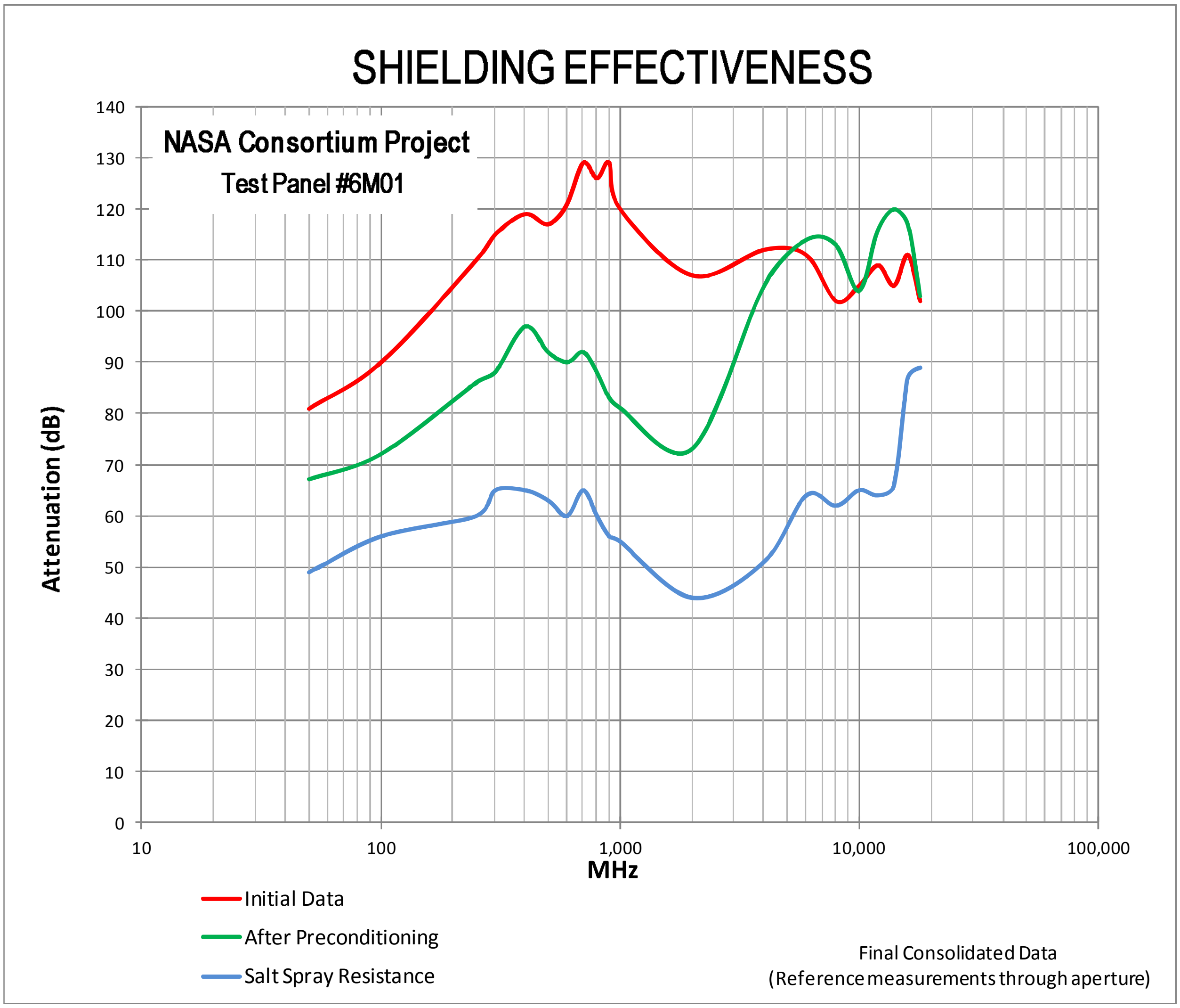
Alodine 1200S – 6061-T6 plate #1



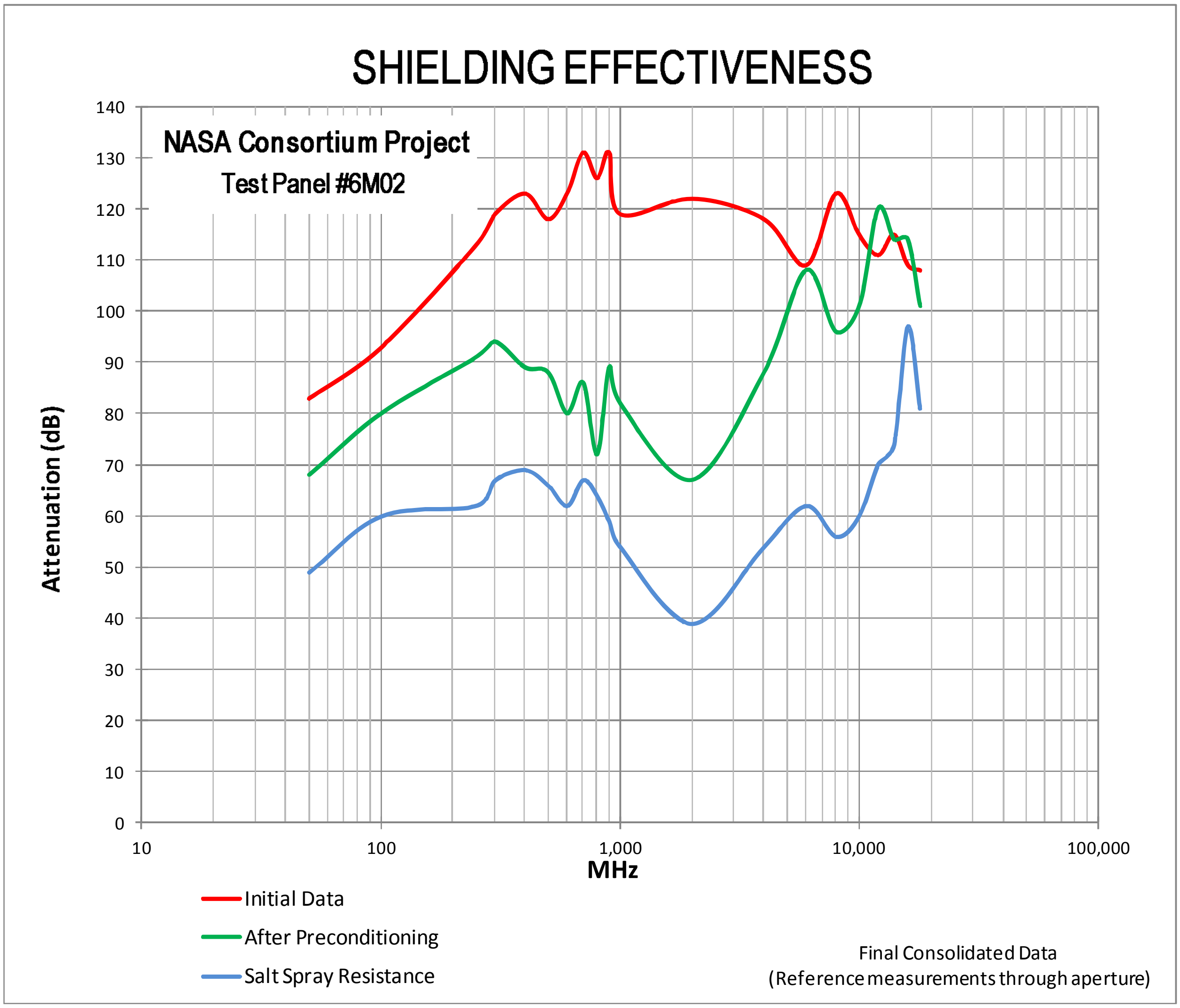
Alodine 1200S – 6061-T6 plate #2



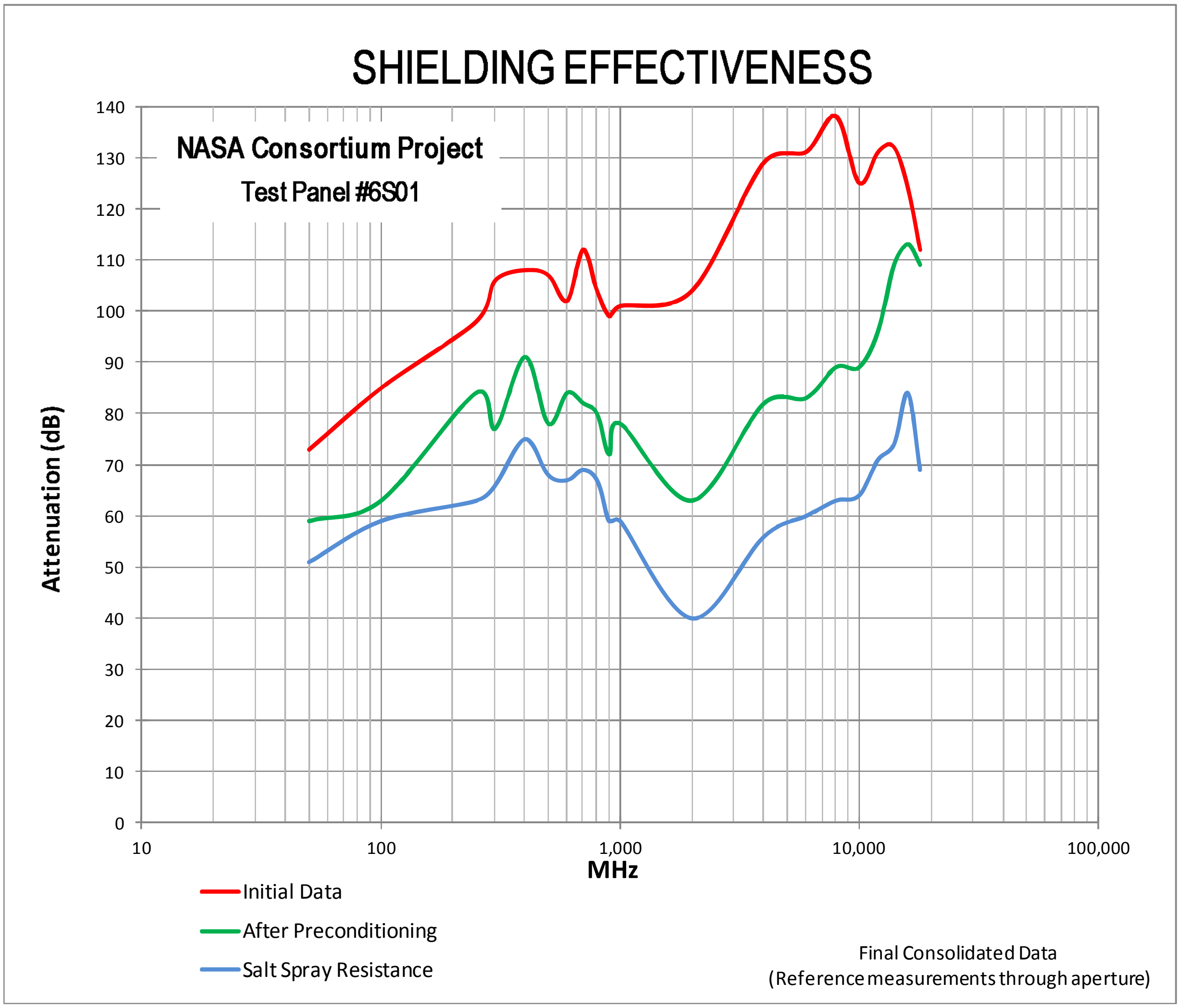
Metalast TCP – 6061-T6 plate #1



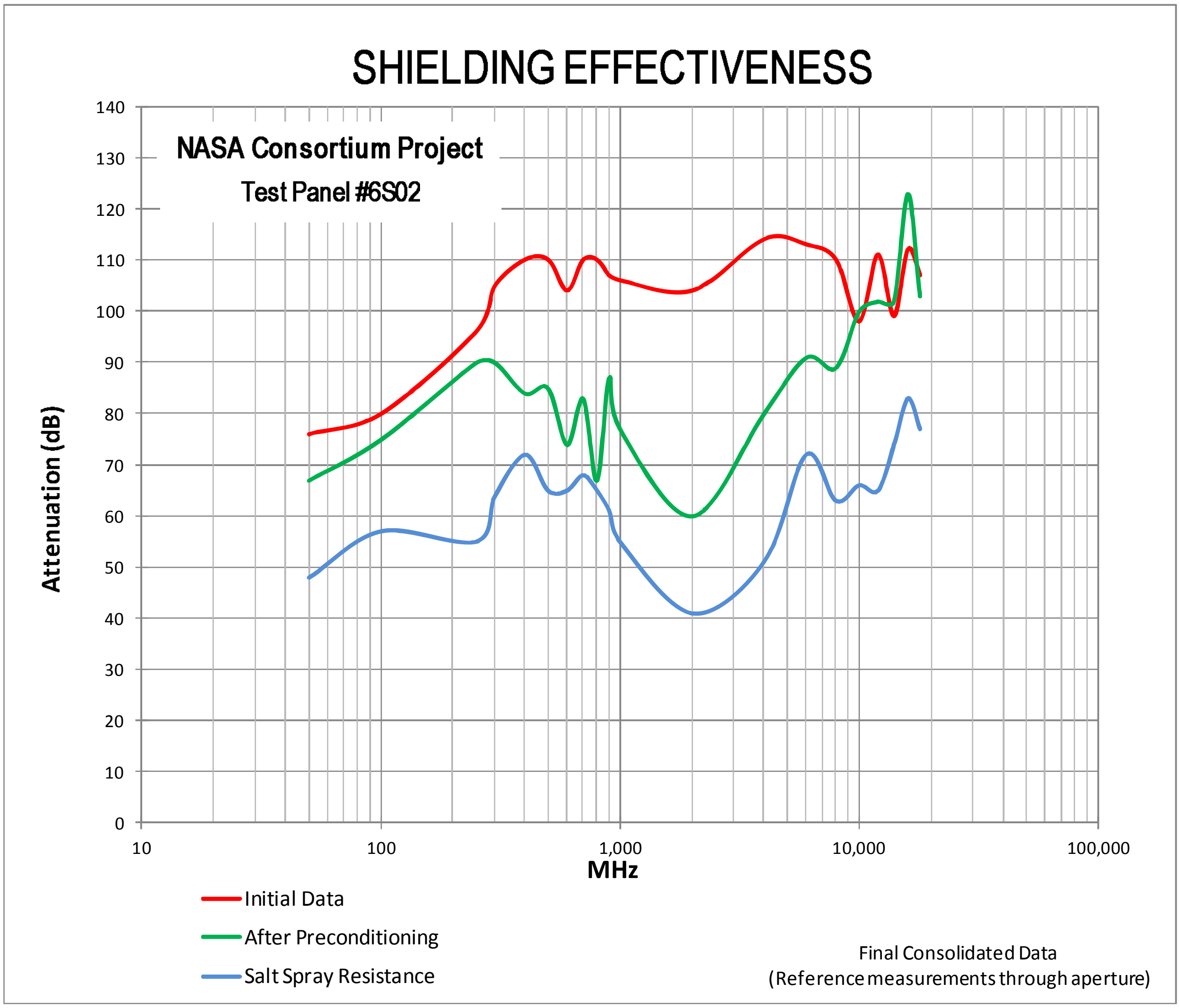
Metalast TCP – 6061-T6 plate #2



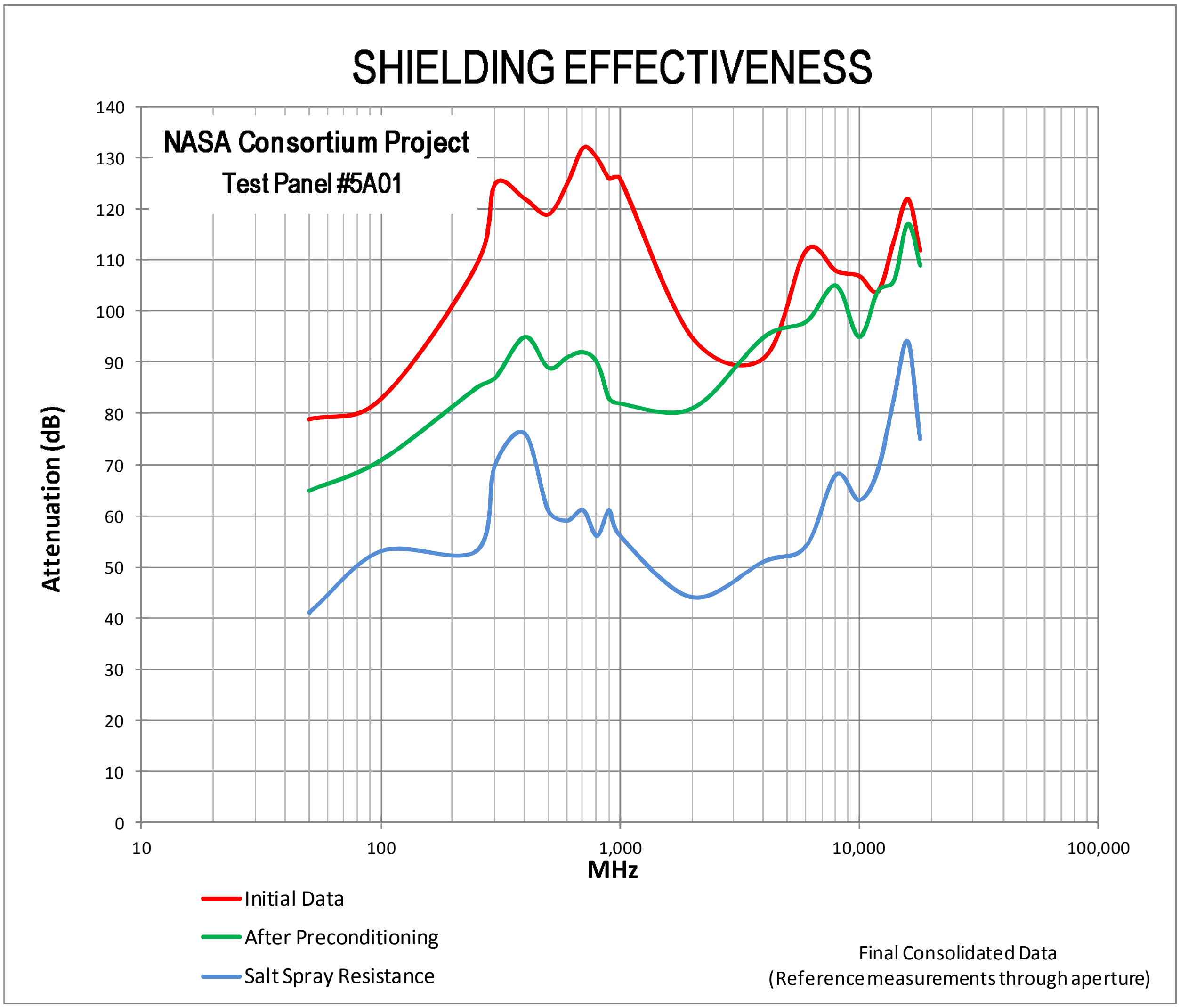
SurTec 650 – 6061-T6 plate #1



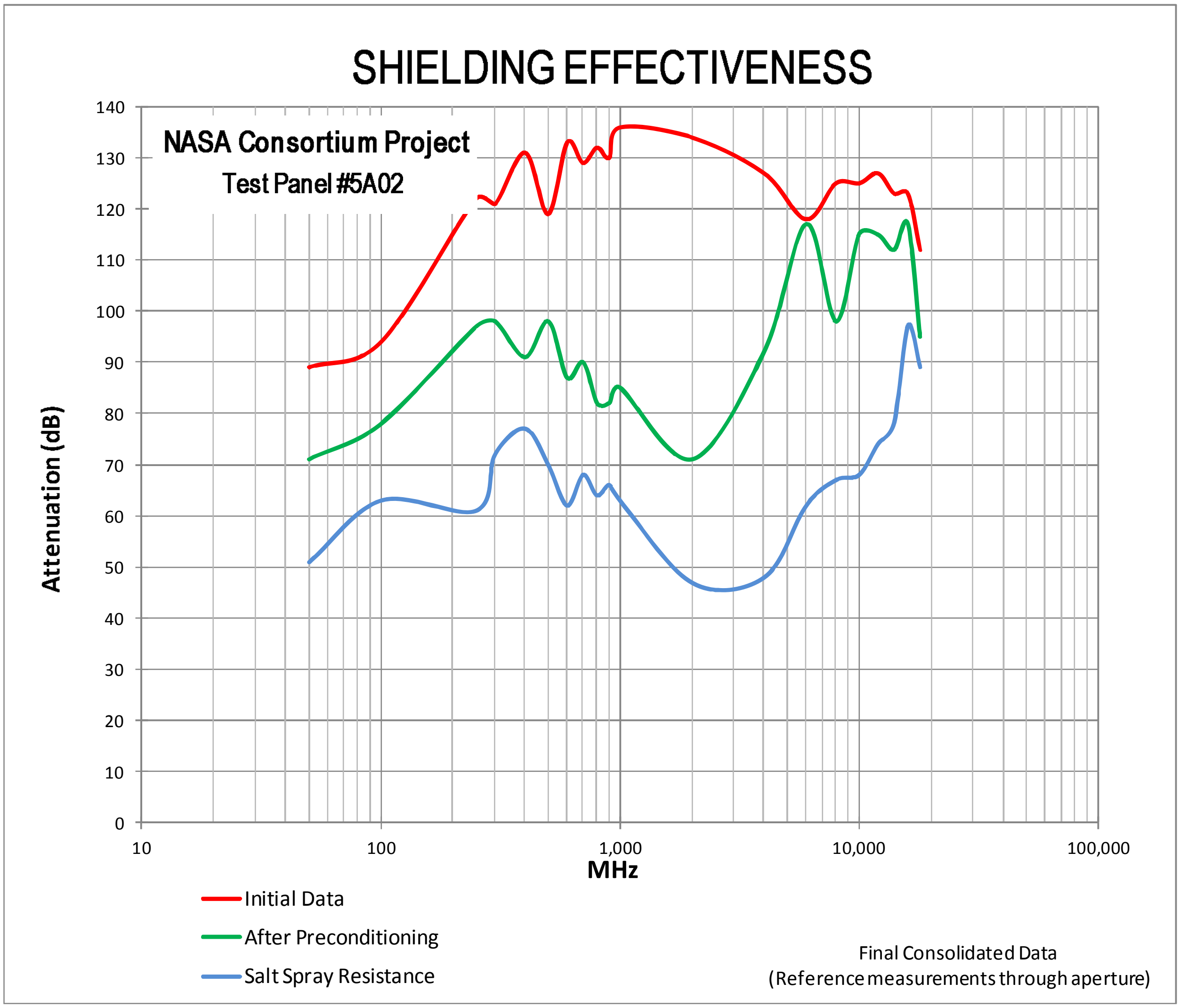
SurTec 650 – 6061-T6 plate #2



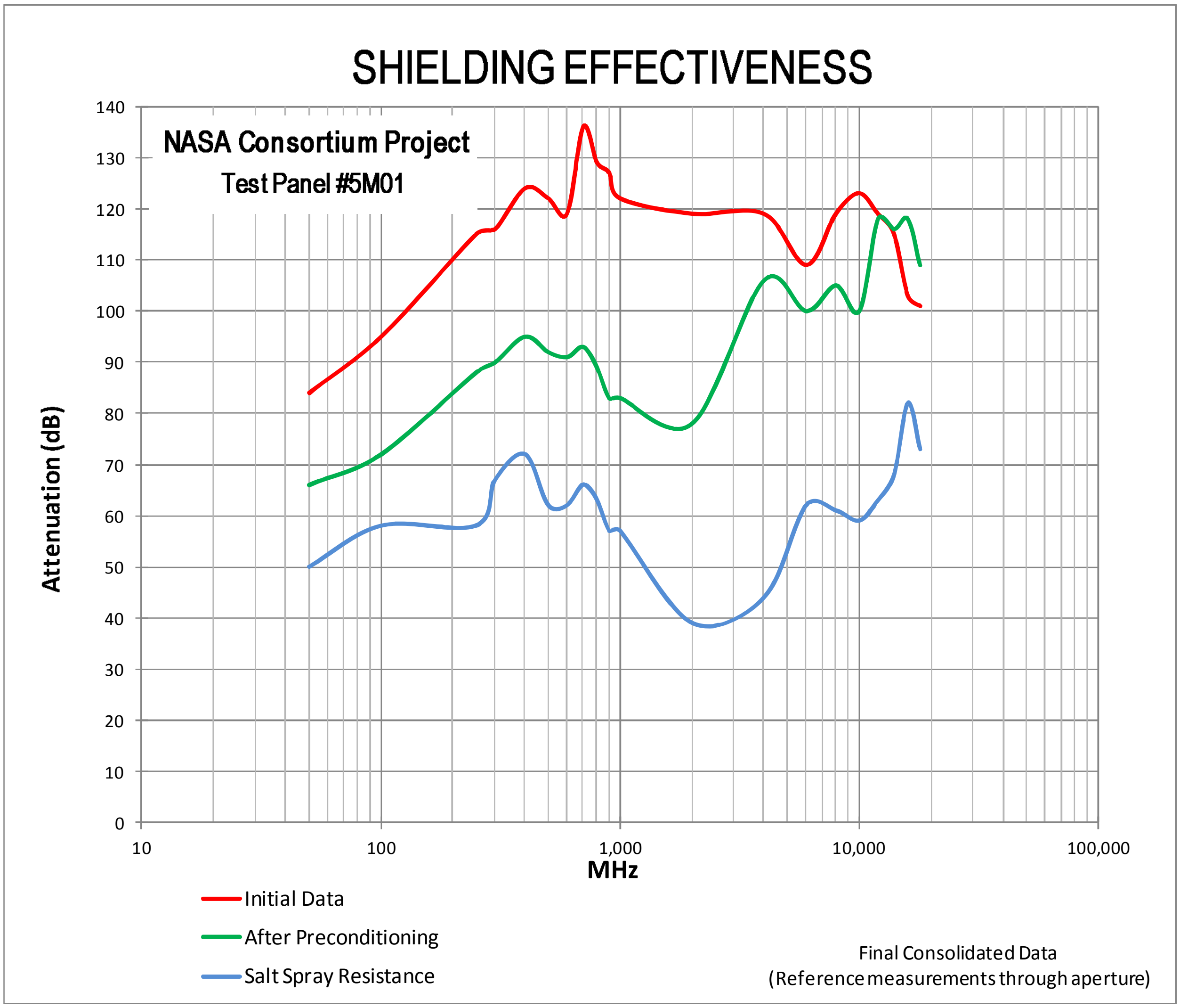
Alodine 1200S – 5052-H32 plate #1



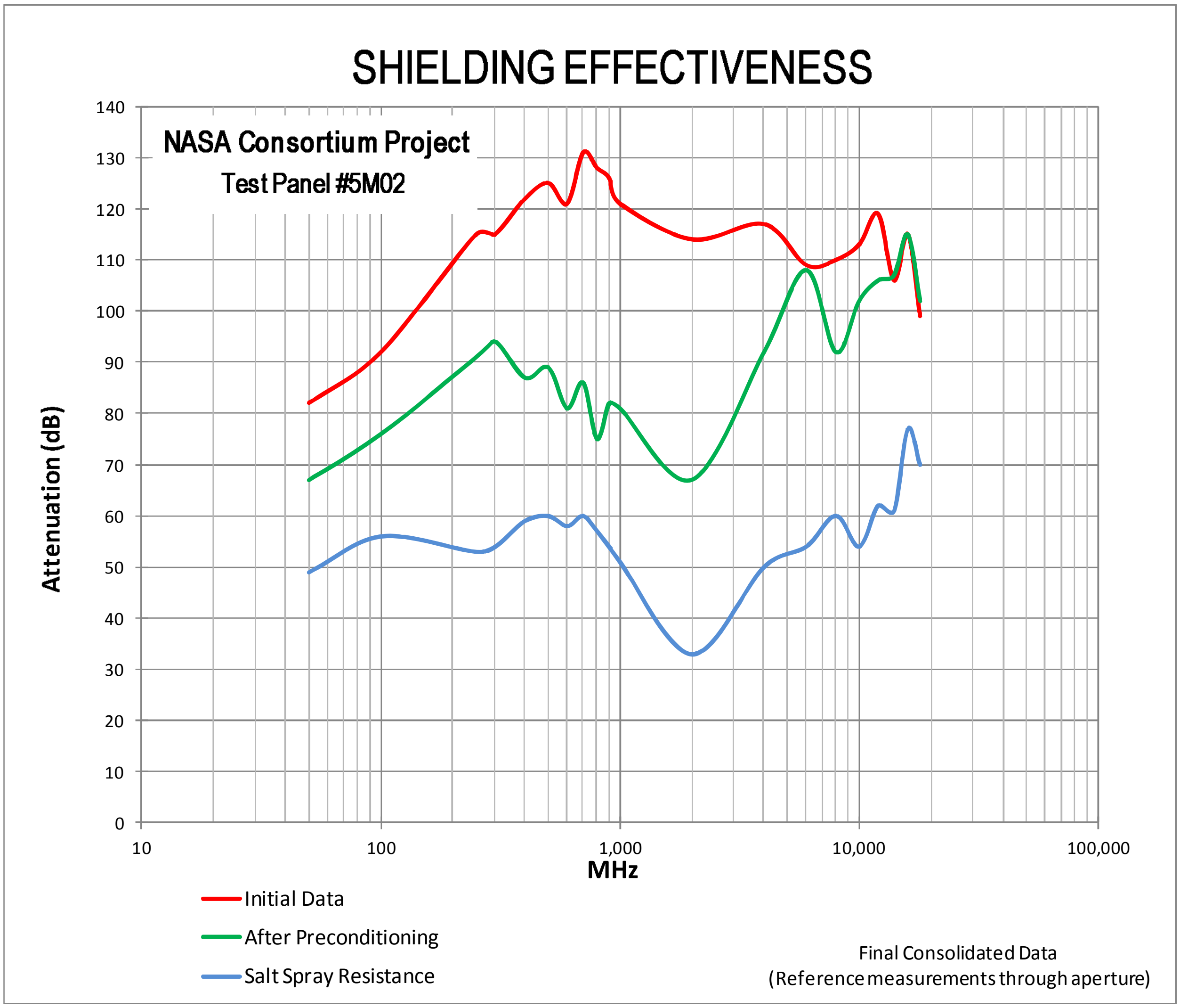
