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CORROSION CONTROL TEST METHOD
FOR AVIONIC COMPONENTS

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AIRTASK A320 320A/001B/1F61542000
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The program objective was to develop an accelerated laboratory corrosion test capable of simulating the severe corrosive effects of an aircraft carrier deployment environment. The current standard 5% salt fog test is not severe enough to simulate the carrier environment, thus limiting its usefulness in forecasting corrosion failures.

To provide test standards, representative electrical and electronic units were exposed on an oil burning carrier during a 9 month tropical cruise and on

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-a nuclear carrier during a 10 month tropical cruise. A series of laboratory tests were run to identify corrosion environments which provide good correlation with actual carrier results. The tests were also judged on their ability to promote moisture related electrical failures.

During the final phase of the program, 25 electronic and electrical components were exposed to the two most promising test methods.

The selected test method is a modification of the NADC sulfur dioxide salt fog test. It utilizes a much higher exposure temperature and a dilute substitute ocean water solution for fog generation. In one week this test method produces both corrosion damage and electrical failures that correlate with the condition of the test articles exposed for nine to ten months on an aircraft carrier.

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FOREWORD

This final report describes work performed on Navy Contract N62269-79-C-0257 "Corrosion Control Test Method for Avionic Components." The work reported herein was performed by the McDonnell Aircraft Company, McDonnell Douglas Corporation, St. Louis, Missouri. The program was administered under the direction of the Naval Air Development Center by Irving Shaffer.

The program was conducted by the Materials and Process Development Department at McDonnell Aircraft Company, St. Louis, and was managed by H. C. Turner, with A. W. Morris as principal investigator. Other contributors to the program include H. M. Keeser, E. Malakelis, and E. A. Muegge who were responsible for running the laboratory tests.

This report covers the entire program contract period from December 1979 to March 1981.

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1. INTRODUCTION AND SUMMARY

1.1 INTRODUCTION - A major reason for the increased effectiveness of modern military aircraft is the greatly enhanced capabilities of their avionic systems. Therefore, successful mission completion is increasingly dependent on avionic reliability. A Naval Air Development Center investigation (Reference 1) shows that environmental related effects, such as corrosion, play a significant role in reducing avionics reliability, as well as increasing maintenance and replacement costs.

An effective way of minimizing corrosion problems on future products is to use a qualification test that is capable of identifying weaknesses or oversights in the design of avionic systems that result in premature corrosion related failures. This enables the designer to take the necessary corrective action before the system is put into fleet service.

The MIL-STD-810 5% salt fog test is currently the only test specified in standards and specifications for evaluating avionic components for resistance to marine environments. The neutral environment of the salt fog test cannot duplicate the wide range of service induced corrosion mechanisms because natural environments are generally acidic as a result of the prevailing presence of sulfur dioxide. For example, Ketcham (Reference 2) reports that moisture films on aircraft deployed on the flight deck of four different carriers had pH's ranging from 2.4 to 4.0.

The program objective is to develop an avionic corrosion test that is tailored to the needs of certifying line replaceable units (LRU) or individual components intended for use in aircraft carrier deployed weapon systems. To be effective, the test method must produce corrosion failures in a few days that normally occur after months or years of service. On the other hand, it must not produce failures that will not occur in service. The test method should also be designed for exposing LRU's in their avionic boxes or electrical connectors without the benefit of enclosures to represent weapon system installation practice.

1.2 SUMMARY - The program plan is shown in Figure 1. Test articles were selected which represent state-of-the-art technology, a variety of materials and protective finishes and which are a mix of components - some with a history of corrosion related service failures and others with a history of satisfactory performance. To be satisfactory a test must fail test articles which fail in service but must not fail components that perform satisfactory in service.

Sets of test articles were fabricated for carrier and laboratory exposure. Test articles were first exposed on the radar mast of the nuclear carrier Nimitz. Other test articles were exposed on the radar mast of the conventional carrier Constellation (see Figure 2). Test article sets used in the initial