Alodine 1200S – 5052-H32 plate #2



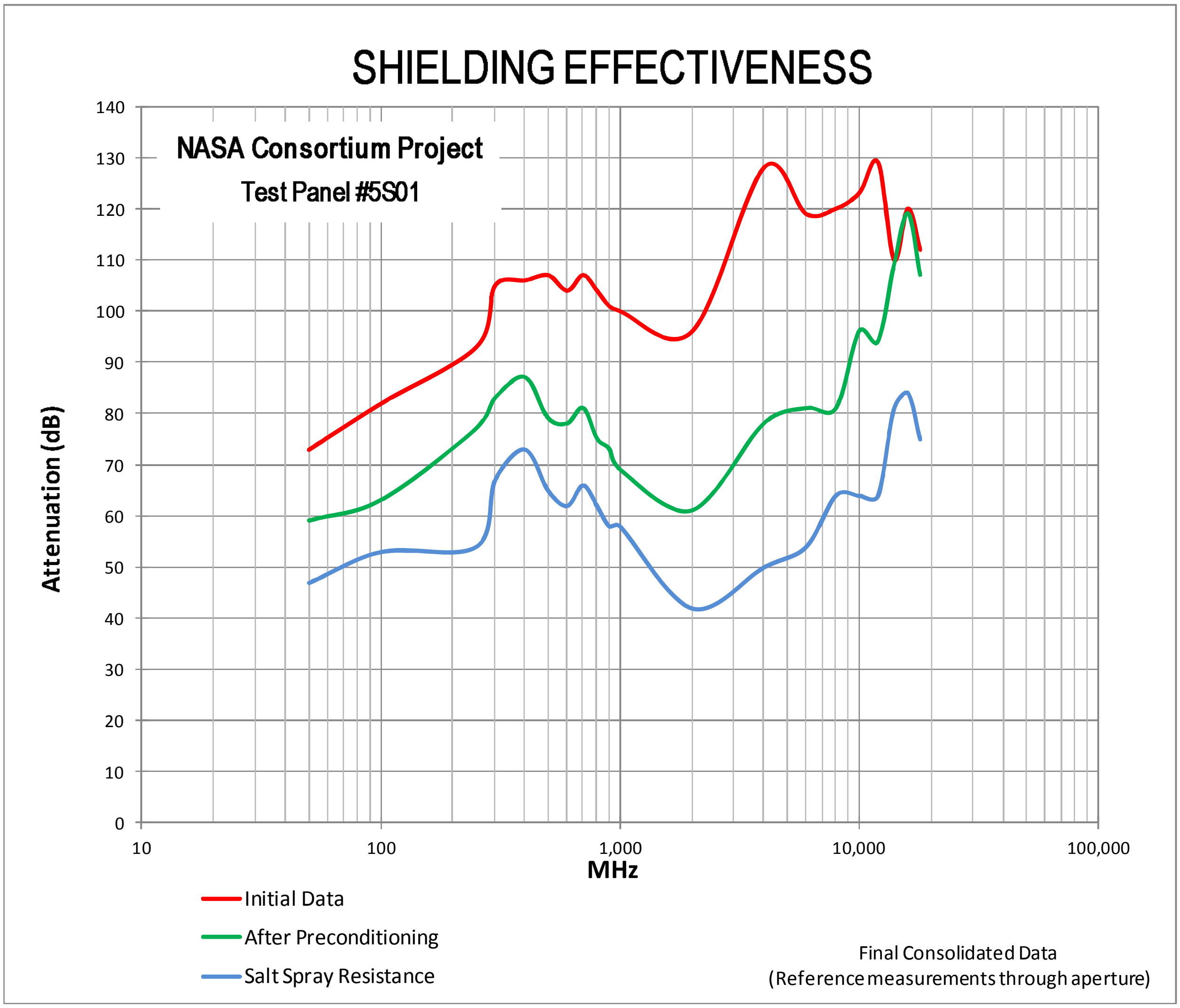
Metalast TCP – 5052-H32 plate #1



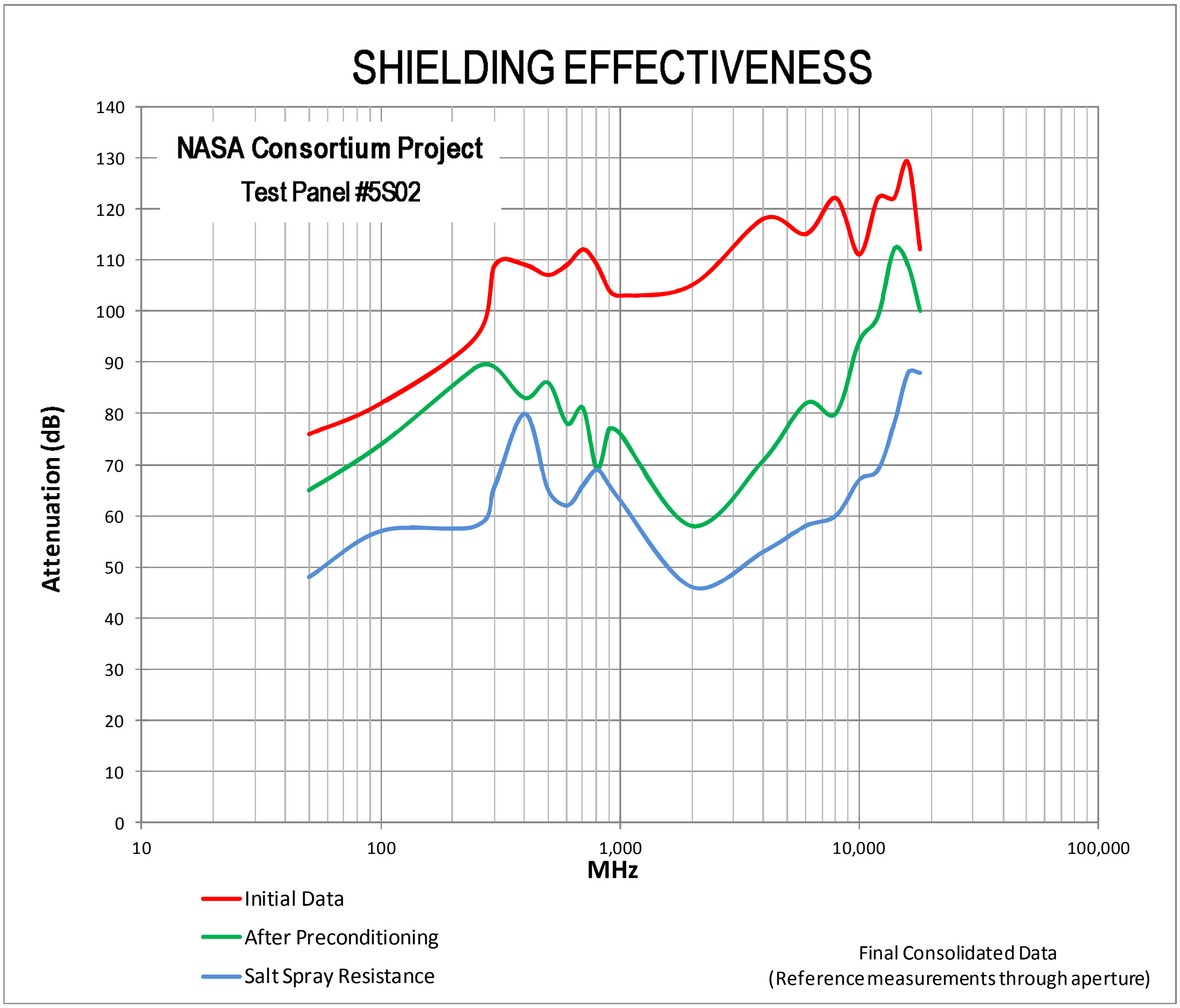
Metalast TCP – 5052-H32 plate #2



SurTec 650 – 5052-H32 plate #1

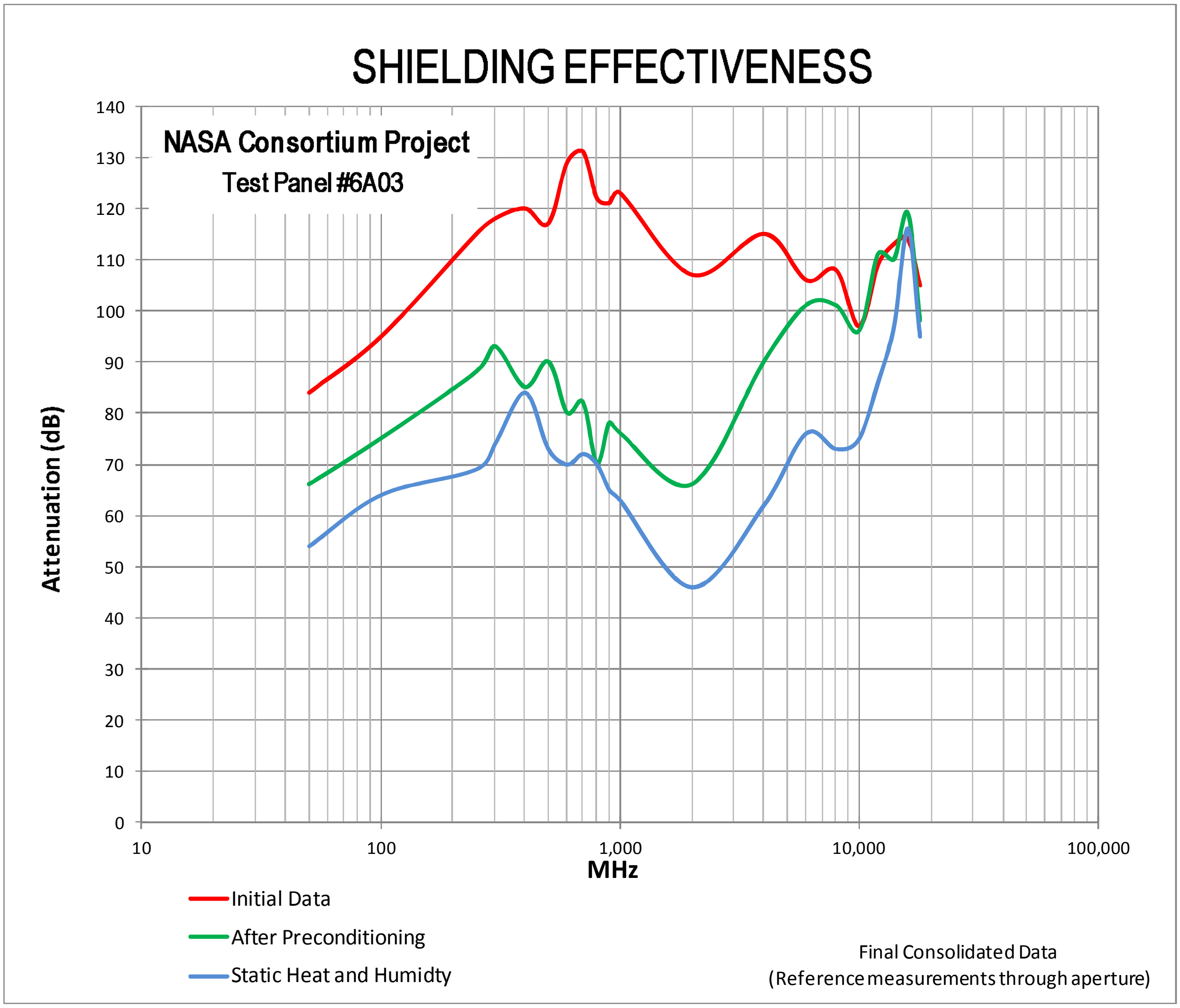


SurTec 650 – 5052-H32 plate #2

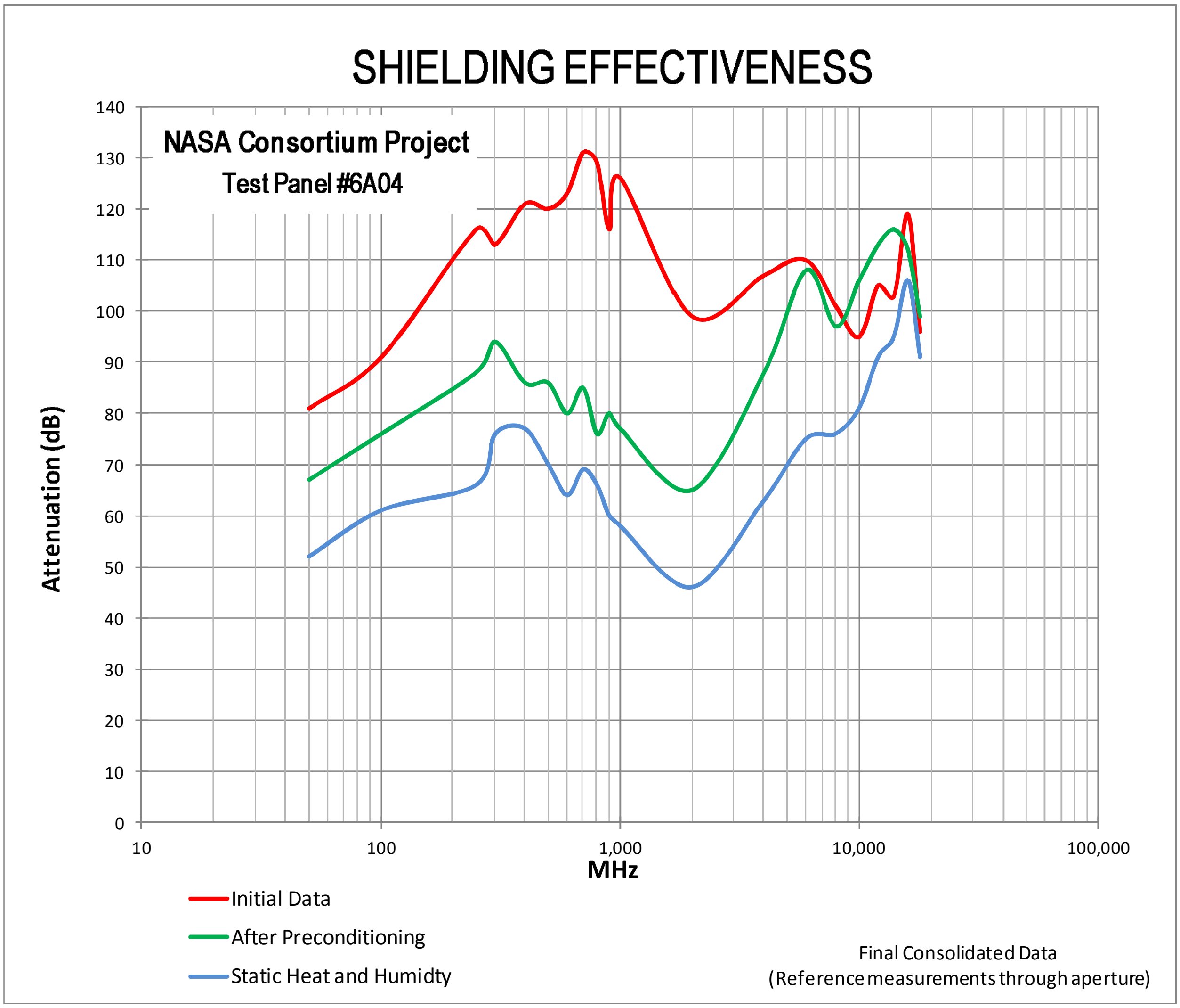


Appendix D – Shielding Effectiveness Results – Static Heat and Humidity Testing

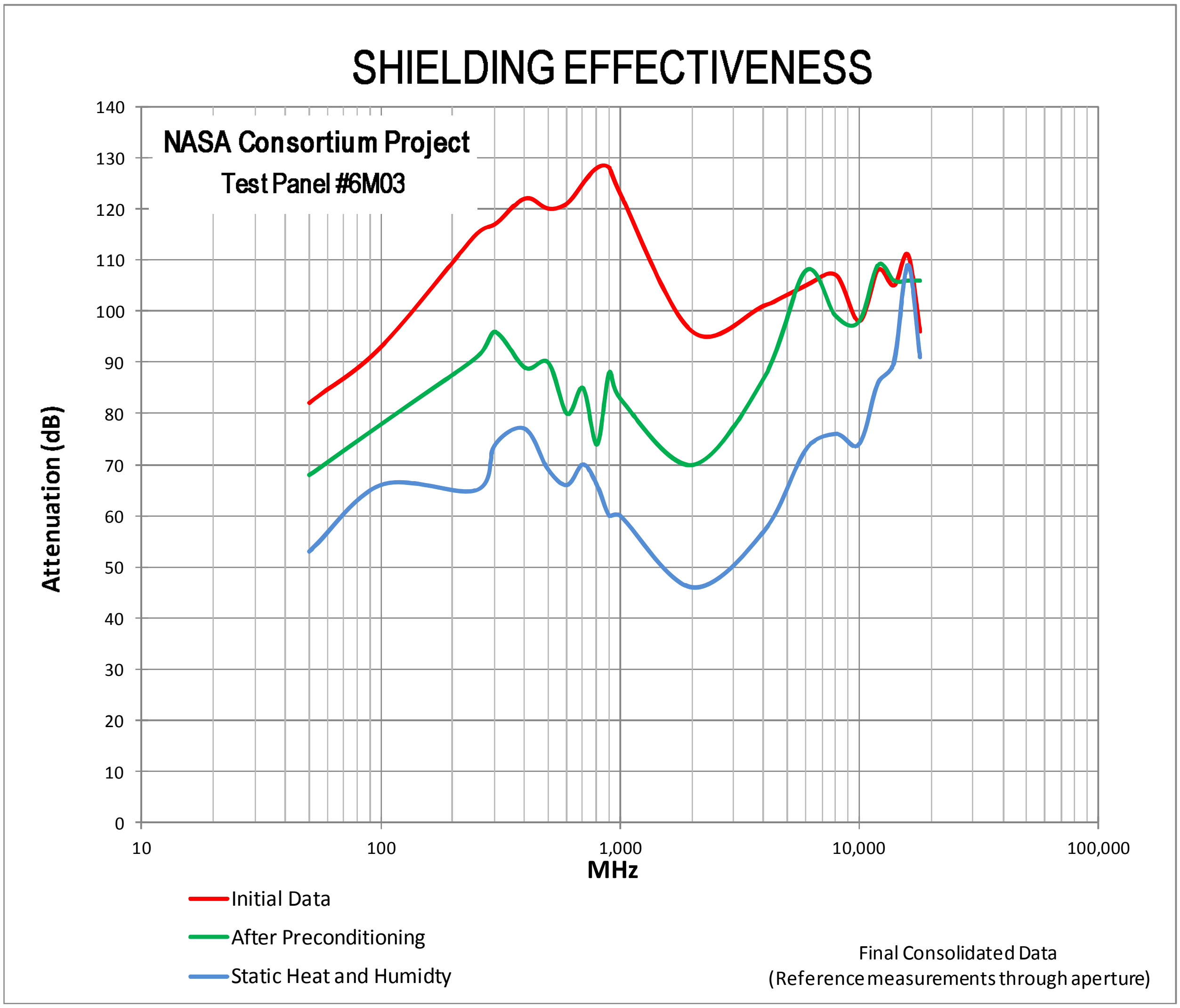
Alodine 1200S – 6061-T6 plate #3



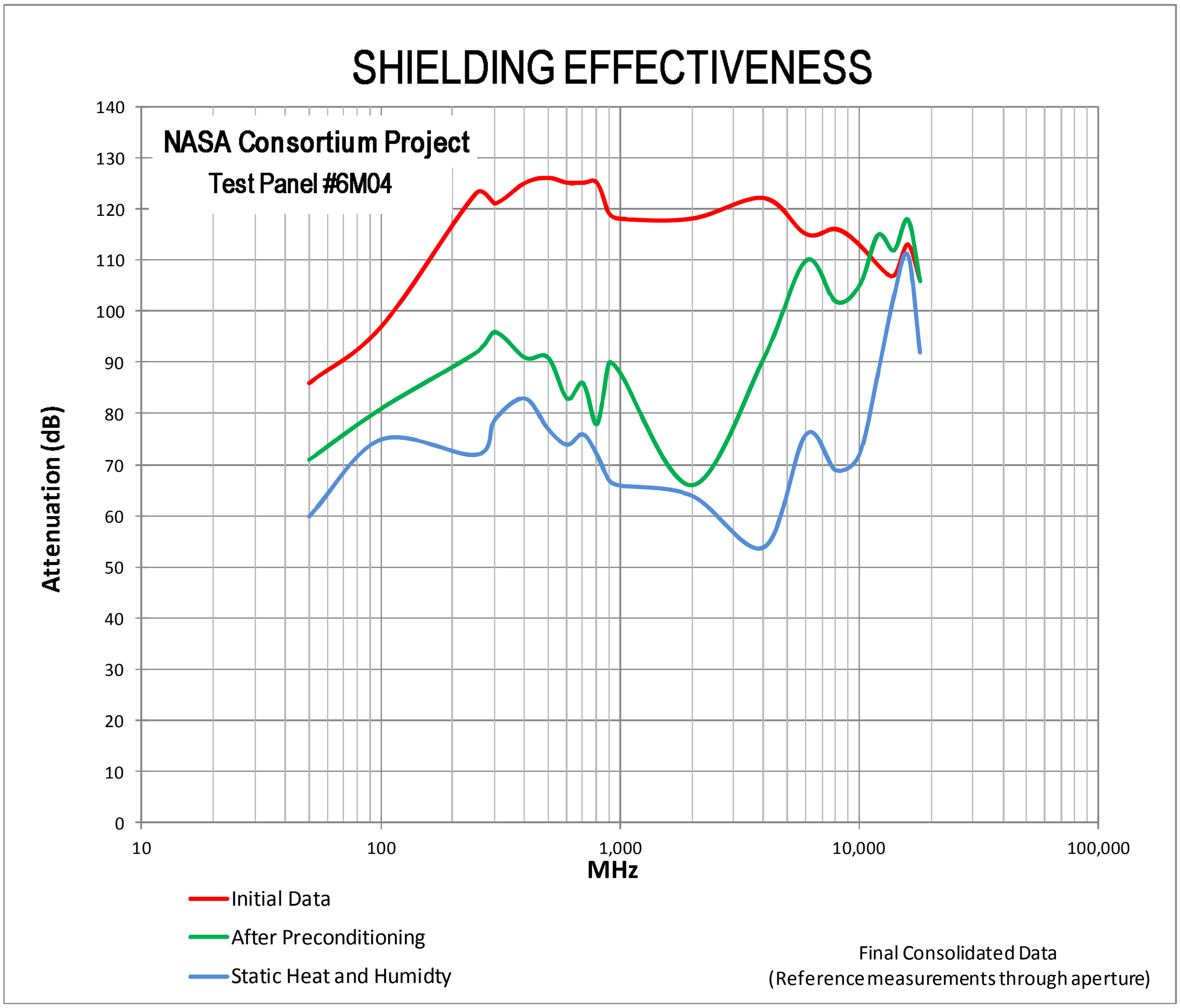
Alodine 1200S – 6061-T6 plate #4



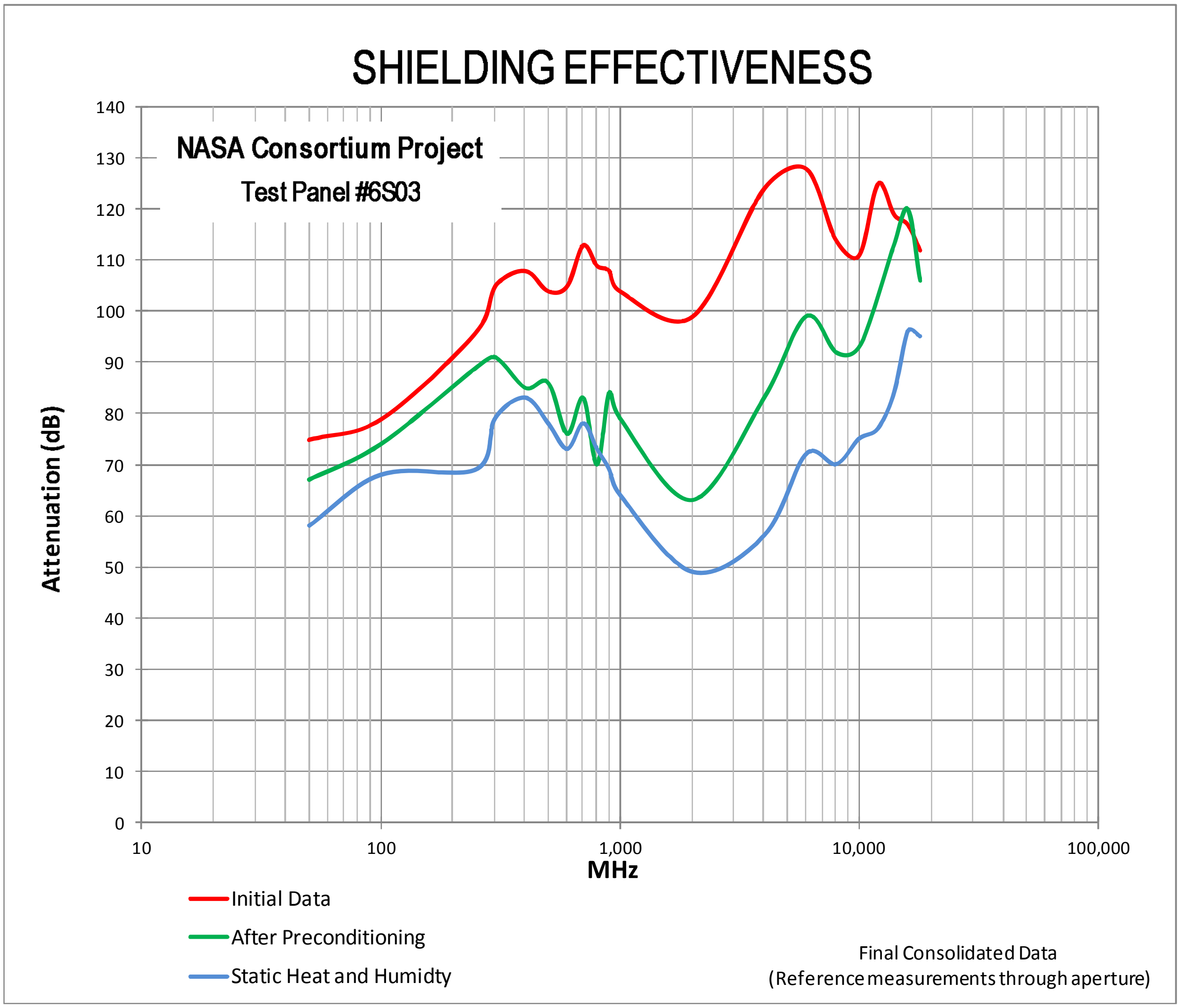
Metalast TCP – 6061-T6 plate #3



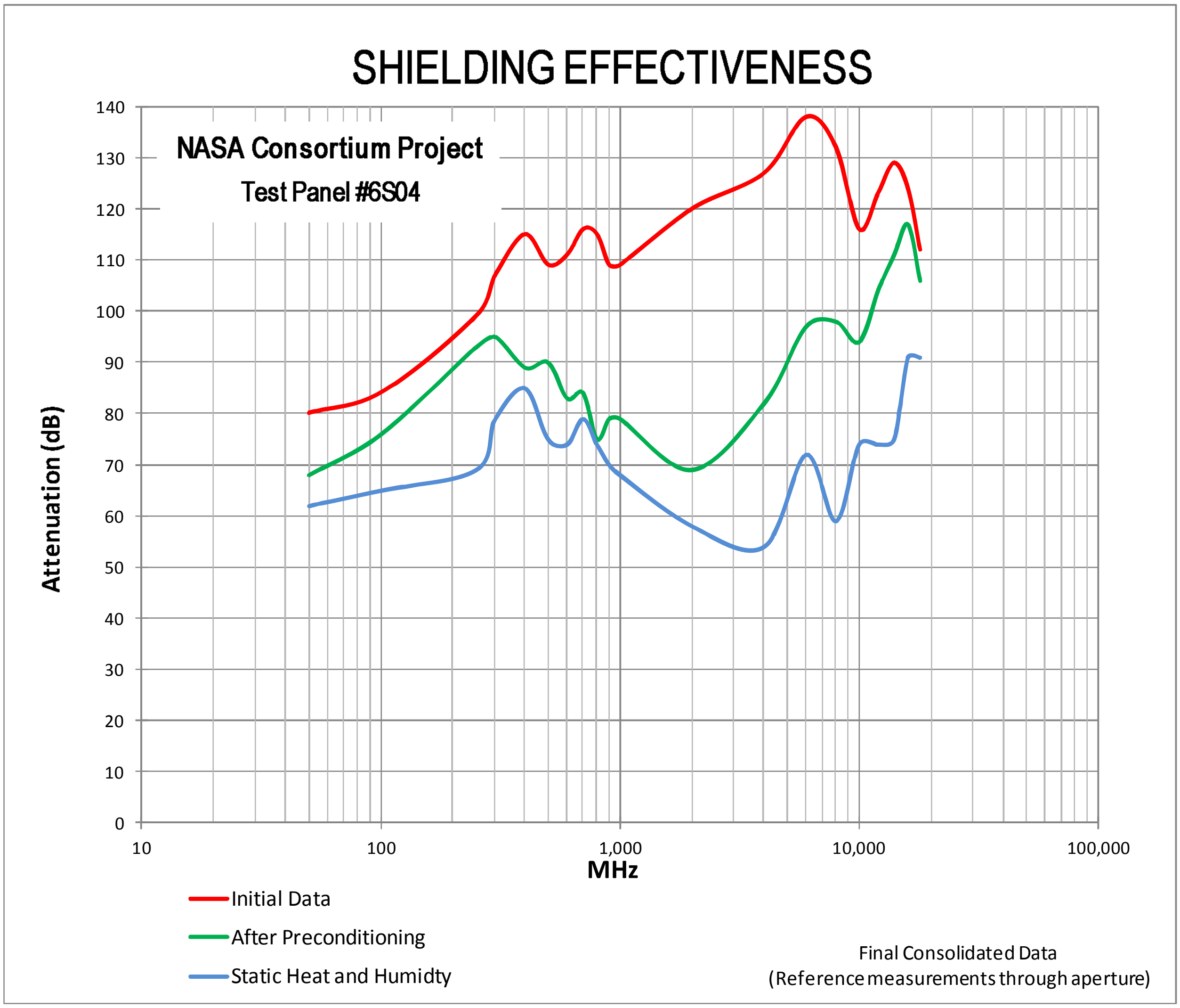
Metalast TCP – 6061-T6 plate #4



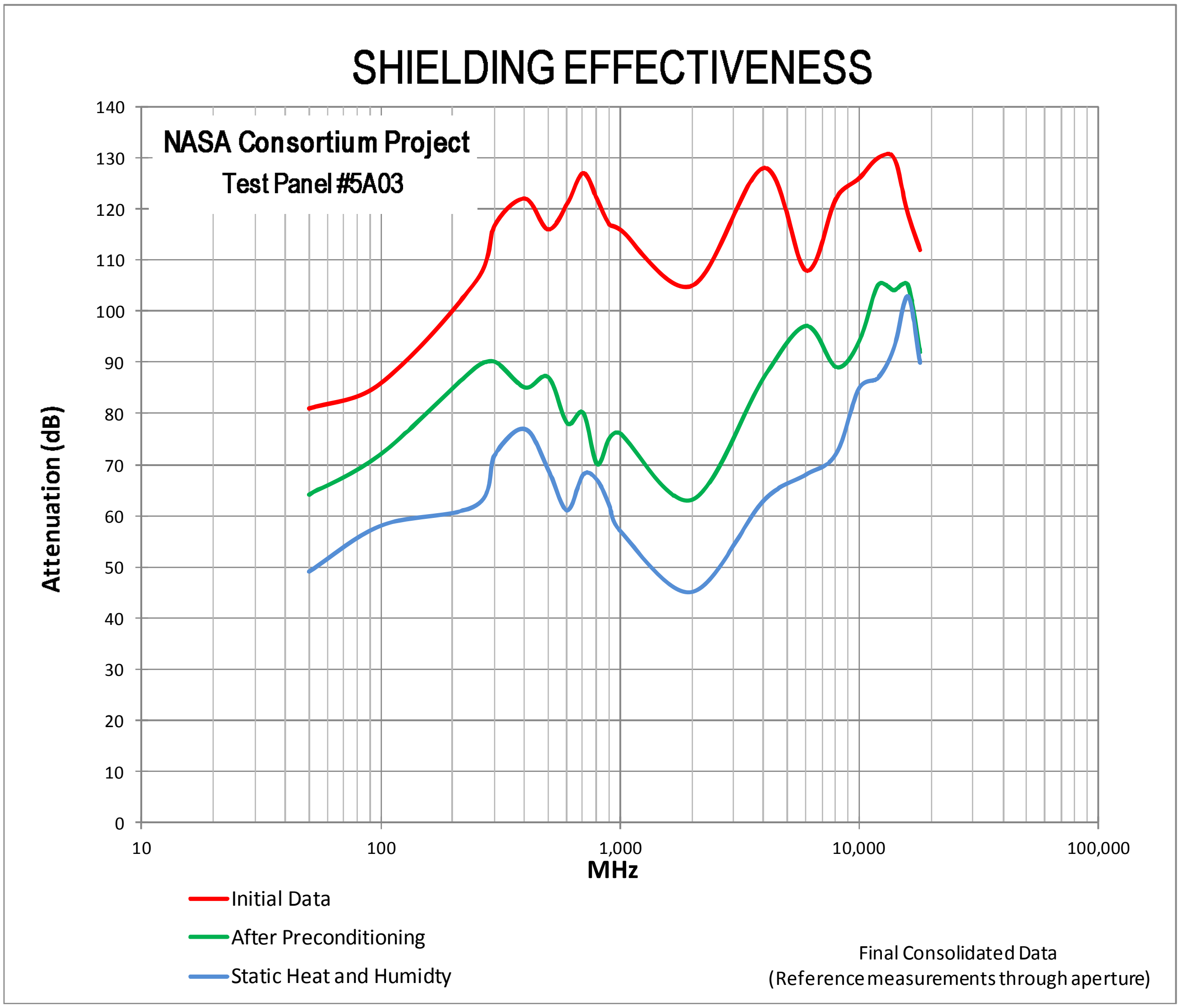
SurTec 650 – 6061-T6 plate #3



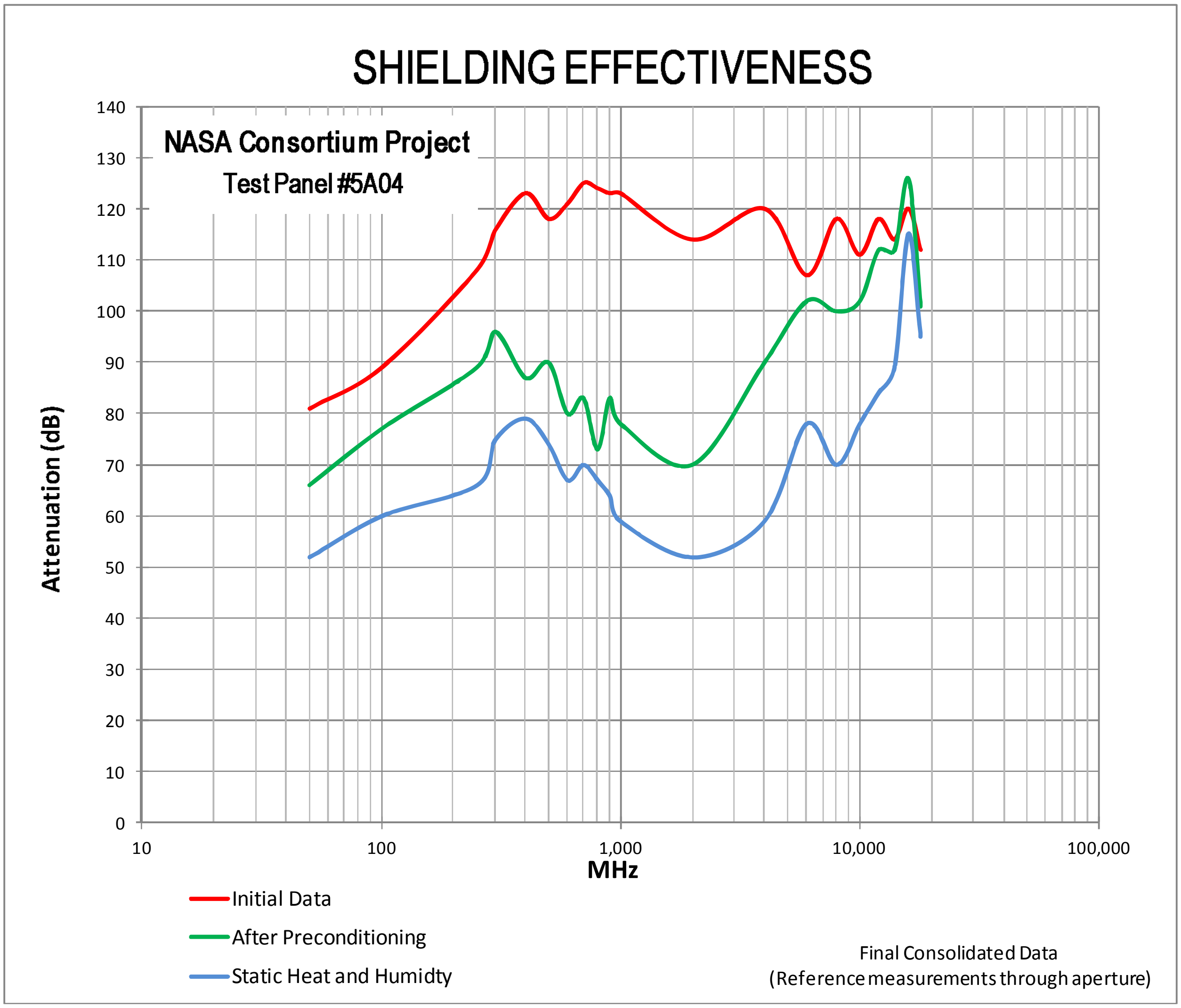
SurTec 650 – 6061-T6 plate #4



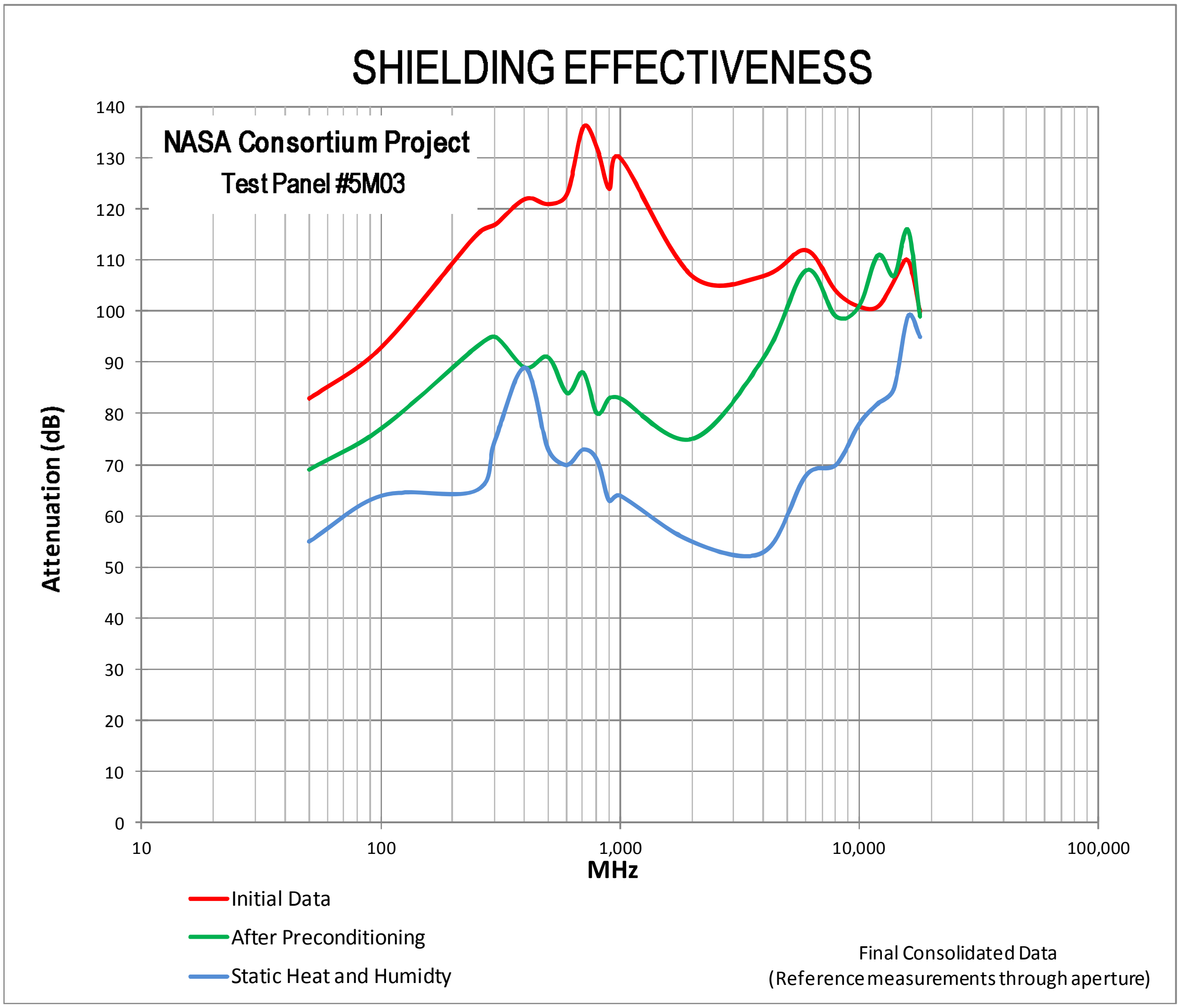
Alodine 1200S 5052-H32 plate #3



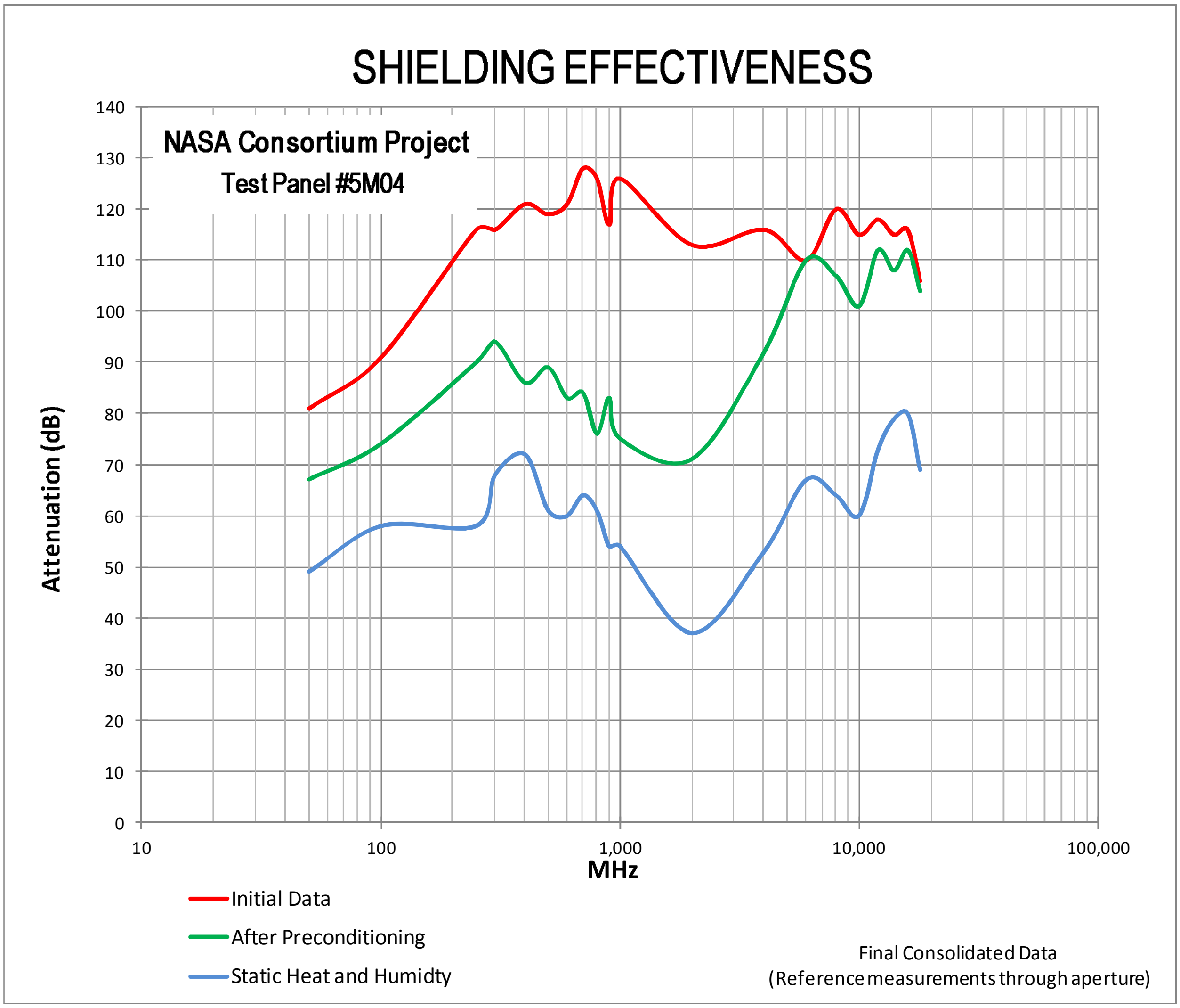
Alodine 1200S 5052-H32 plate #4



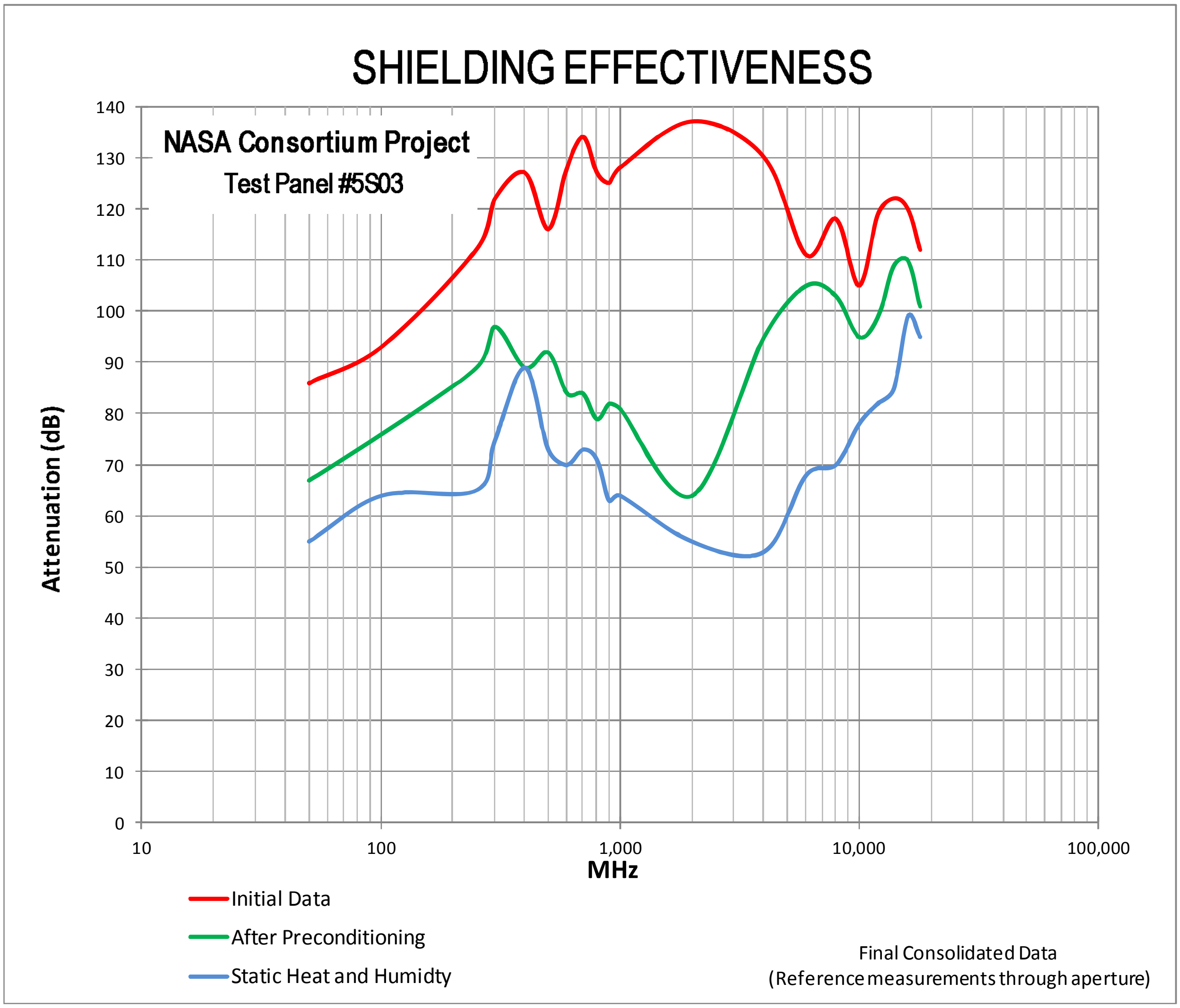
Metalast TCP – 5052-H32 plate #3



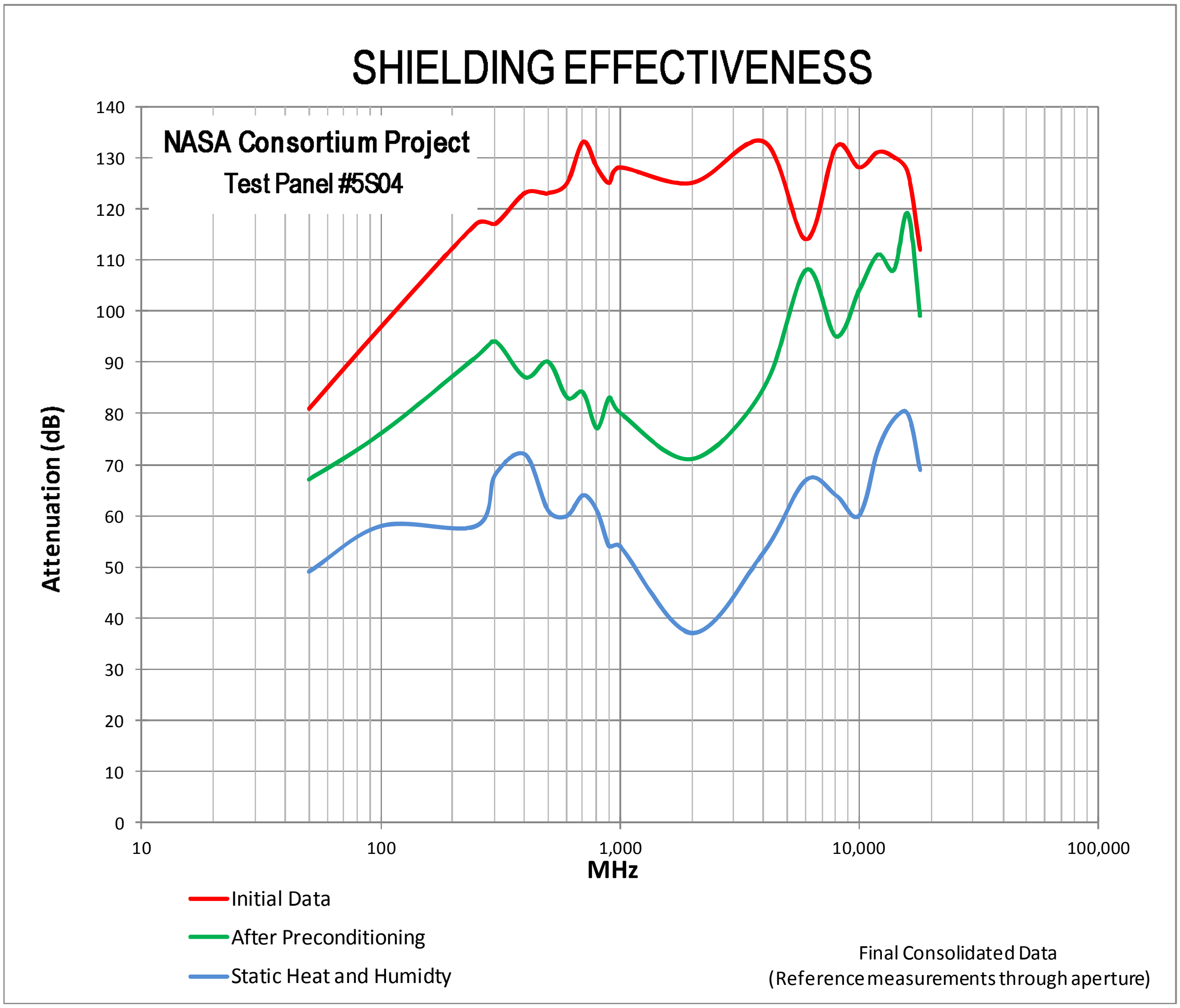