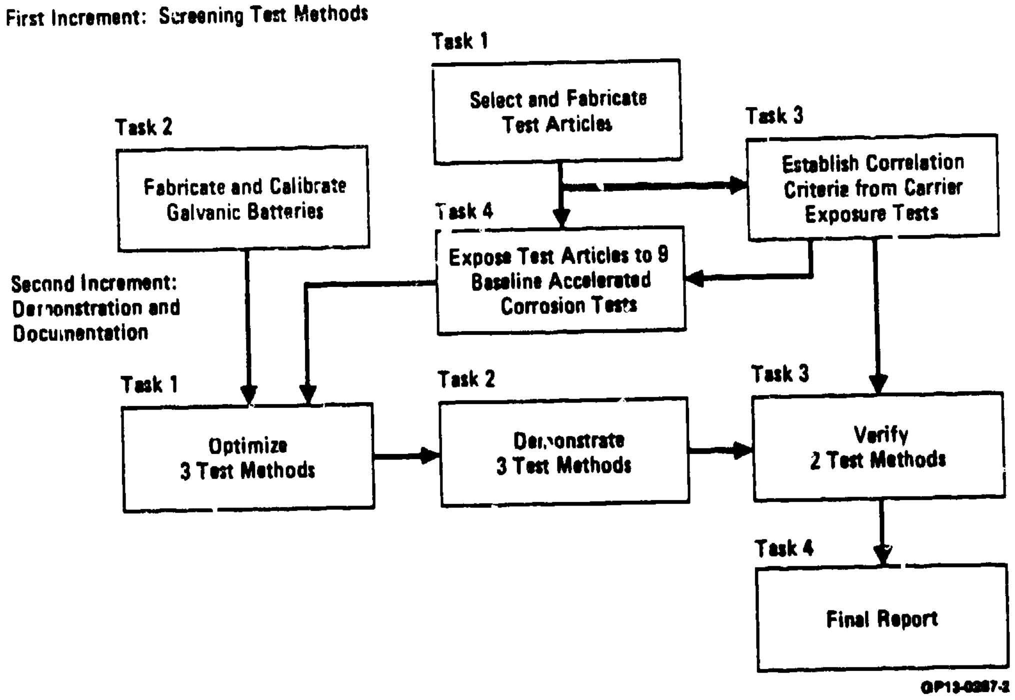

Figure 1 Program Plan

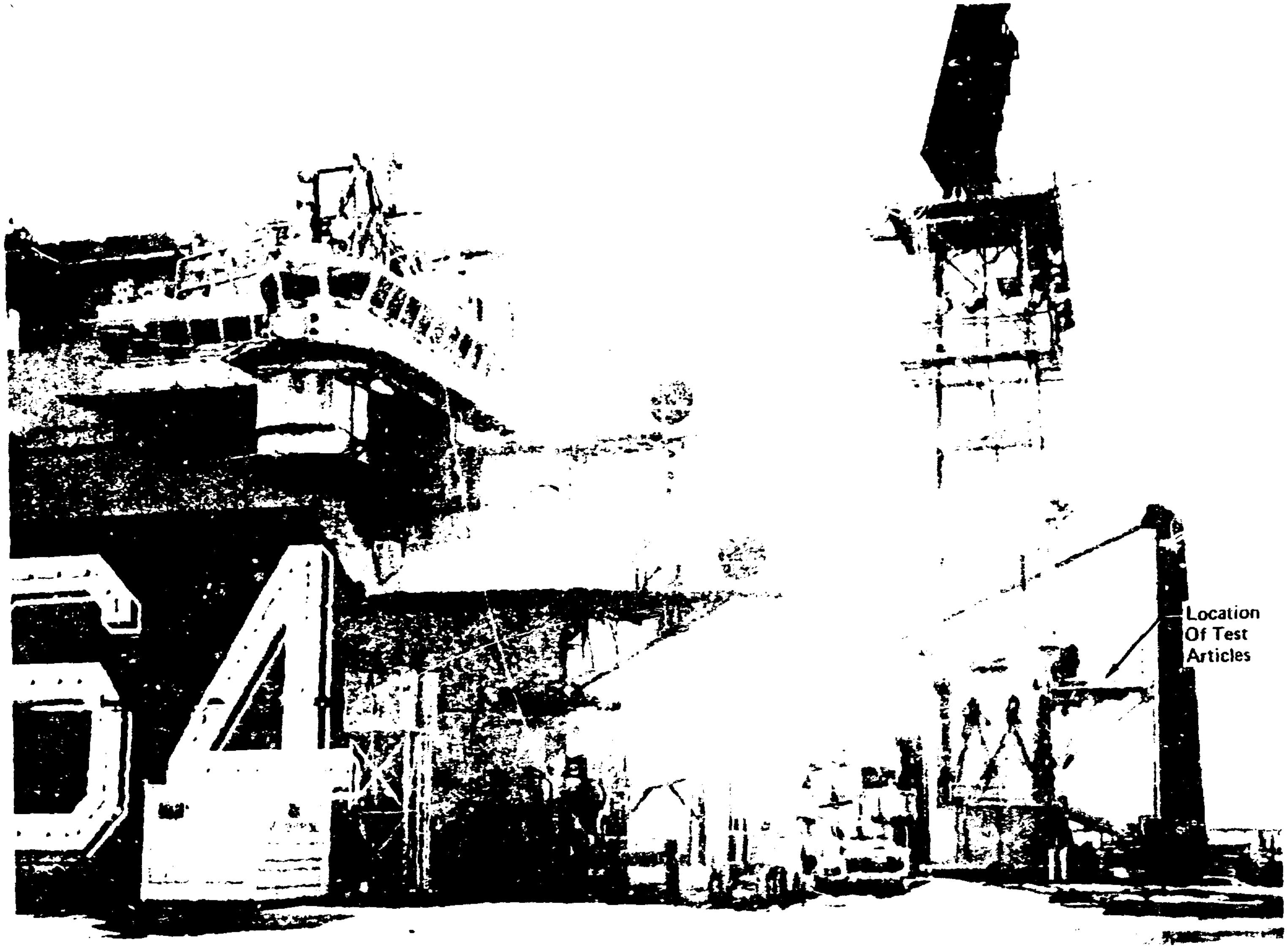

Figure 2 Constellation Rack Exposure

laboratory accelerated tests were similar to those exposed on the Constellation. Test articles exposed on both the Nimitz and Constellation were combined for the set of articles used in the final verification accelerated tests. These carrier exposed test articles were used as test standards. Laboratory tests were rated on their ability to duplicate the condition of the test standards.