Metalast TCP – 5052-H32 plate #4



SurTec 650 – 5052-H32 plate #3

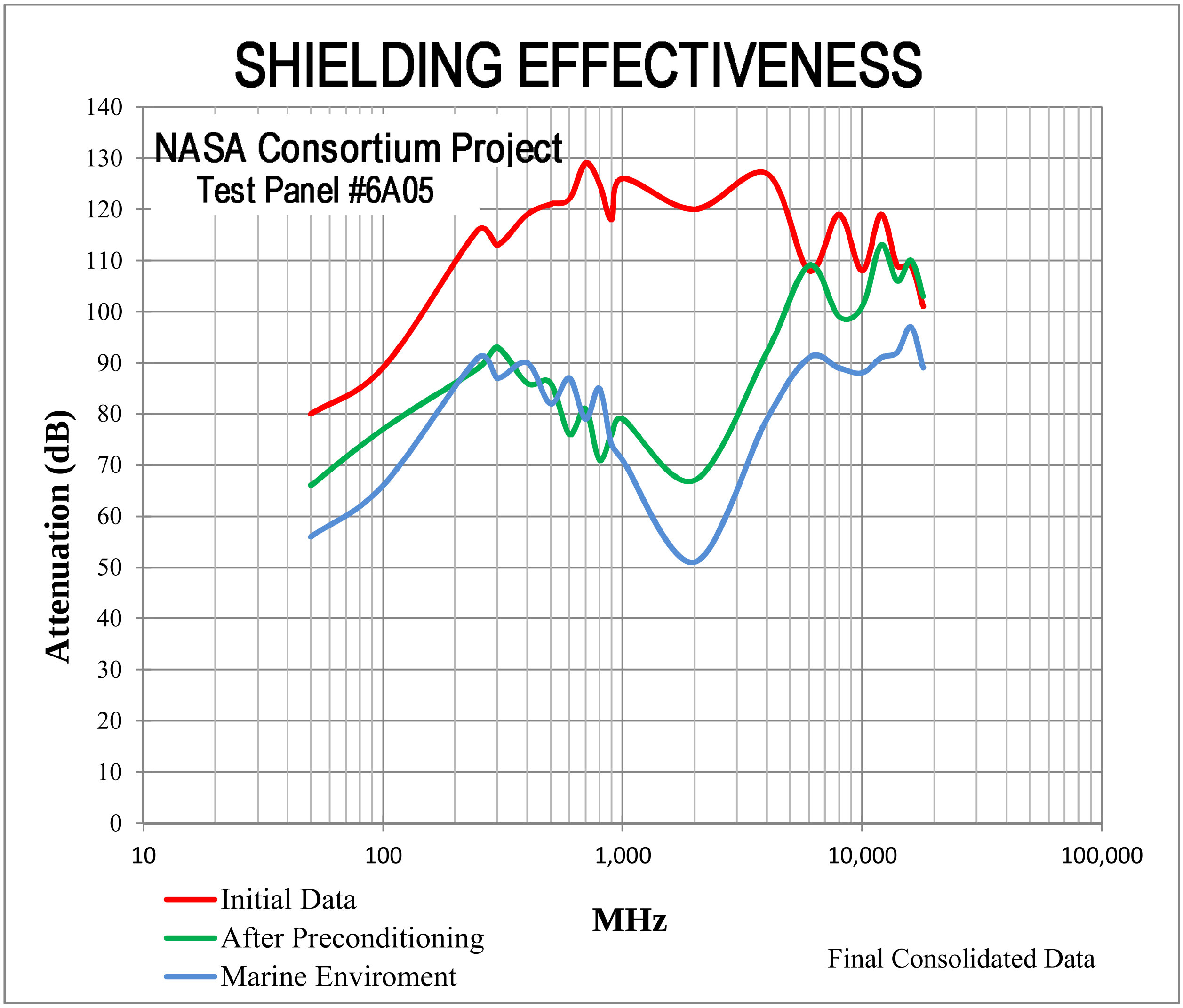


SurTec 650 – 5052-H32 plate #4

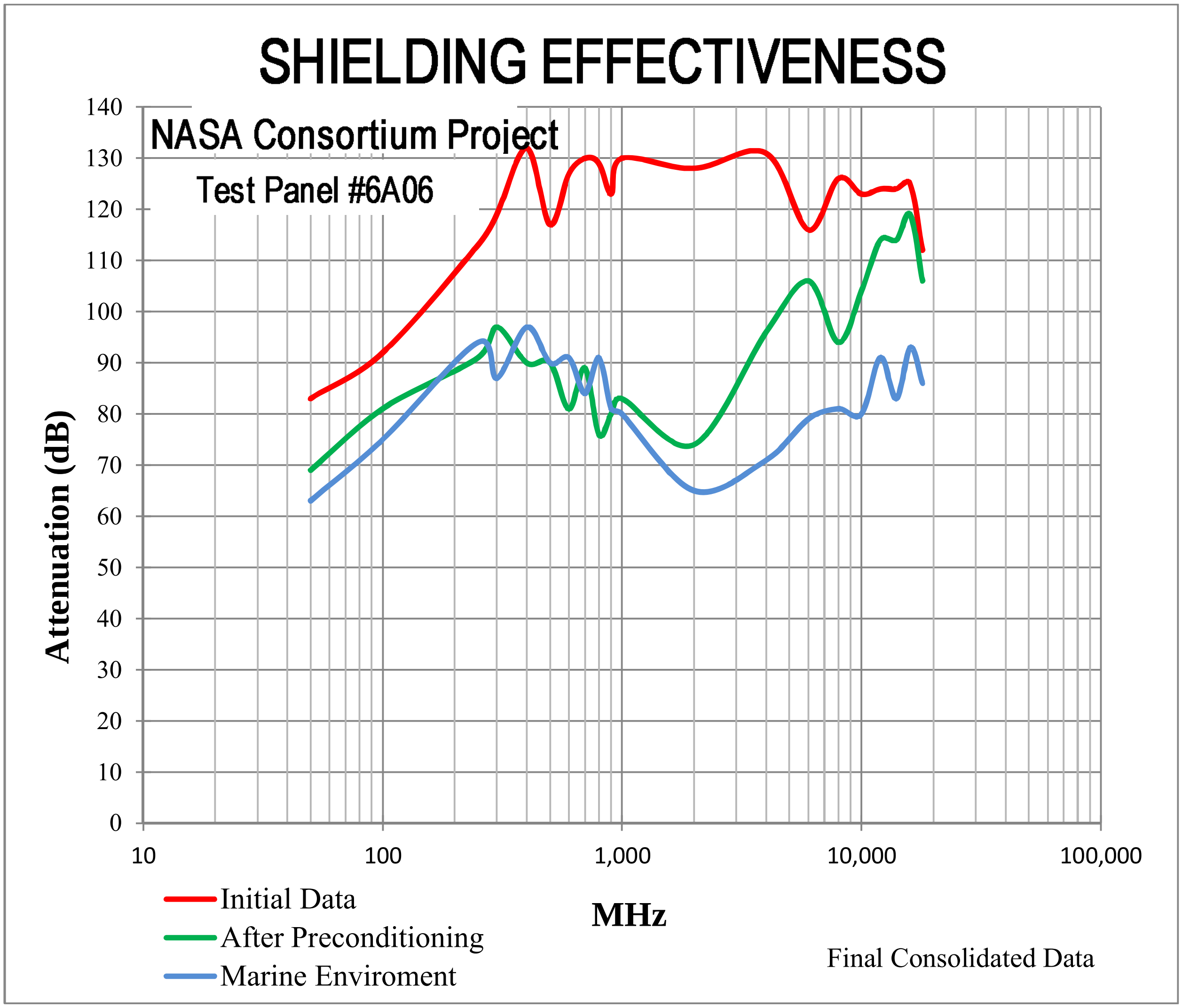


Appendix E – Shielding Effectiveness Results – Beach Exposure Testing

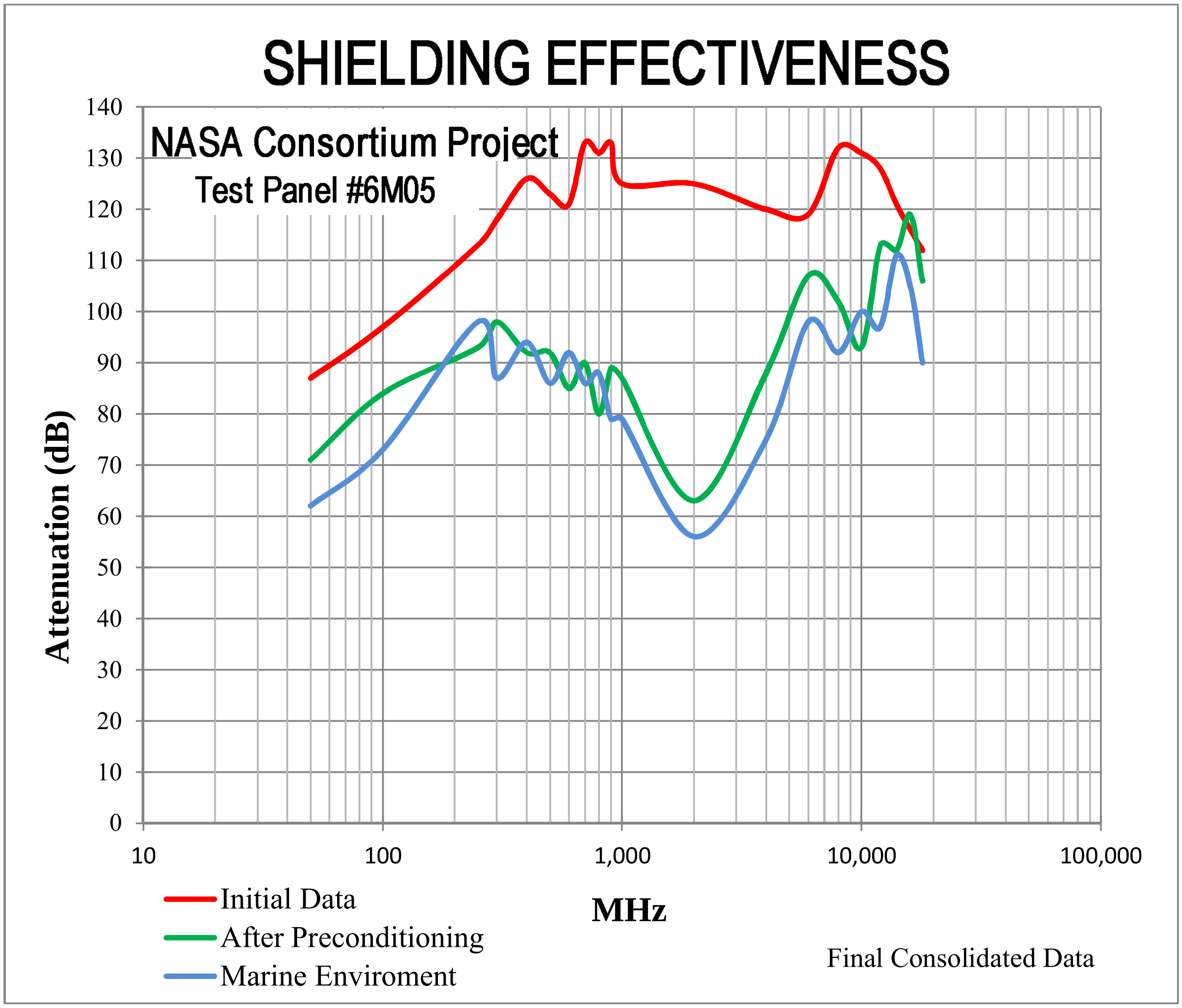
Alodine 1200S – 6061-T6 plate #5



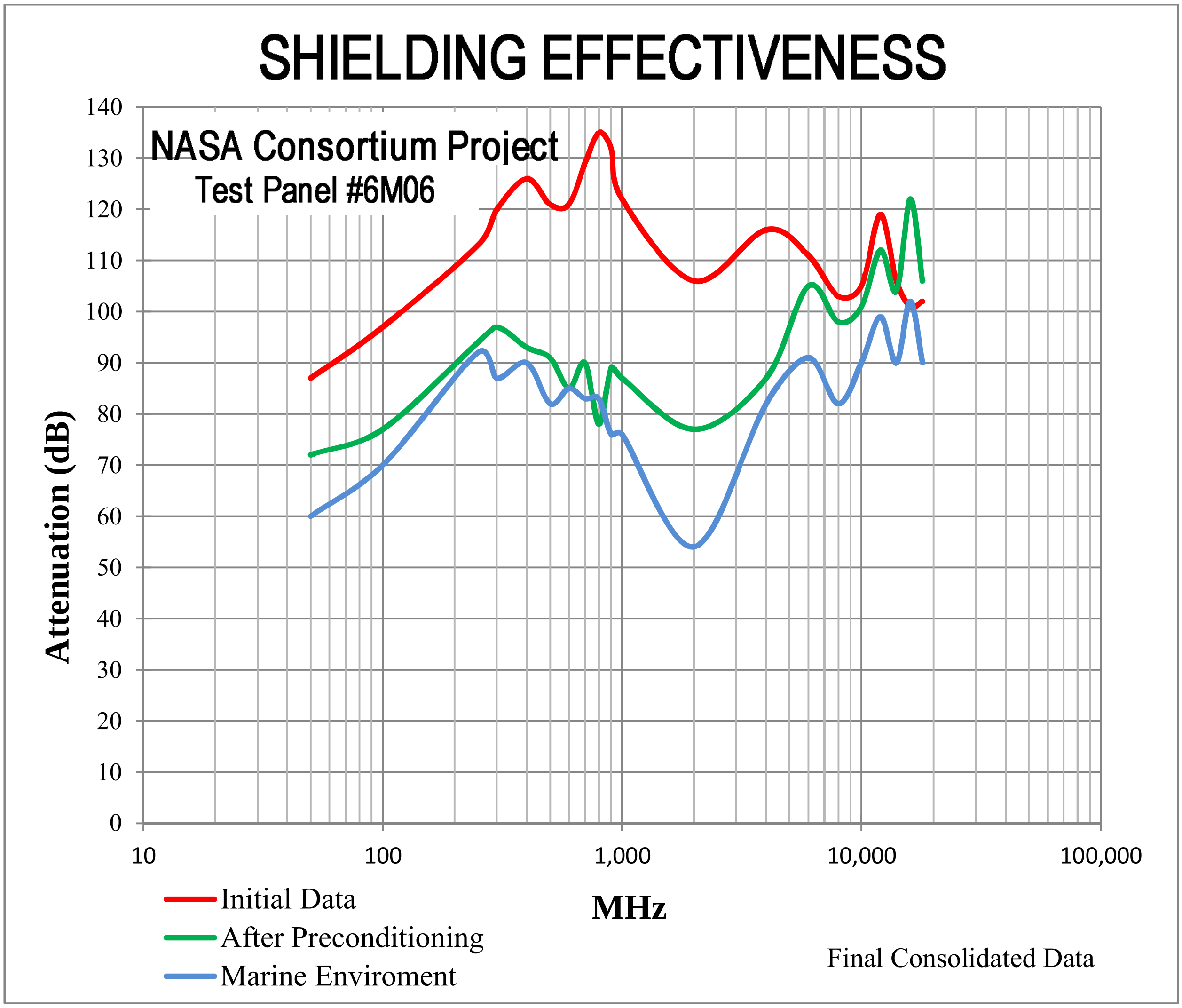
Alodine 1200S – 6061-T6 plate #6



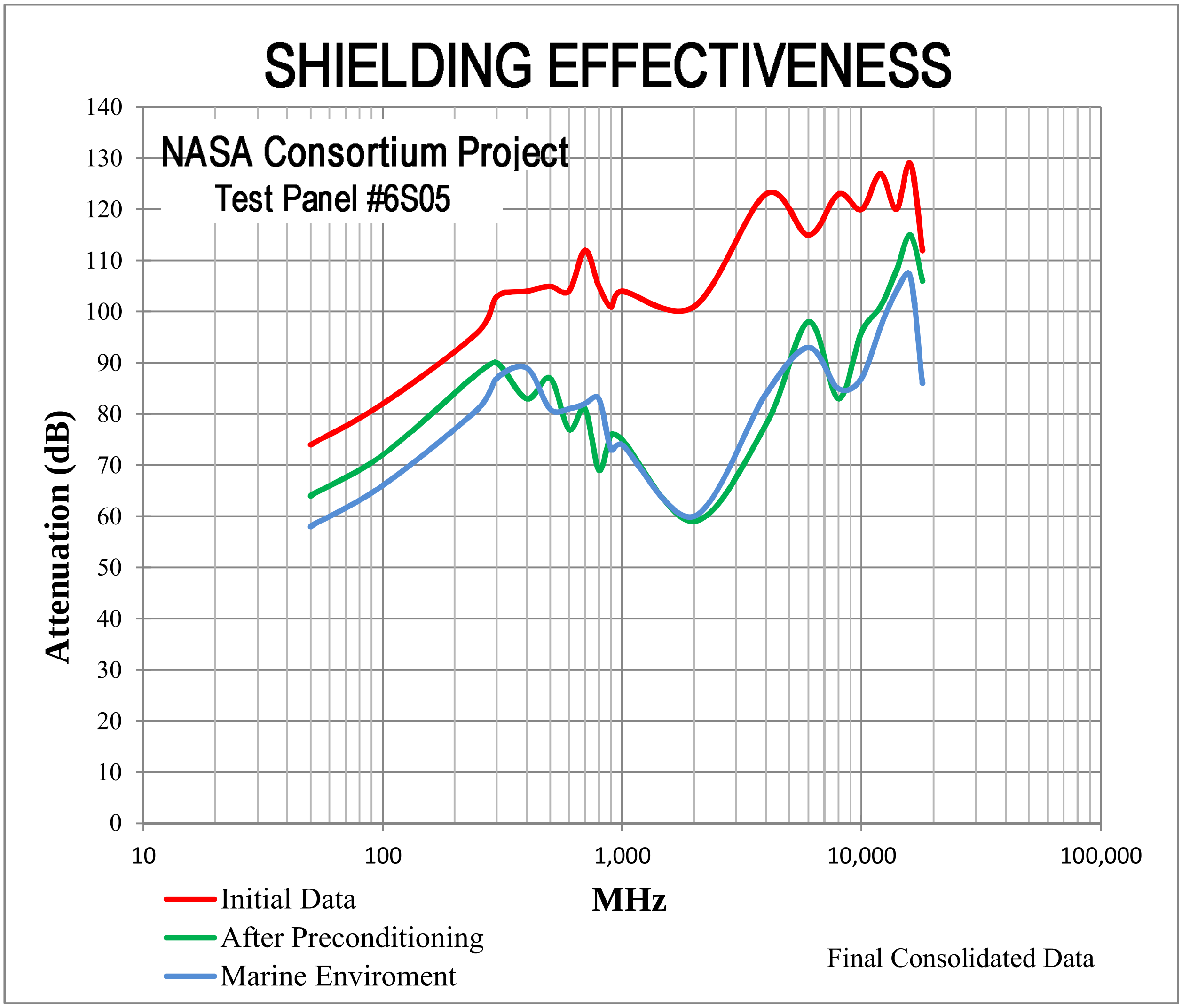
Metalast TCP – 6061-T6 plate #5



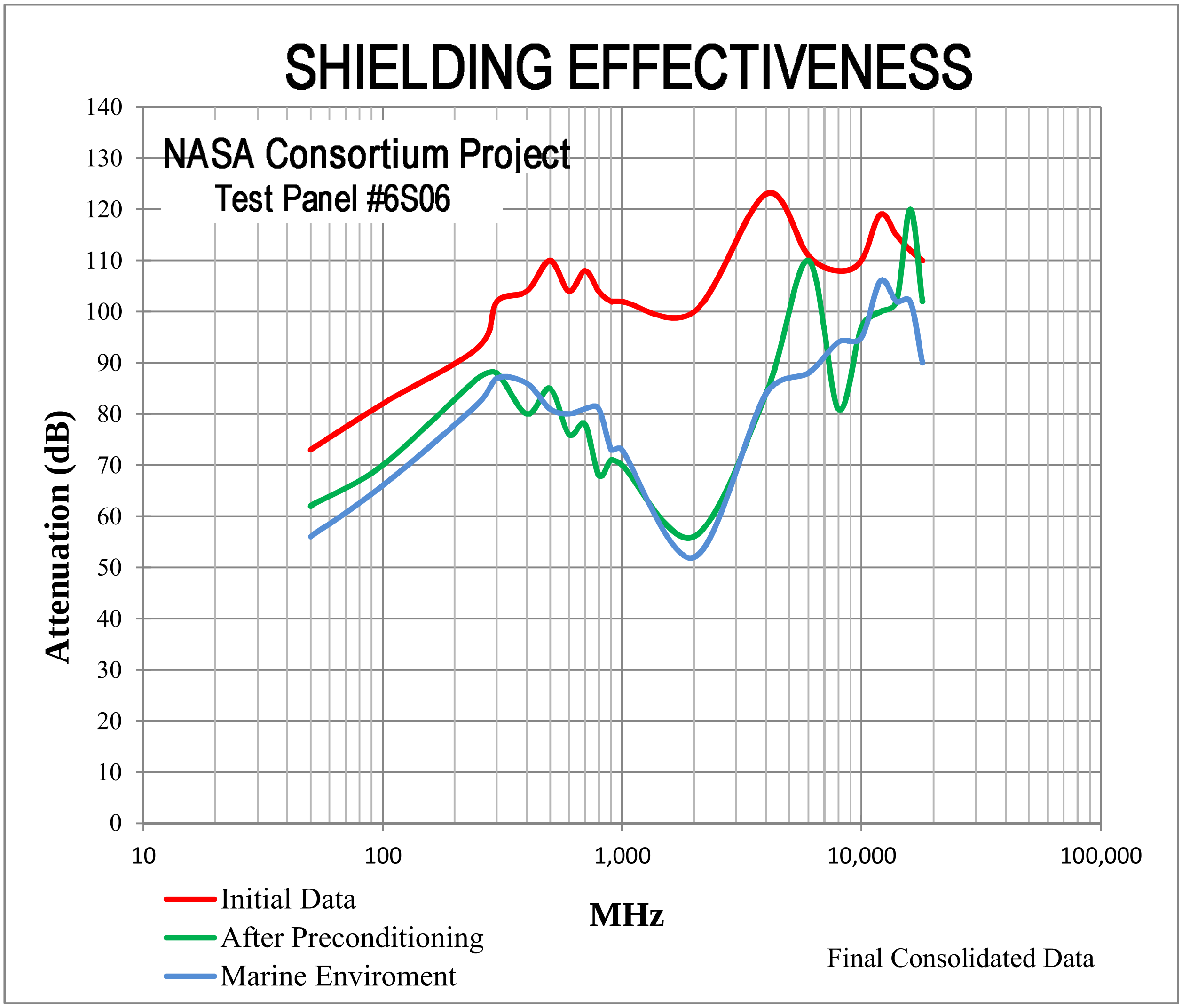
Metalast TCP – 6061-T6 plate #6



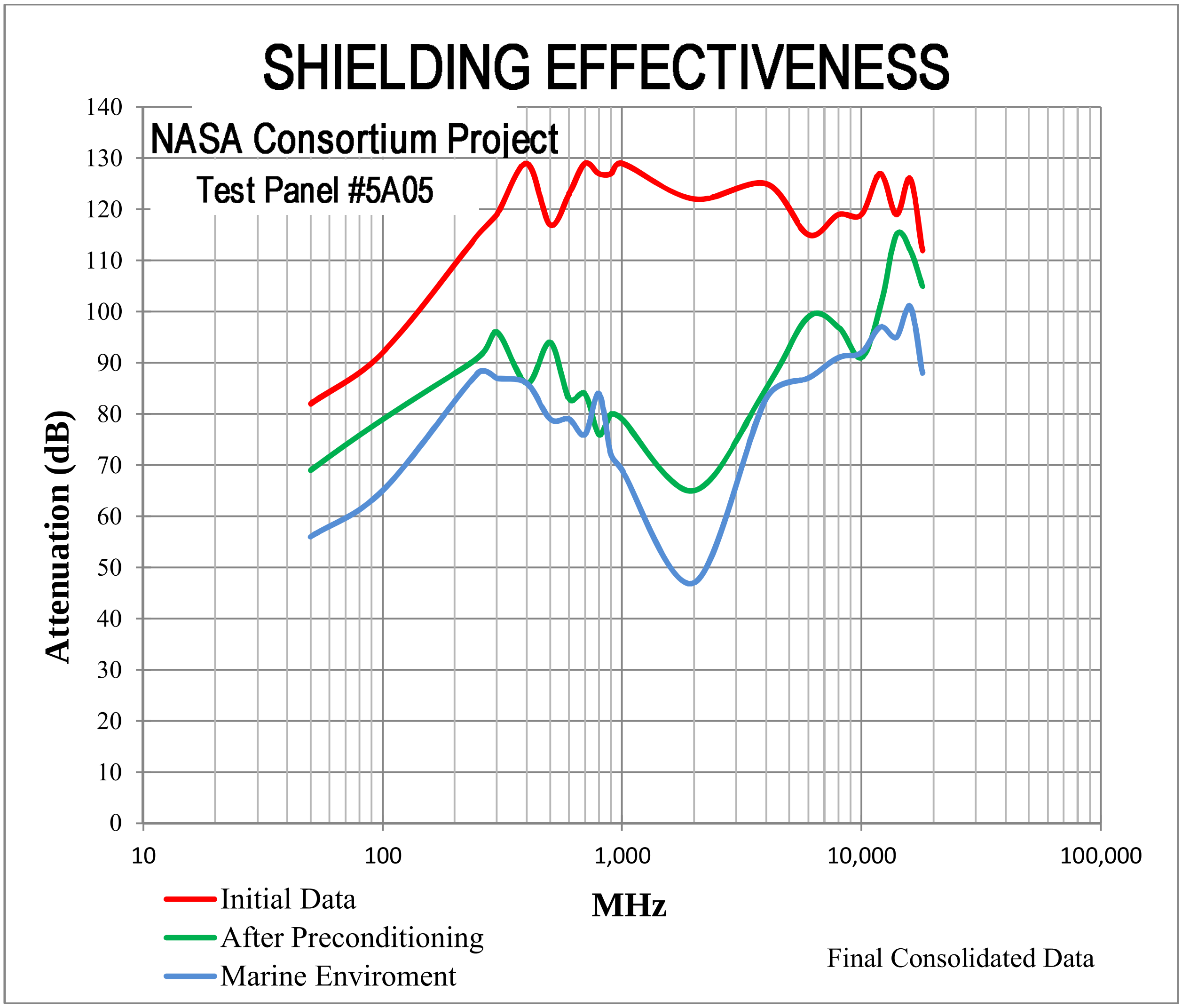
SurTec 650V – 6061-T6 plate #5



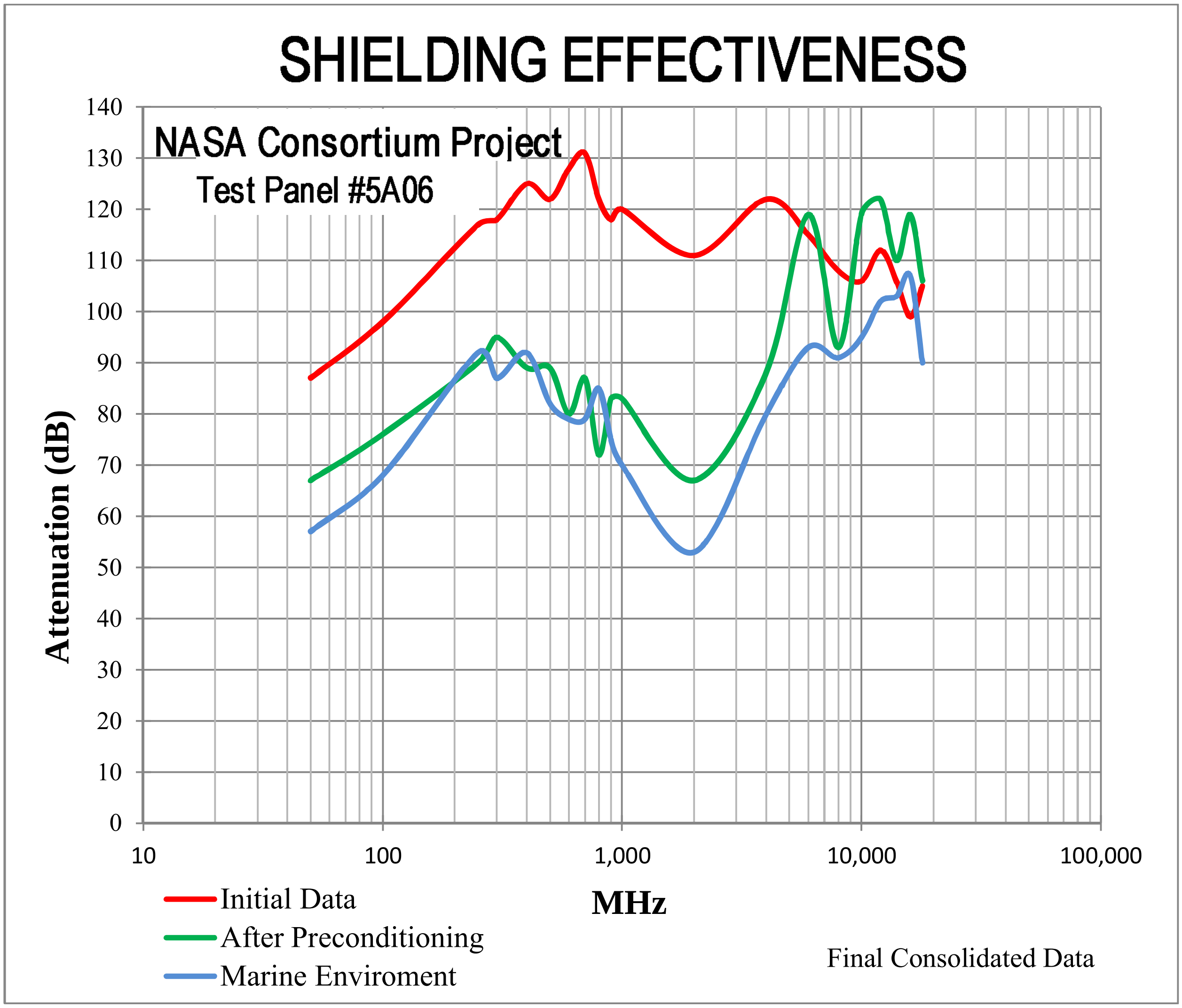
SurTec 650V – 6061-T6 plate #6



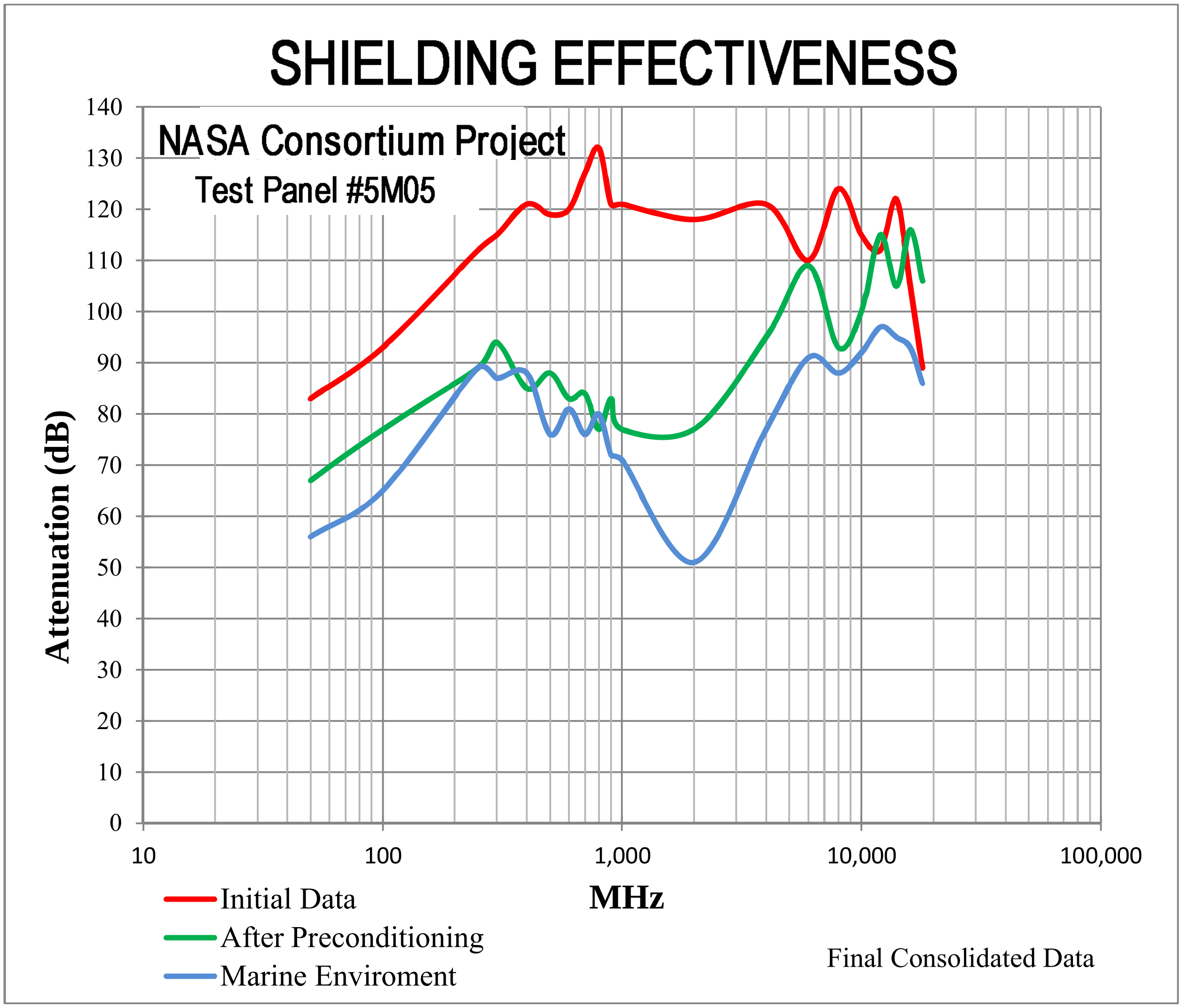
Alodine 1200S – 5052-H32 plate #5



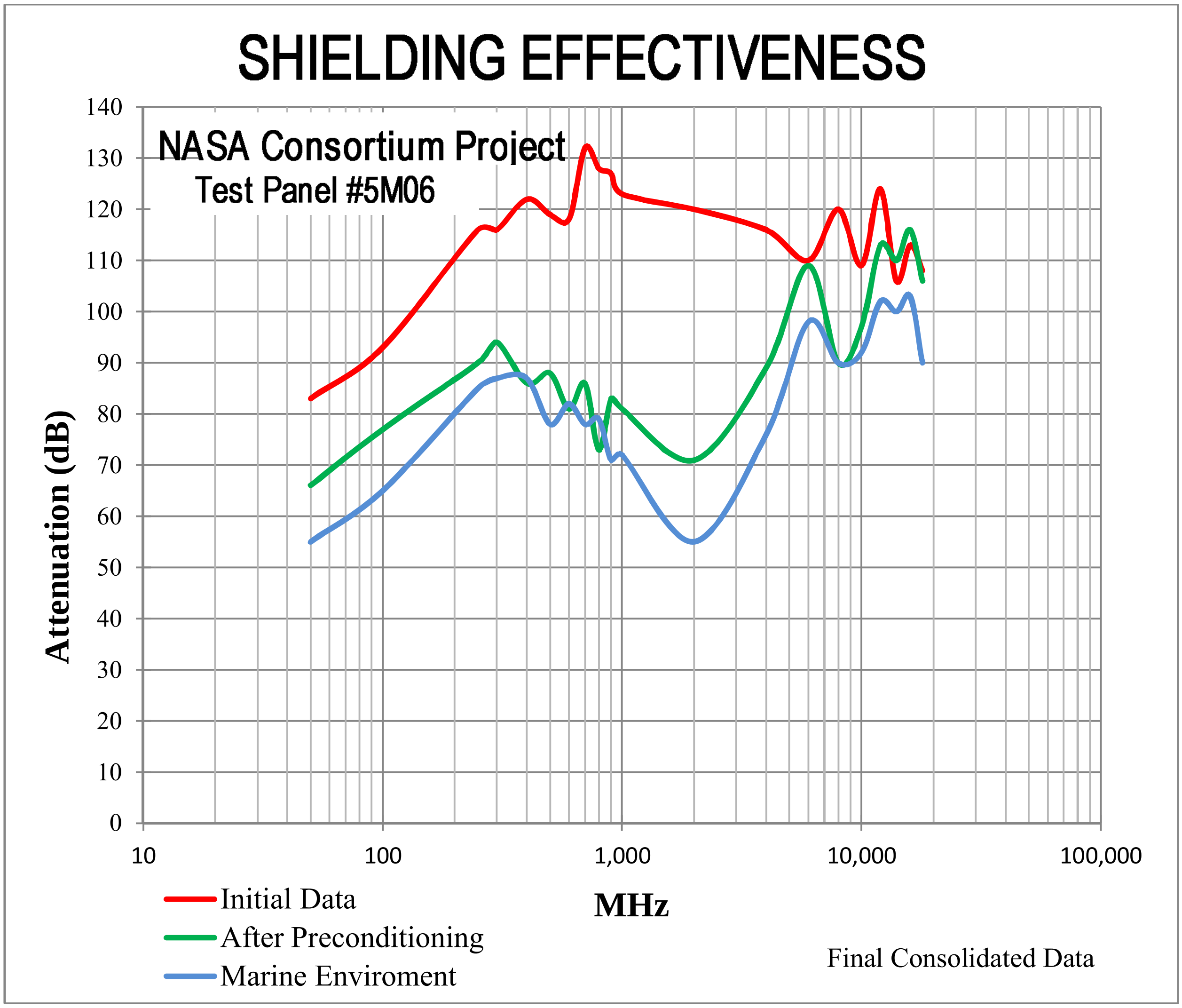
Alodine 1200S – 5052-H32 plate #6



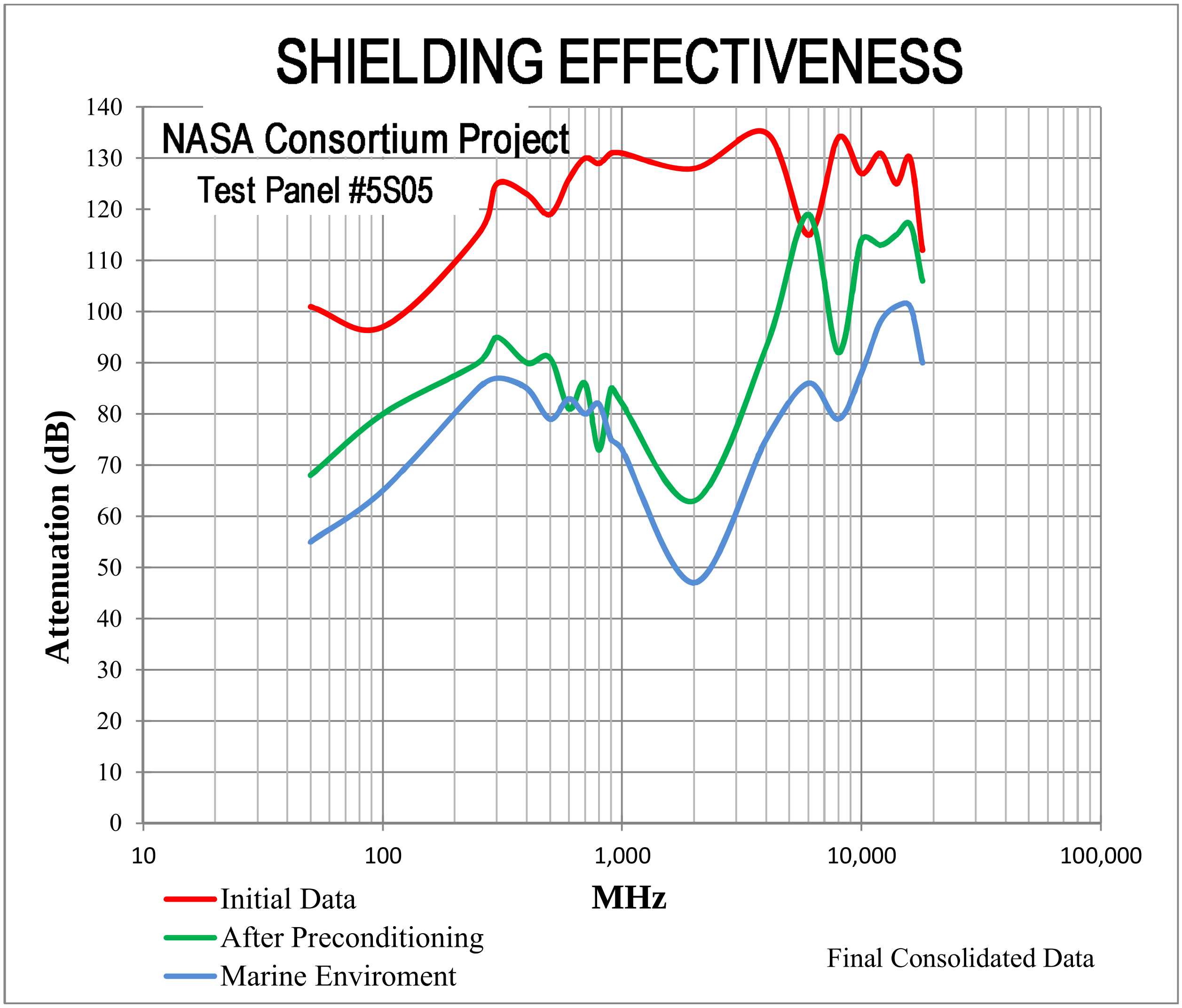
Metalast TCP – 5052-H32 plate #5



Metalast TCP – 5052-H32 plate #6



SurTec 650A – 5052-H32 plate #5



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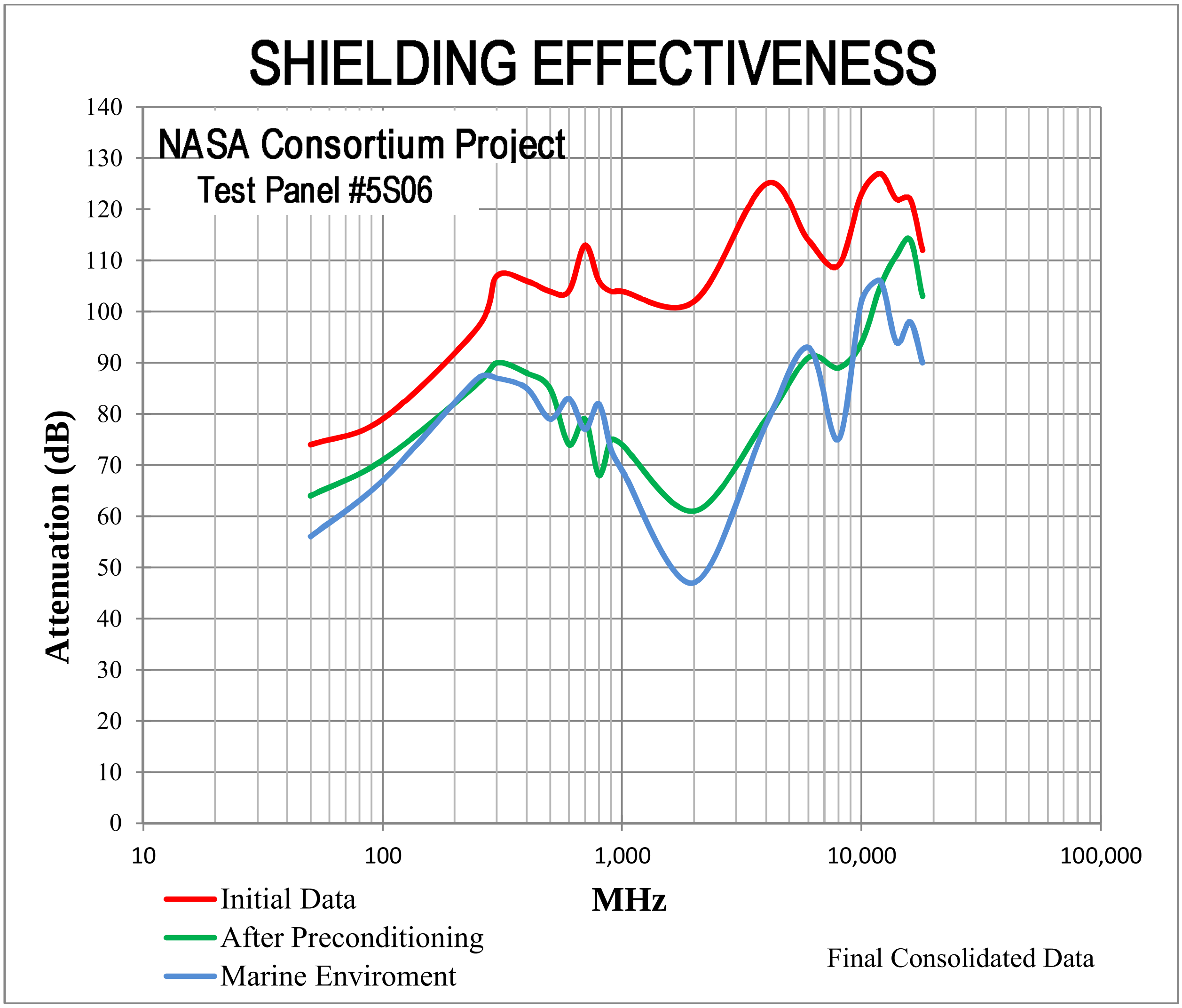

Appendix F – Test Plate Pictures – Salt Spray Testing

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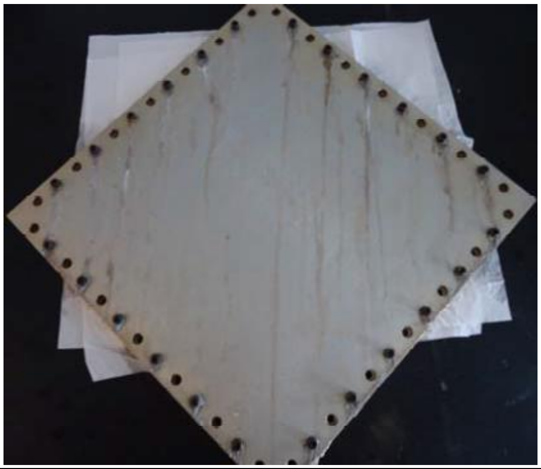
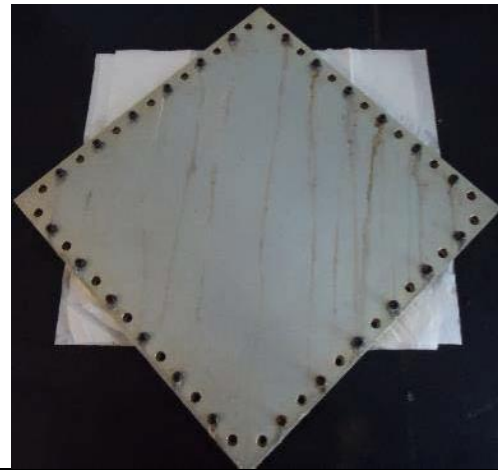
</td><td>6A02 – Week 1
</td></tr>
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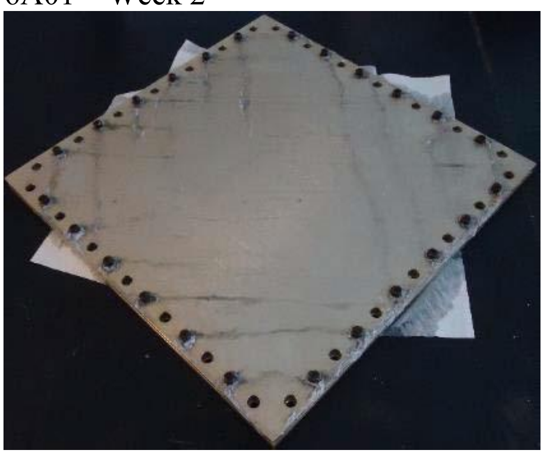
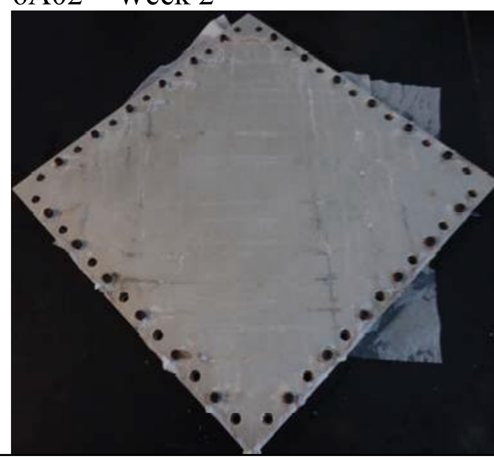
</td><td>6A02 – Week 2
</td></tr>
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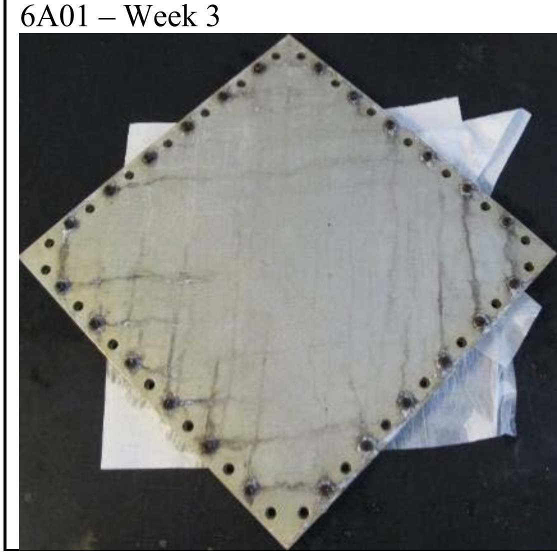
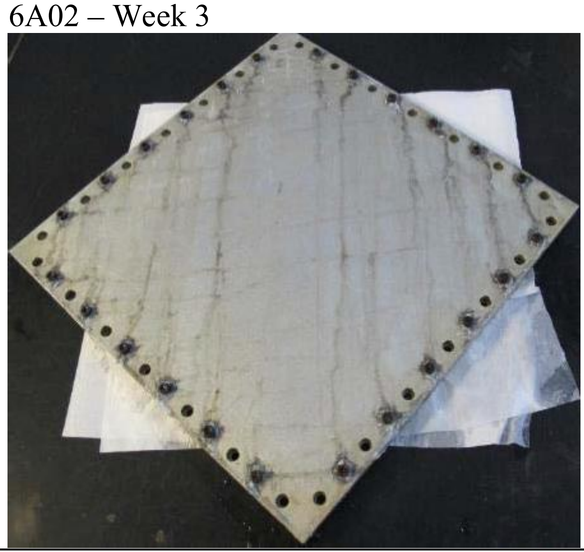
</td><td>6A02 – Week 3
</td></tr>
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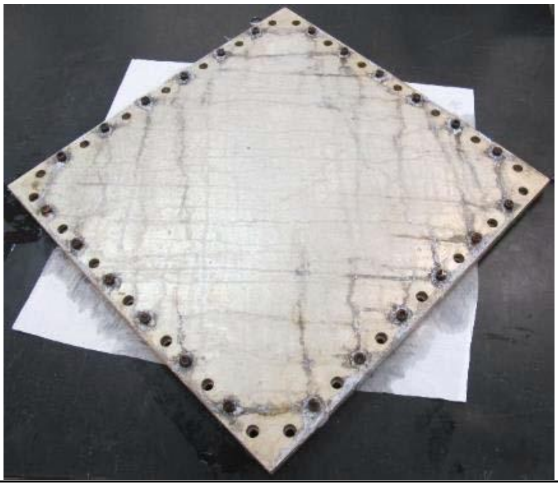	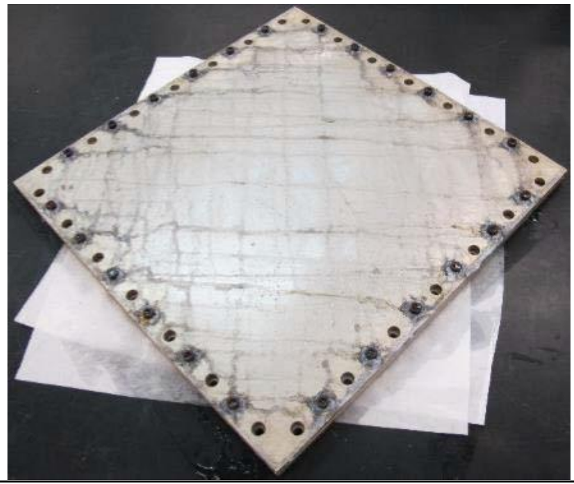
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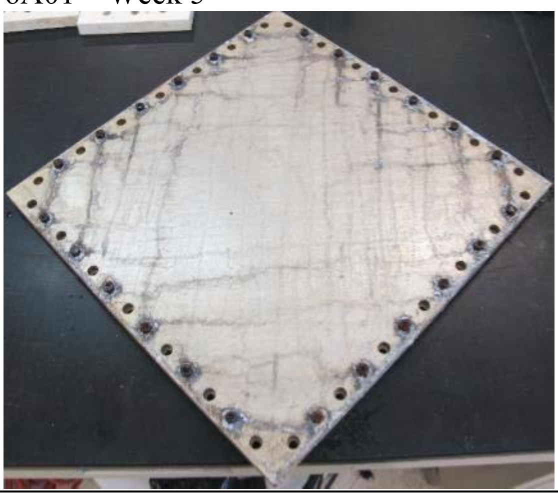	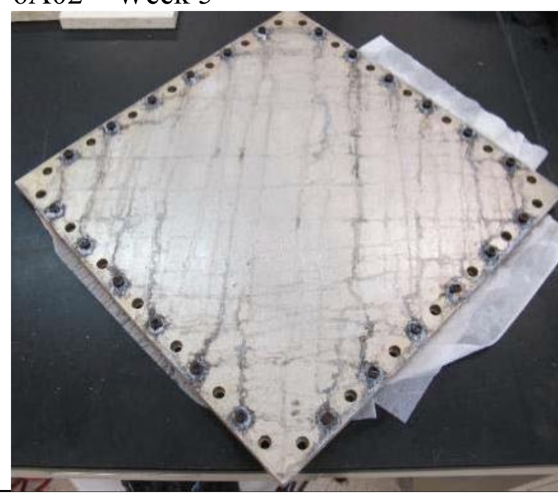
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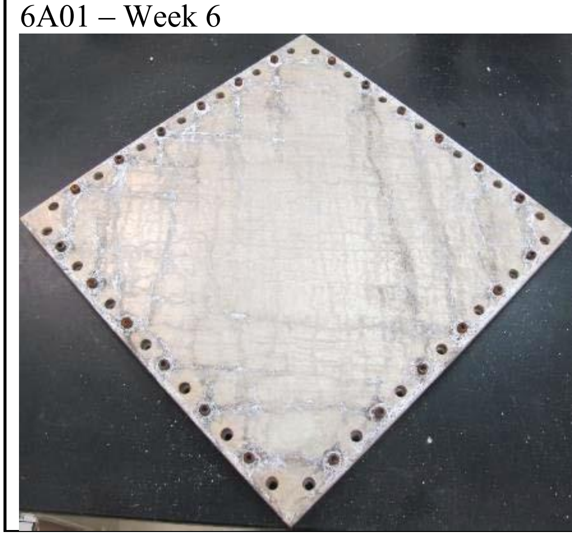
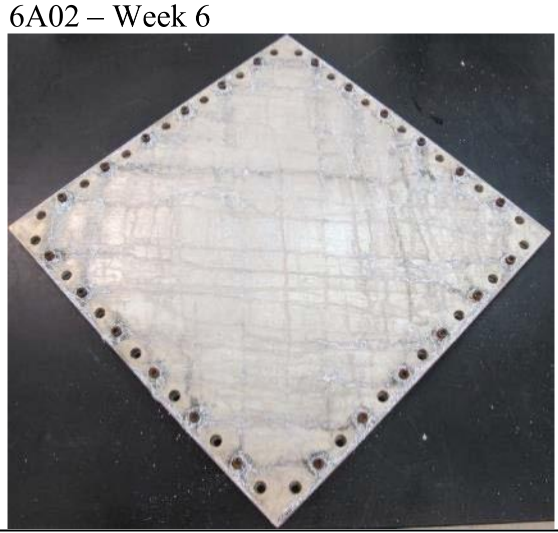
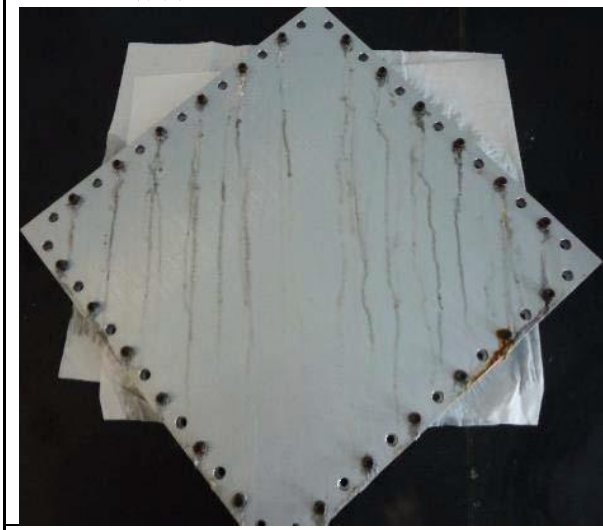
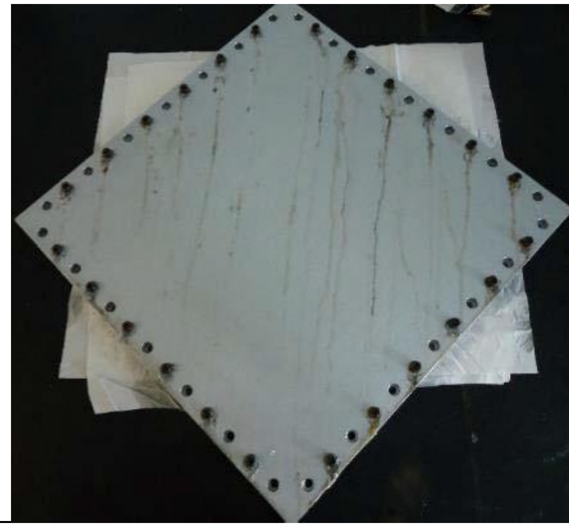
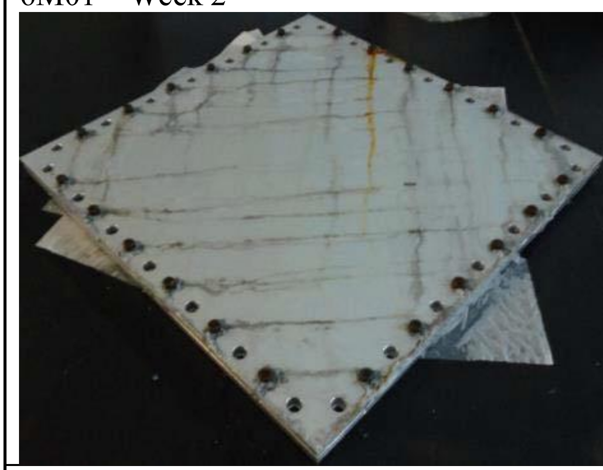
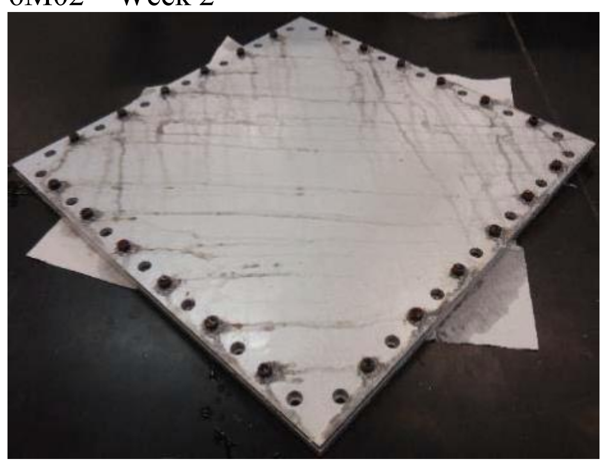
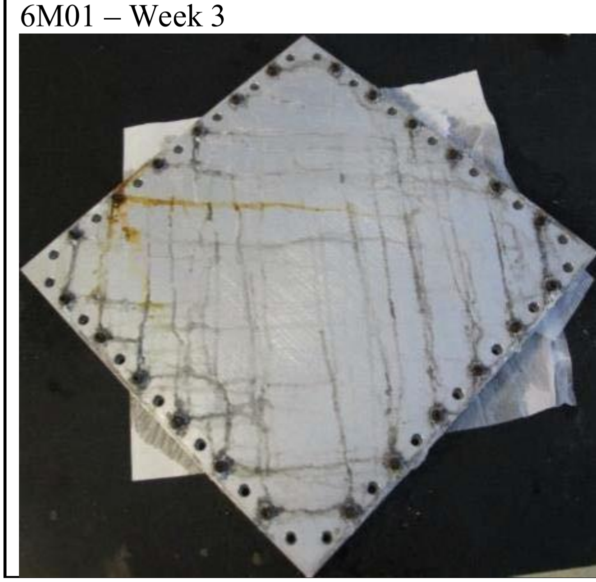
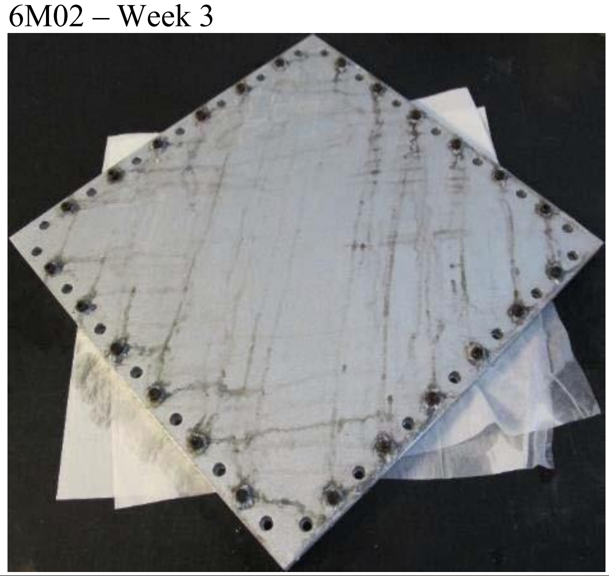
	

Metalast TCP – 6061-T6	
6M01 – Week 1 	6M02 – Week 1 
6M01 – Week 2 	6M02 – Week 2 
6M01 – Week 3 	6M02 – Week 3 

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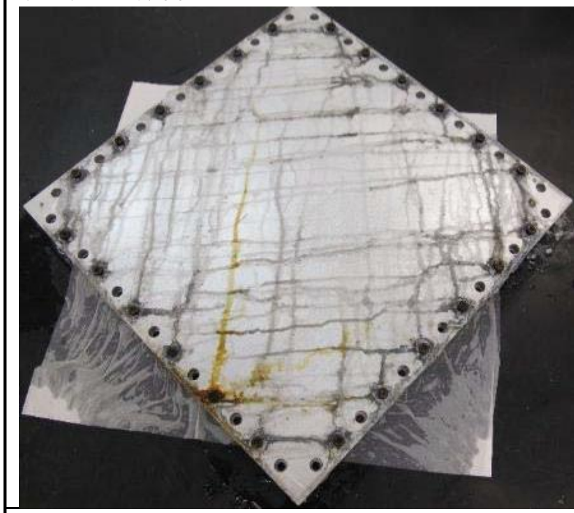	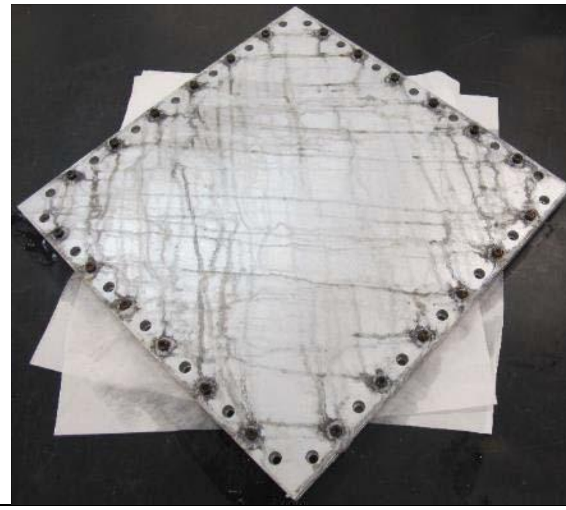
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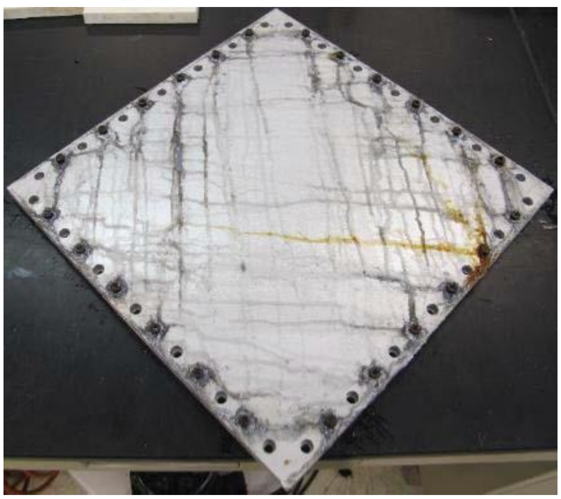	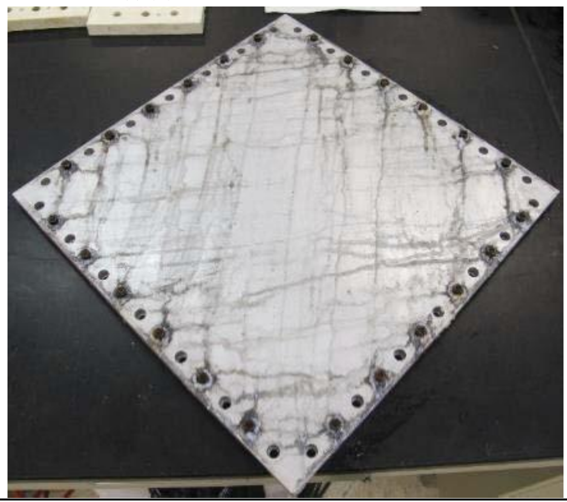
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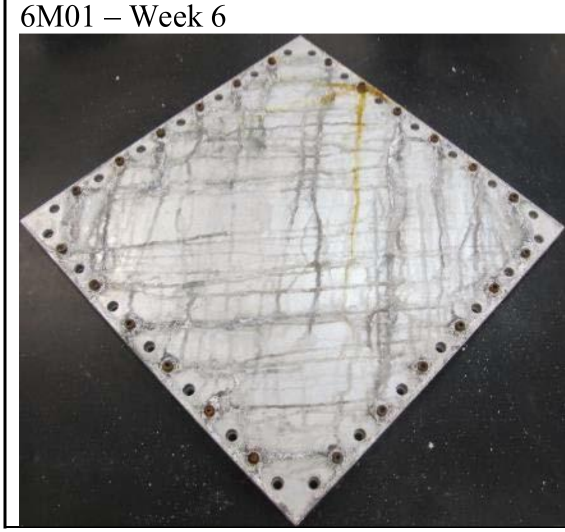
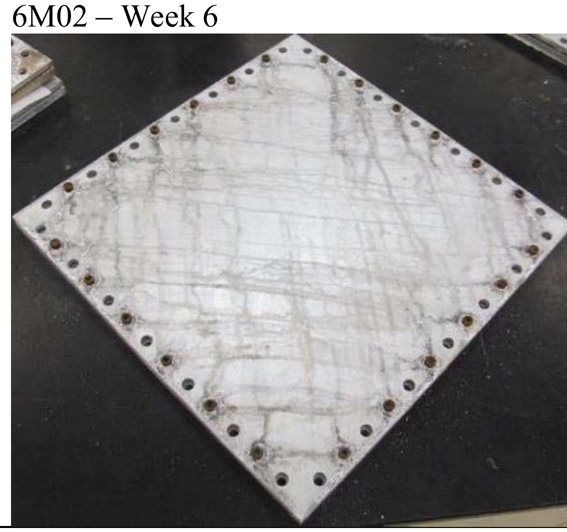
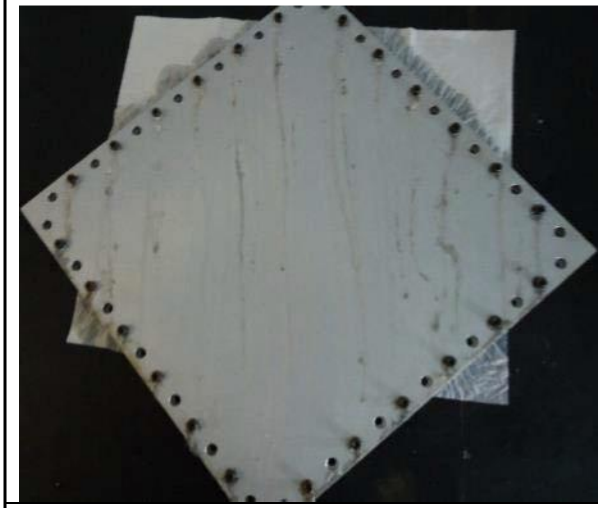
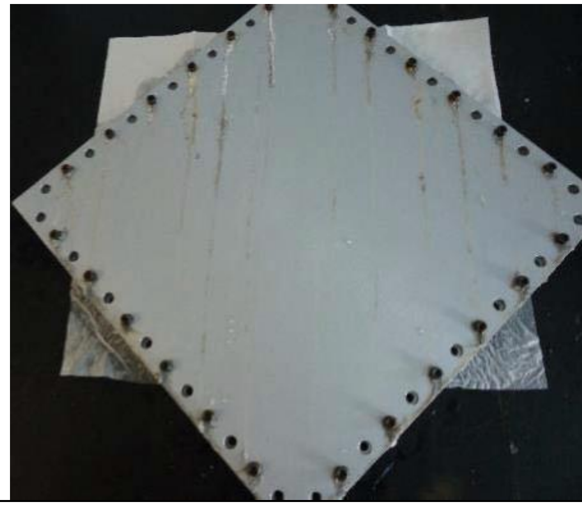
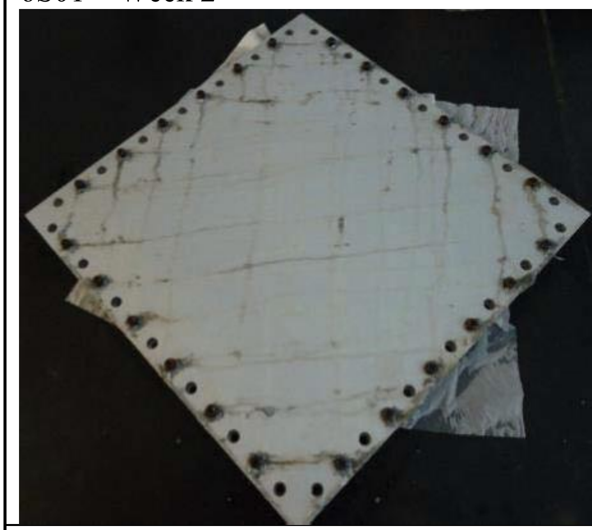
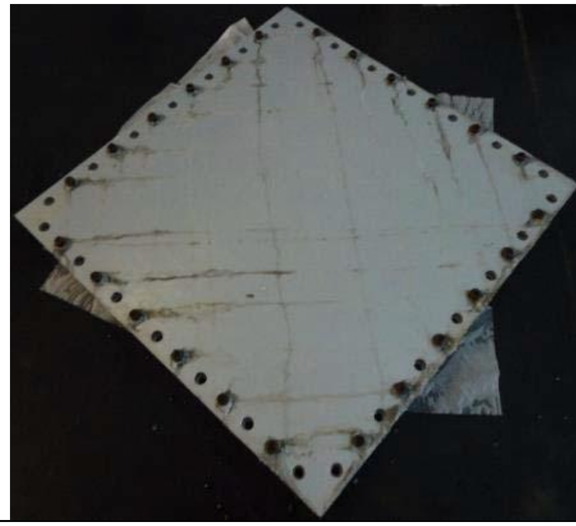
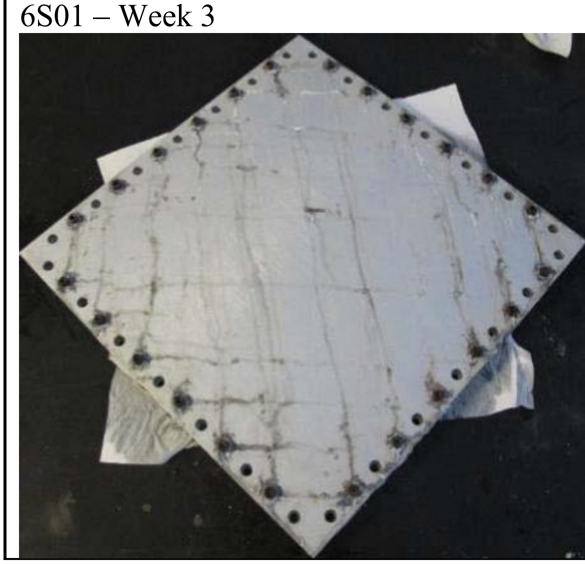
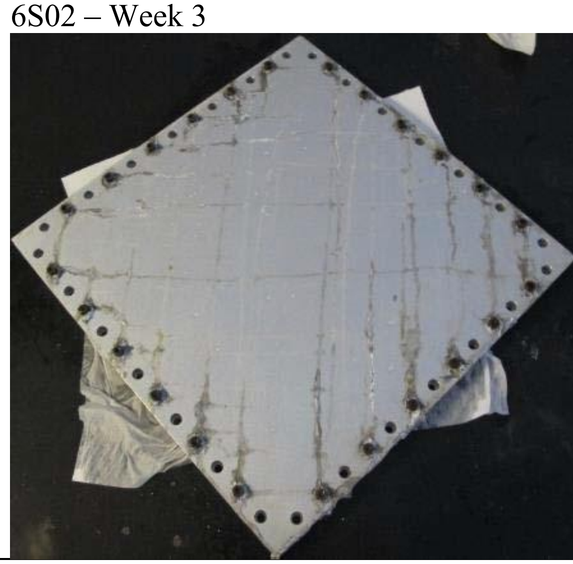
	

SurTec 650 – 6061-T6	
6S01 – Week 1 	6S02 – Week 1 
6S01 – Week 2 	6S02 – Week 2 
6S01 – Week 3 	6S02 – Week 3 

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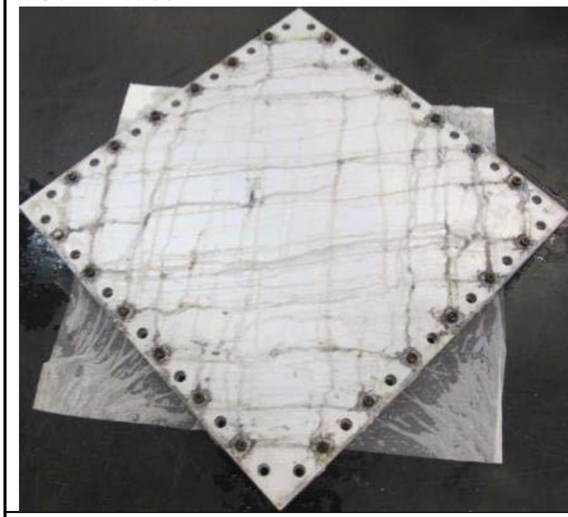	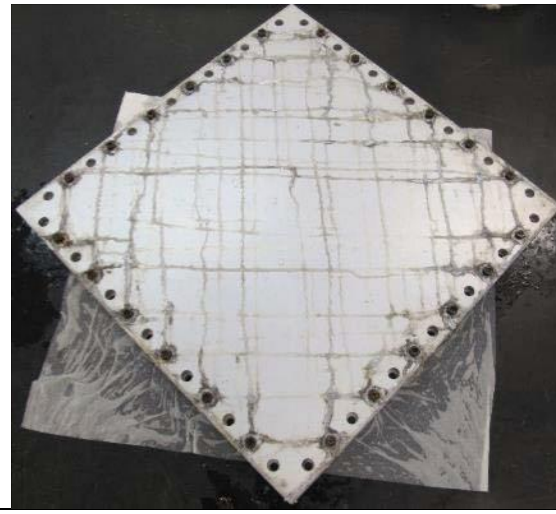
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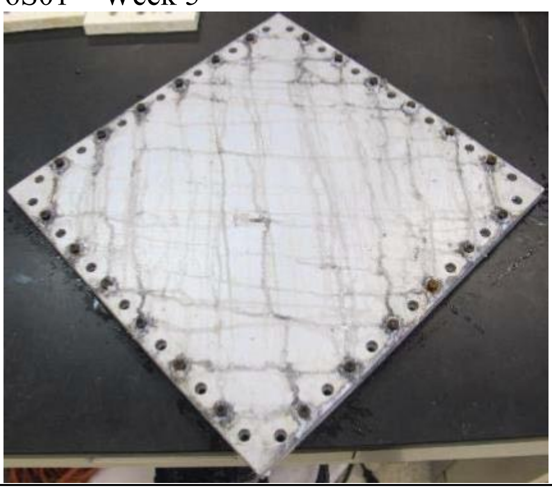	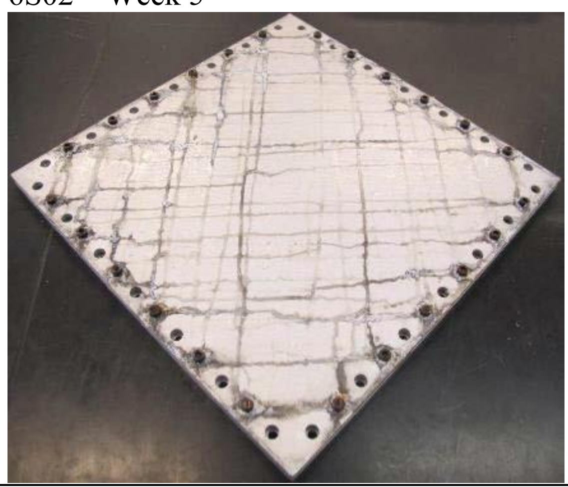
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	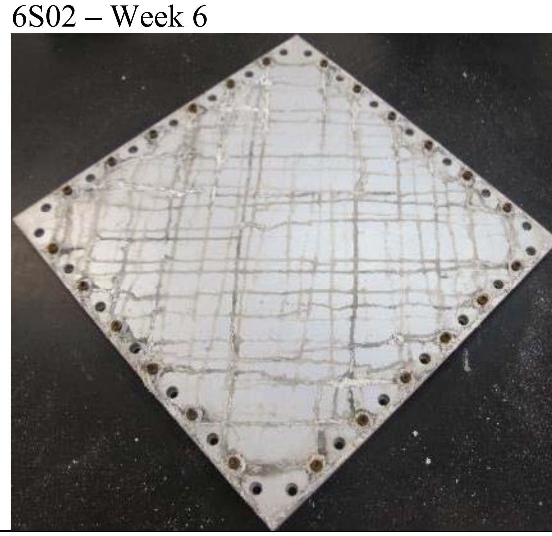

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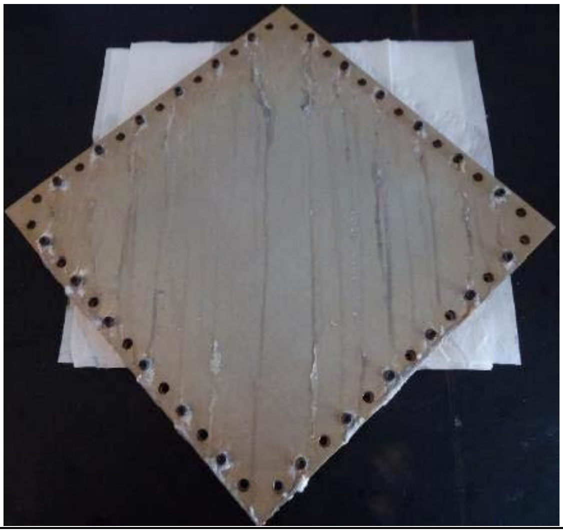
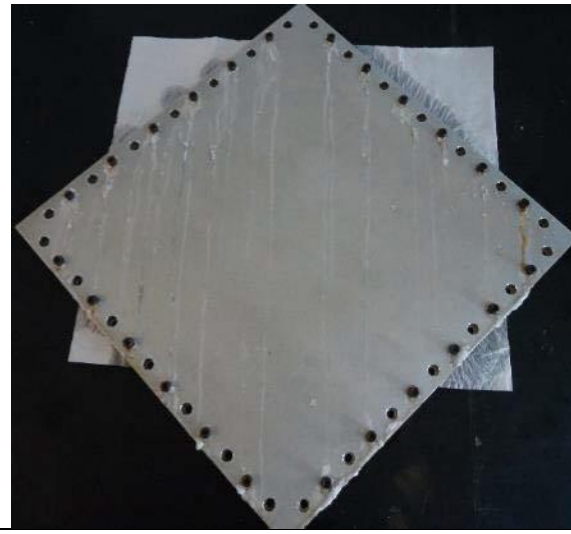
</td><td>5A02 – Week 1
</td></tr>
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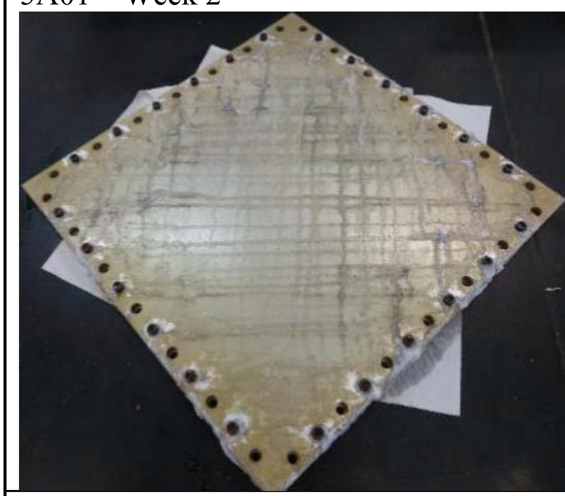
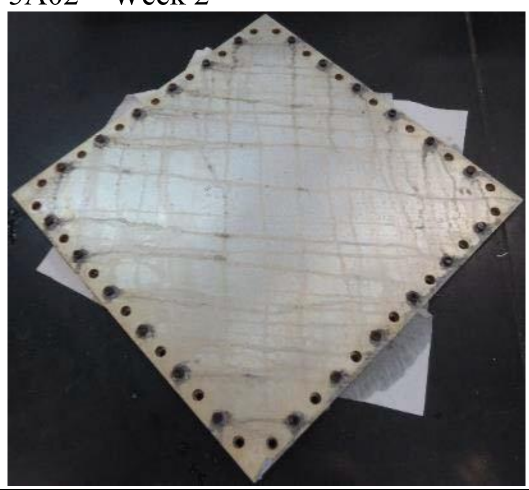
</td><td>5A02 – Week 2
</td></tr>
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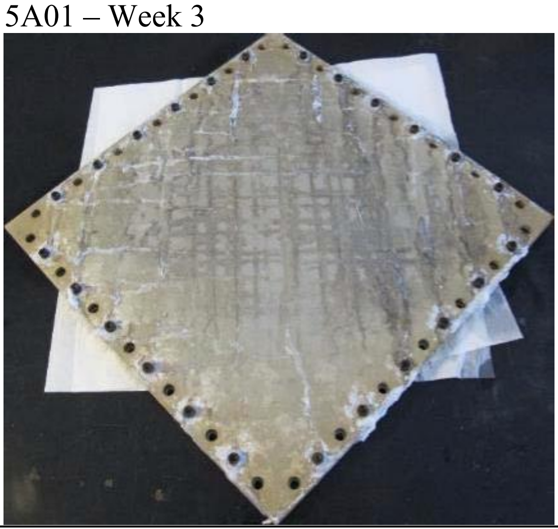
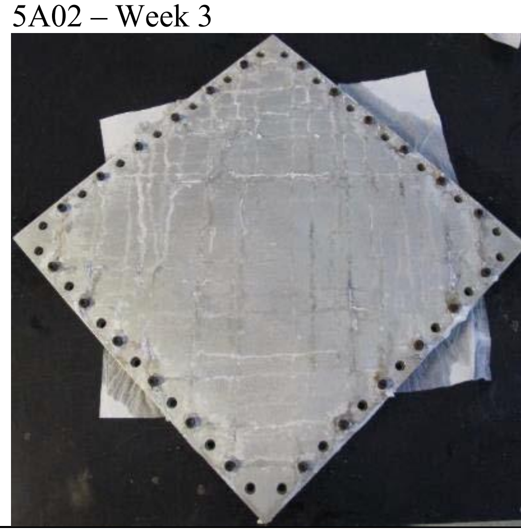
</td><td>5A02 – Week 3
</td></tr>
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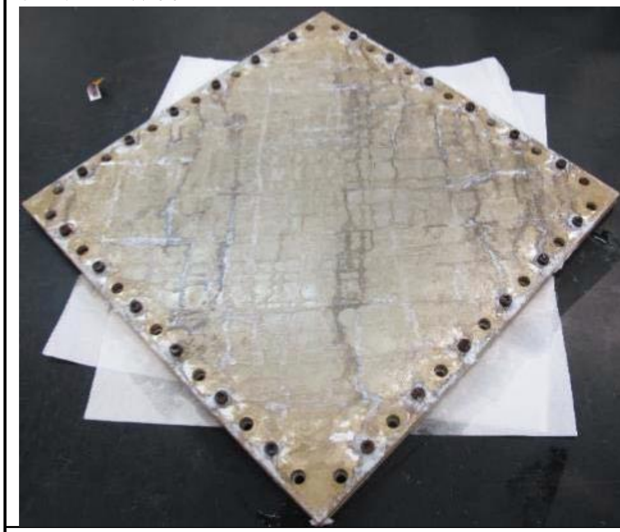	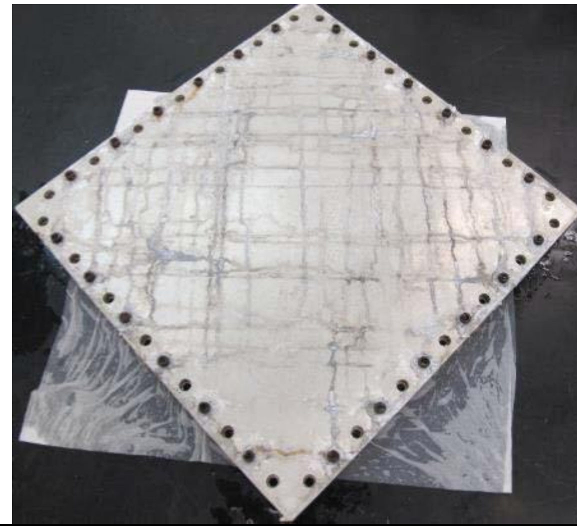
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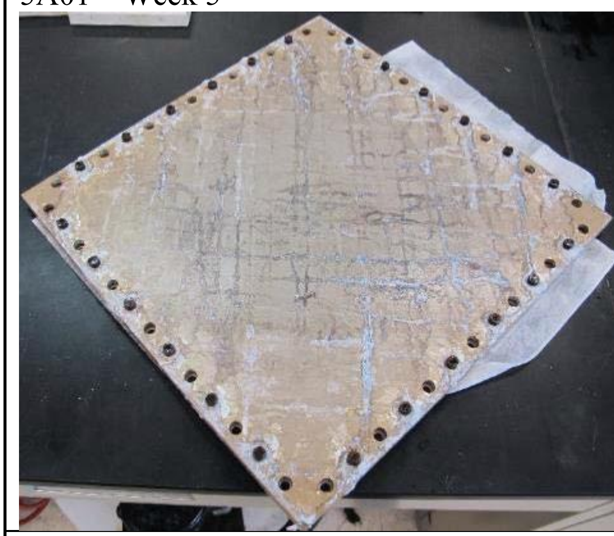	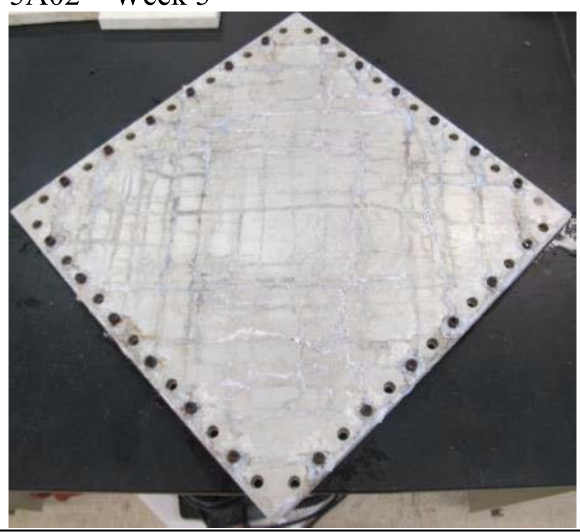
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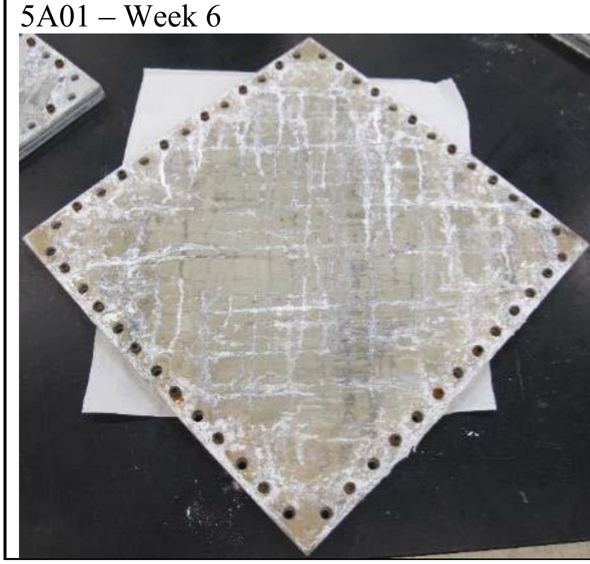
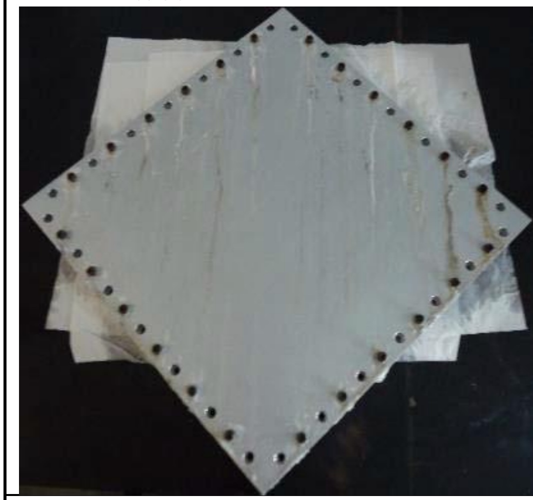
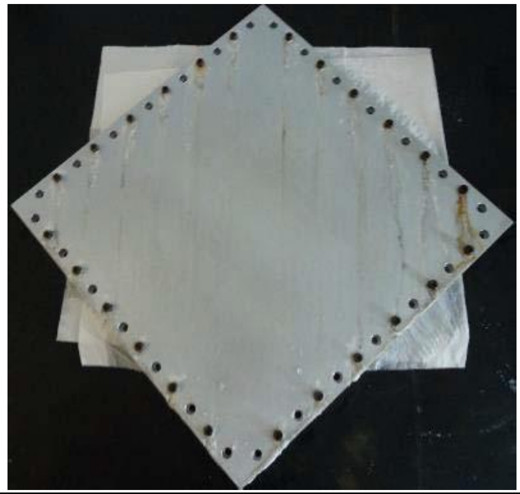
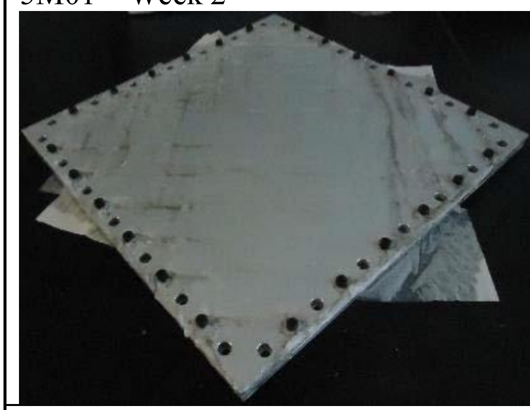
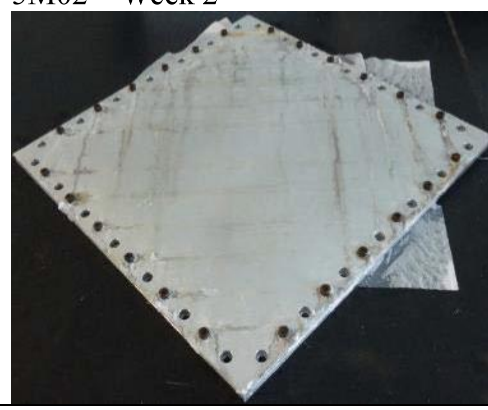
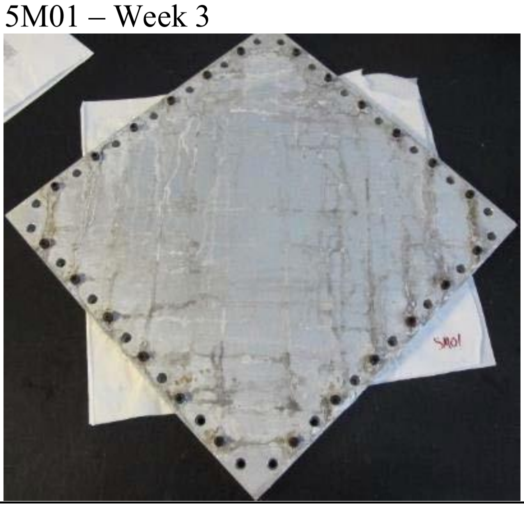
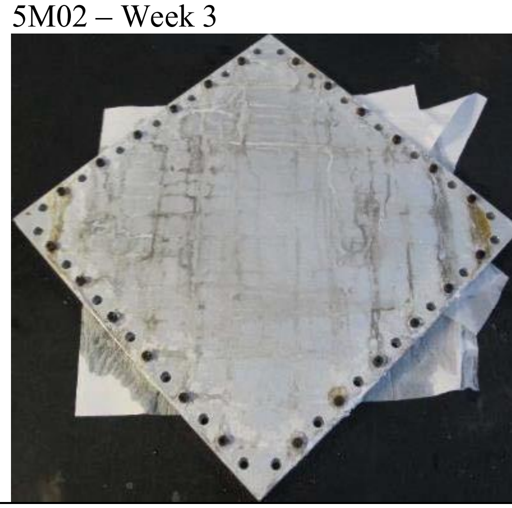
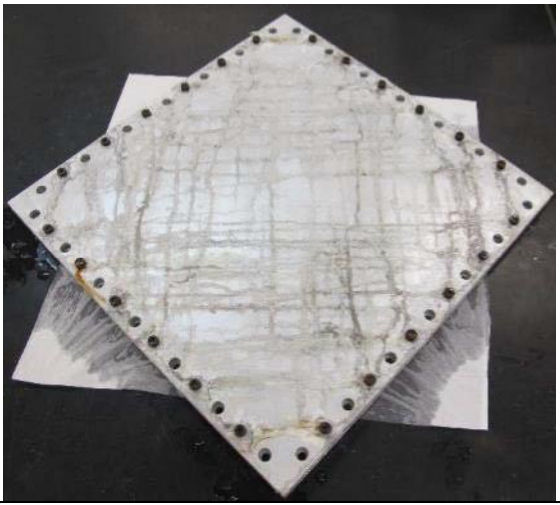
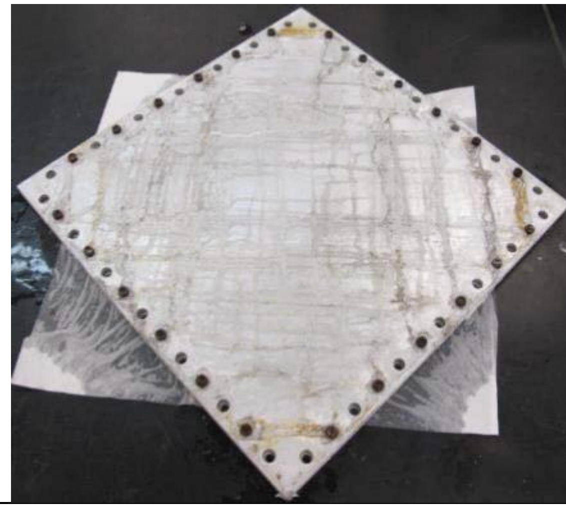
	

Metalast TCP – 5052-H32	
5M01 – Week 1 	5M02 – Week 1 
5M01 – Week 2 	5M02 – Week 2 
5M01 – Week 3 	5M02 – Week 3 

5M01 – Week 4	5M02 – Week 4
	
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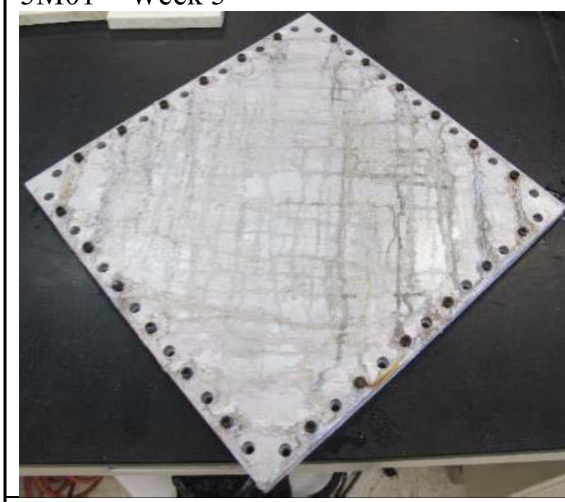	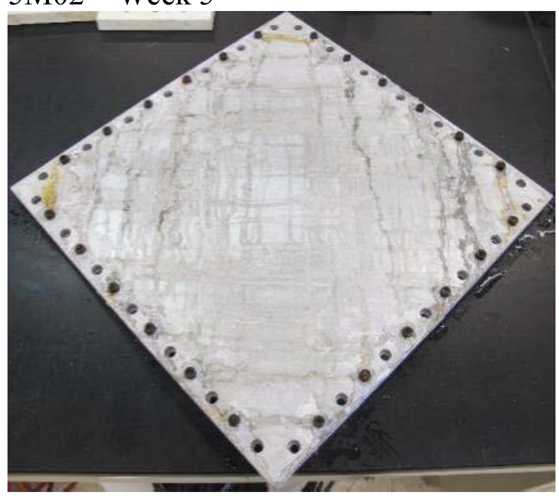
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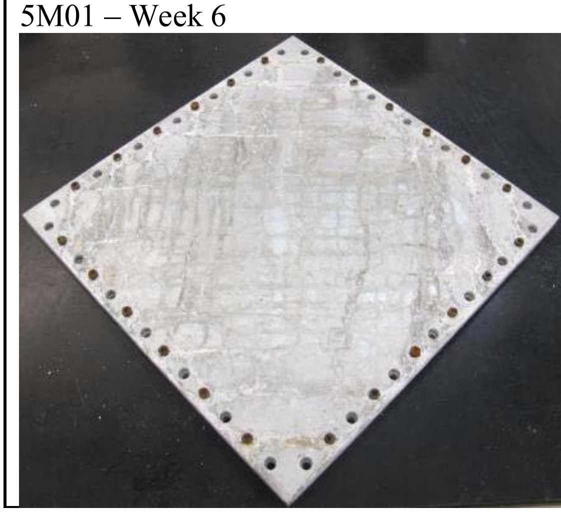
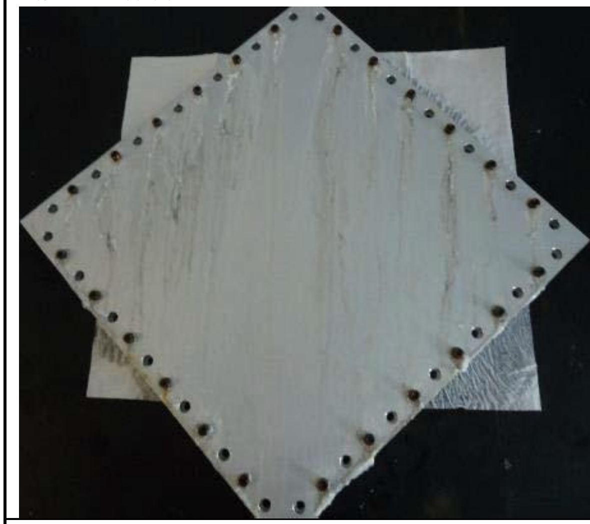
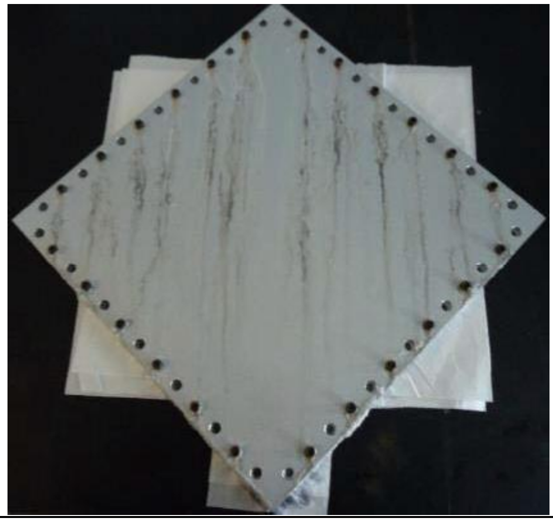
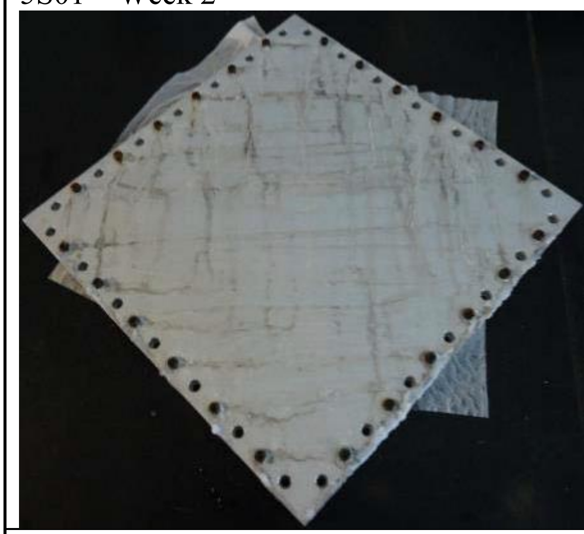
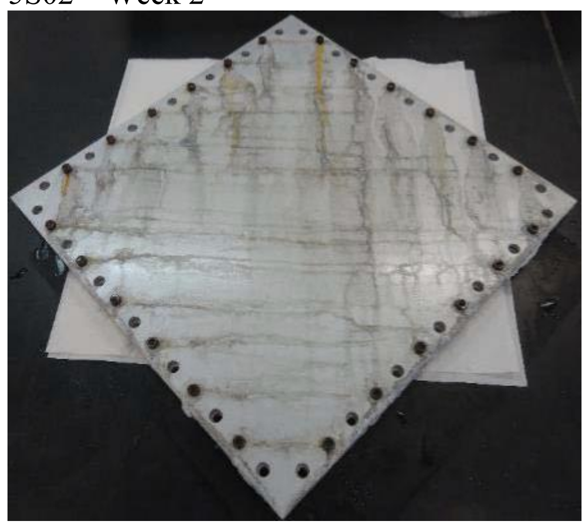
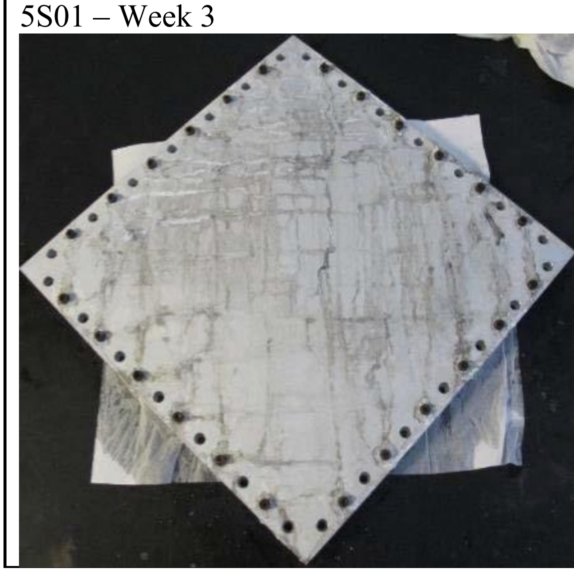
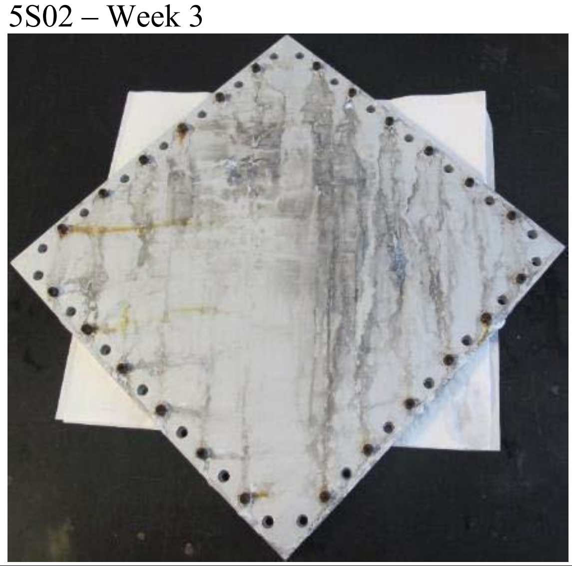
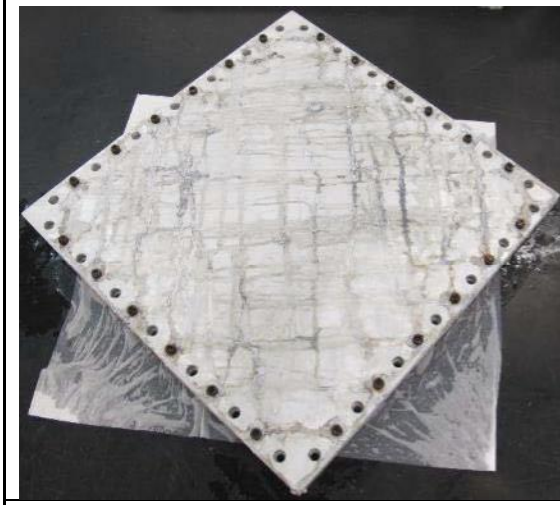
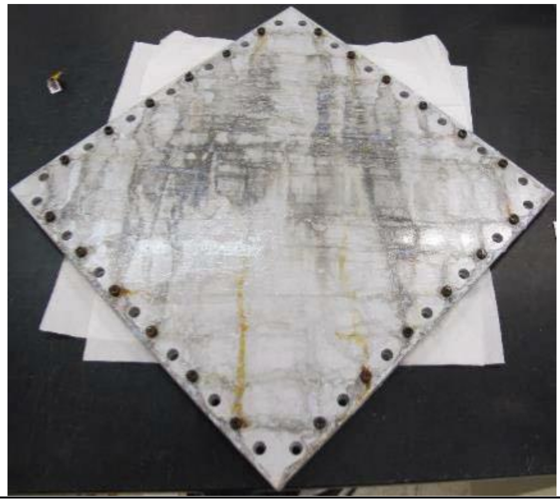
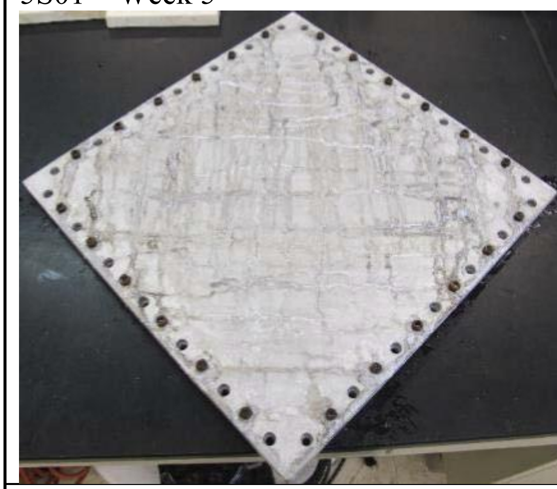
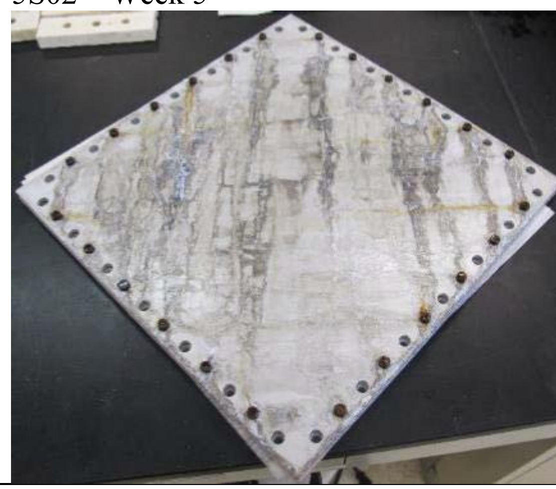
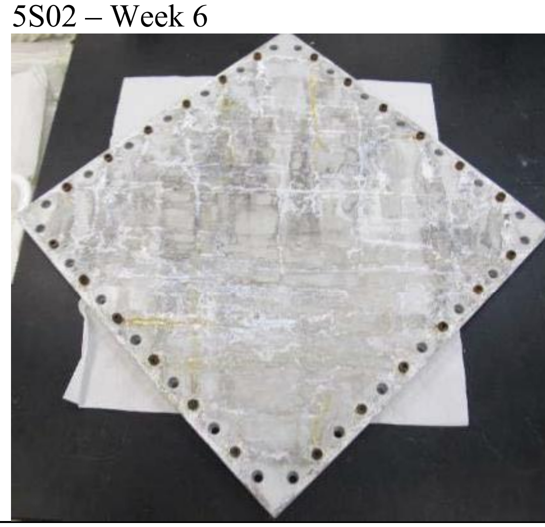
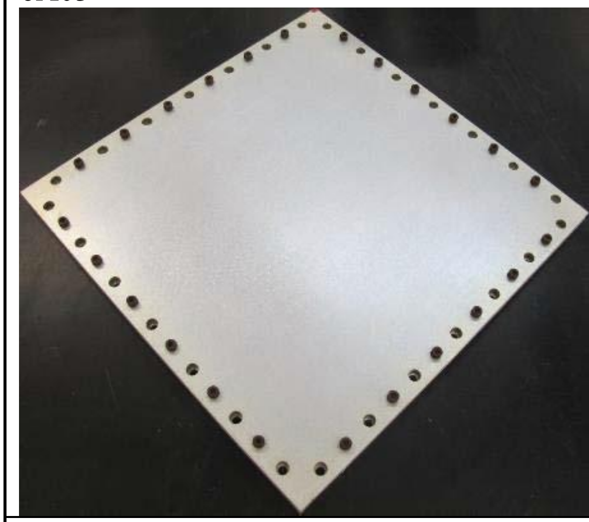
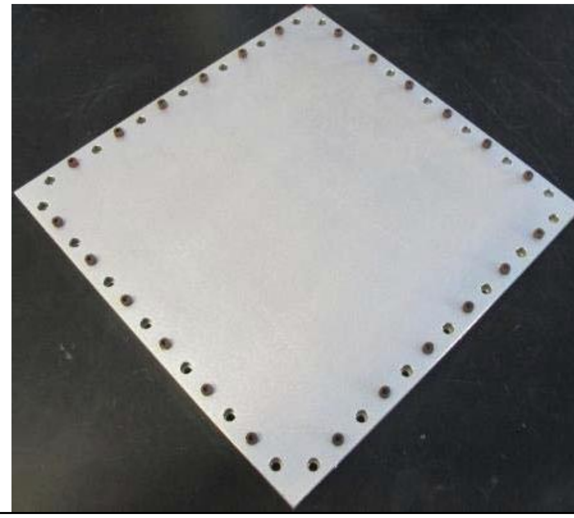
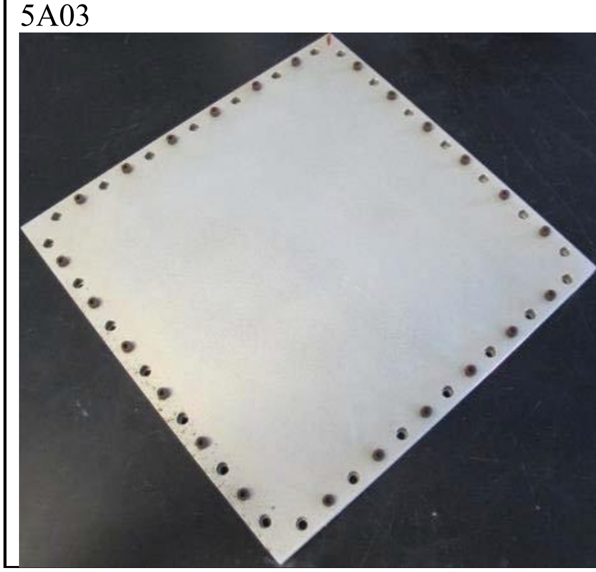
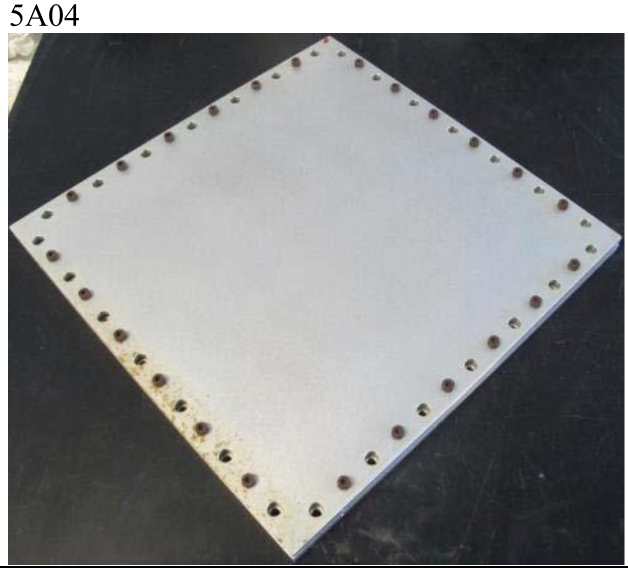
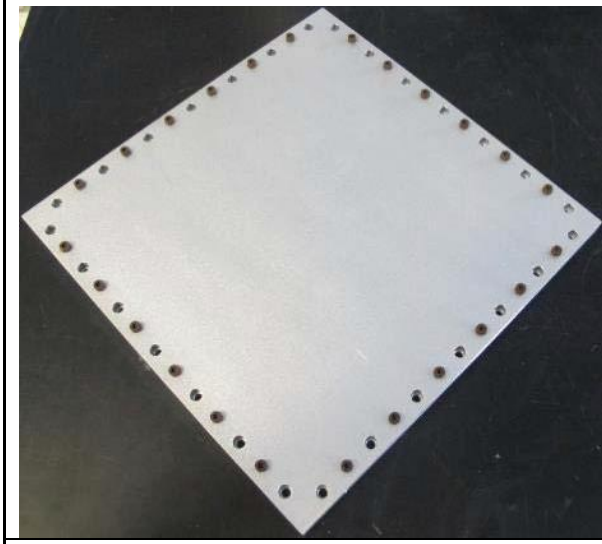
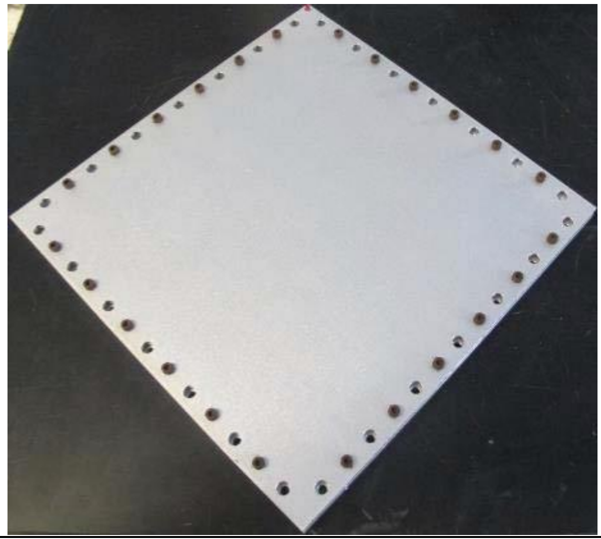
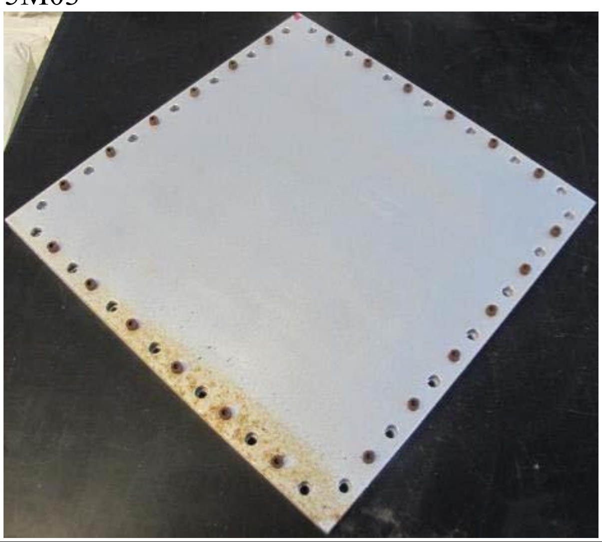
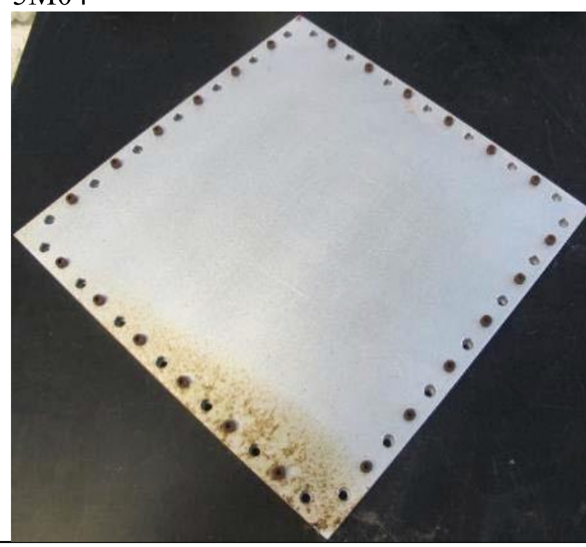
	

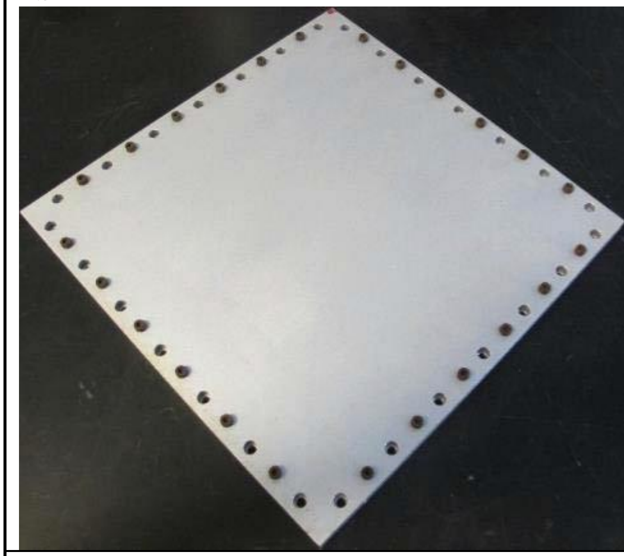
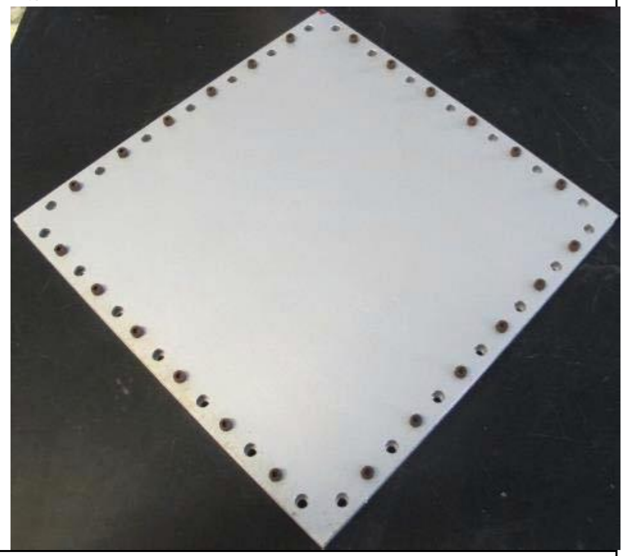
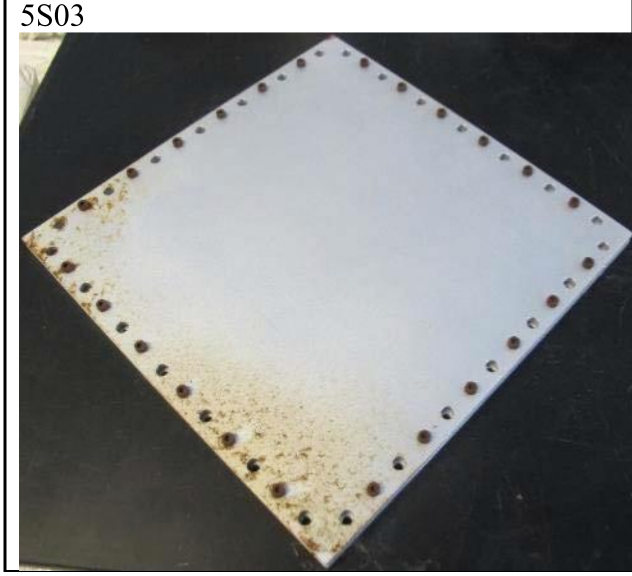
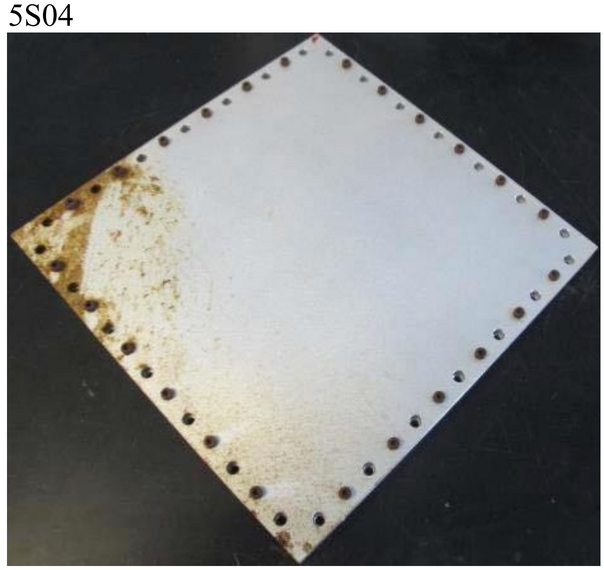
SurTec 650 – 5052-H32	
5S01 – Week 1 	5S02 – Week 1 
5S01 – Week 2 	5S02 – Week 2 
5S01 – Week 3 	5S02 – Week 3 

5S01 – Week 4 	5S02 – Week 4 
5S01 – Week 5 	5S02 – Week 5 
5S01 – Week 6 	5S02 – Week 6 

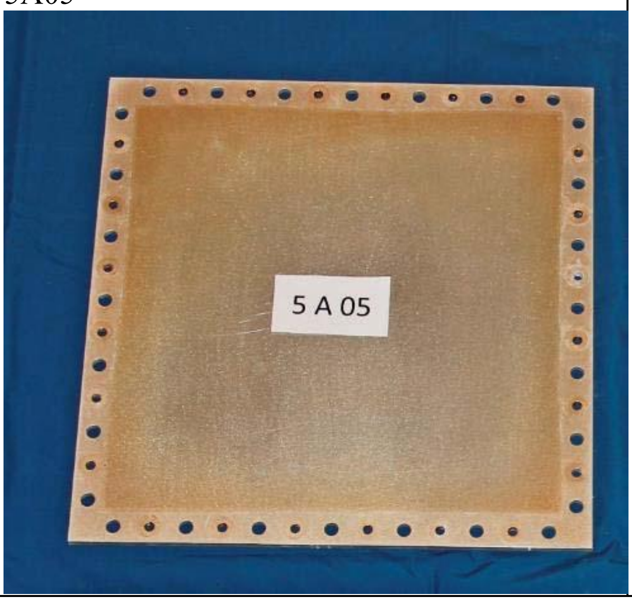
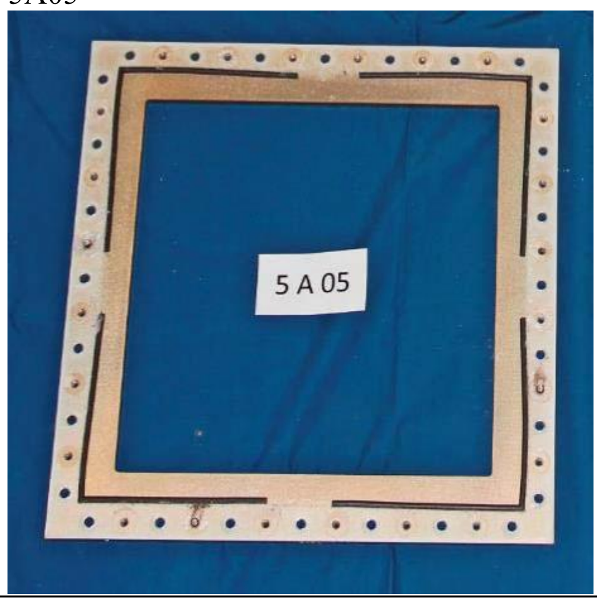
Appendix G – Test Plate Pictures – Static Heat and Humidity Testing

Alodine 1200S – 6061-T6	
6A03 	6A04 
Alodine 1200S – 5052-H32	
5A03 	5A04 

Metalast TCP – 6061-T6	
6M03 	6M04 
Metalast TCP – 5052-H32	
5M03 	5M04 

SurTec 650 – 6061-T6	
6S03 	6S04 
SurTec 650 – 5052-H32	
5S03 	5S04 

Appendix H – Test Plate Pictures – Beach Front

Alodine 1200S – 6061-T6	
6A05 	6A05 
Alodine 1200S – 5052-H32	
5A05 	5A05 

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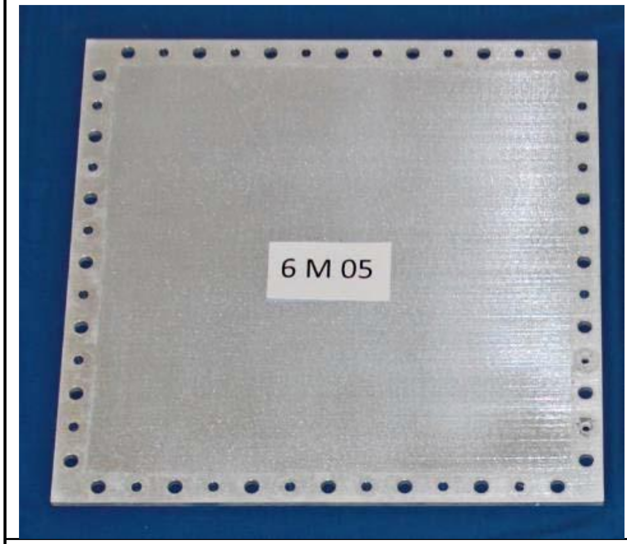
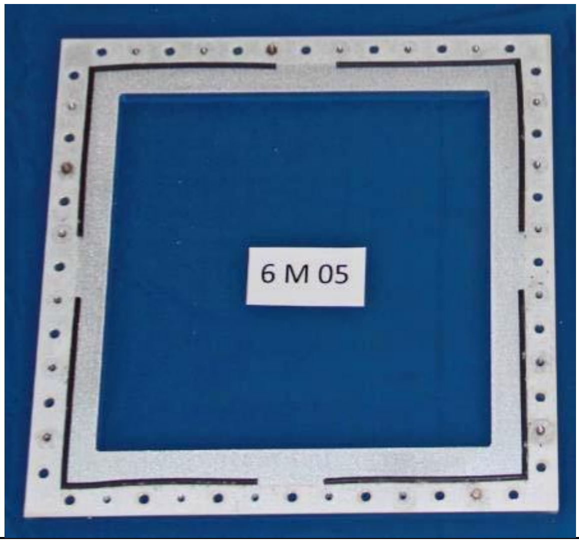
</td><td>6M05
</td></tr>
<tr><th colspan="2">Metalast TCP – 5052-H32</th></tr>
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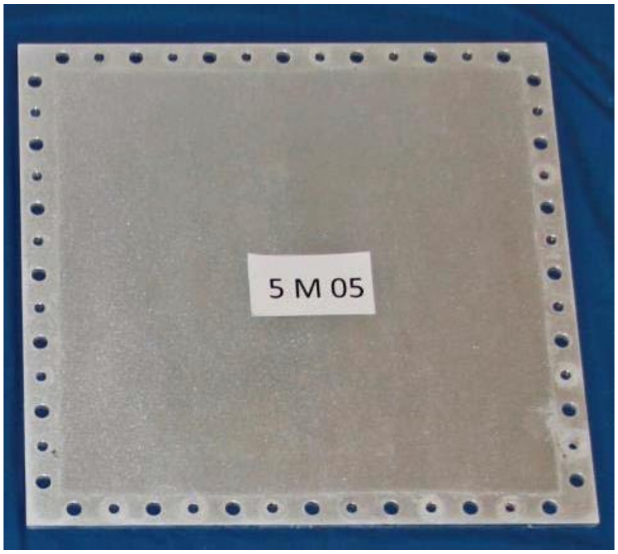
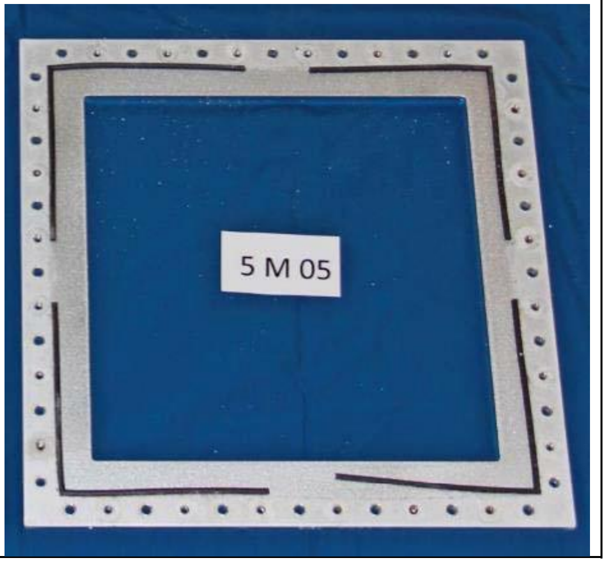
</td><td>5M05
</td></tr>
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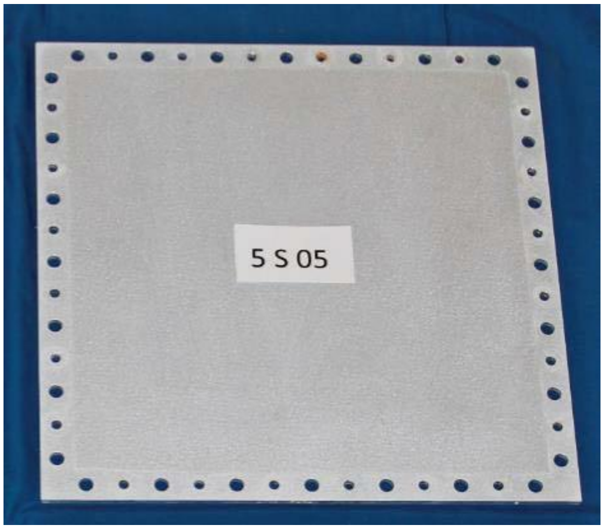
SurTec 650 – 6061-T6	
6S05 	6S05 
SurTec 650 – 5052-H32	
5S05 	5S05