Three different environmental type test methods were used as the starting point in the search for an effective avionics test method (Type A, Salt Fog; Type B, SO_2/Salt Fog with humidity; Type C, Sulfur Monochloride/Humidity). There are three variations of each of the three environmental types making a total of 9 baseline tests.

Of the three salt fog tests, Type A variant #1 is the standard salt fog method - the only method now referenced in military specifications; #2 is the NADC sulfur dioxide/salt fog (SO_2/SF) test which by agreement with NADC is used for testing the corrosion resistance of F-18 hardware (except avionics). The other test variant is experimental.

All Type B test methods utilize a weekly cycle that starts with a 6 hour SO_2/SF exposure to contaminate the surface with the same corrodents that accumulate on aircraft components during carrier service. This is followed by a 162-hr humidity test. Humidity tests by their high temperature and temperature cycling are designed to drive moisture into partially sealed air spaces and speed up moisture absorption by electrical insulation.

Type C test methods use a volatile corrodent, sulfur monochloride (S_2Cl_2), combined with a high temperature-high humidity environment to generate corrosion and electrical failures.

Test articles were exposed for 500 hours to the 9 test environments. The condition of the exposed test articles was compared to corrosion criteria established by the carrier exposure and to electrical criteria established by service history, carrier exposure and arbitrary standards.

Both the NADC SO_2/SF test and a 3.5 ppm S_2Cl_2 test produced more test articles that correlated with established criteria than any of the type B humidity tests.

In the second increment of the program, galvanic batteries were used as an aid in developing test parameters which made it possible to reduce the exposure time required for the SO_2/SF and S_2Cl_2 tests to correlation with carrier exposure data and to optimize a hydrochloric acid/sulfurous acid (HCl/H_2SO_3) test used to replace the Type B tests. The galvanic battery design is based on work by Tomashov (Reference 3) and by Kucera and Mattson (Reference 4).

A demonstration test in which test articles were exposed to the three optimized tests showed that the high temperature SO_2/SF and the HCl/H_2SO_3 tests had a higher correlation score than the S_2Cl_2 test. Therefore these two test methods were selected for the verification test.

In the final verification test, a wide range of test articles were exposed to the modified SO_2/SF and the HCl/H_2SO_3 test. Examination of the test articles after exposure showed the modified SO_2/SF test had the best carrier correlation with 16 test articles showing the same amount of corrosion, 2 test articles with less corrosion and 2 with more. The HCl/H_2SO_3 test was too benign for good correlation because 8 test articles showed less corrosion than the carrier exposed replicas.

Based on its performance data, the high temperature SO_2/SF test is recommended as a replacement for the MIL-STD-810 salt fog test. The standard salt fog test had the lowest correlation of all but one of the 8 baseline tests because, even after 500 hours of exposure, it failed to corrode 8 out of 11 test articles that corroded as a result of carrier exposure.

In contrast, after 1 week exposure to the high temperature SO_2/SF test the electrical connector shells, the nickel plated transistor cases and the printed circuits of the uncoated circuit board exhibited the same amount of corrosion as the carrier exposed test articles. This test method also produced moisture induced failure of 4 pin electrical connectors that have a history of similar failures in service. This effect is the result of the 120°F test temperature compared to only 95°F used in the standard test. As a result, the high temperature SO_2/SF test can be used as a combination corrosion-humidity test. If used in this capacity, it would significantly shorten the time required for the humidity and corrosion qualification testing of avionic equipment.

2. FIRST INCREMENT ACTIVITIES

2.1 TEST ARTICLES - Test articles played a crucial role in meeting the program objectives because the corrosion test candidates under development were rated by their interaction with the test articles. With this in mind, the criteria for their selection contained the following requirements. They had to represent state-of-the-art technology so that materials, finishes and configurations would be relevant. The test articles must represent a wide range of structural material/finish combinations to preclude choosing a test method that produced environmental effects similar to a service environment on some material/finish combinations but not on others. Electrical connectors of a certain type were chosen because they had a history of corrosion failures in the field. On the other hand, a conformal coated circuit board was chosen because of a history of satisfactory performance. Obviously in order to be considered satisfactory, a test environment must fail test articles which fail in service but must not fail test articles which have a good service record. Test articles used in both program increments are listed in Table I.

2.1.1 Baseline and Demonstration Test Articles - The set of test articles selected for the baseline tests included:

- A 4-pin connector assembly (4 circuits) with a case history of shell corrosion and electrical shorts
- A circuit board shown in the photograph in Figure 3 with two types of capacitors (3 each) and 3 transistor cans soldered to the printed circuits. Each set of test articles included a circuit board that has a conformal coating and one that was not coated
- Three resistors mounted as shown in Figure 3. One resistor package was conformal coated - the other was not
- Test circuit coupons with parallel circuits spaced 0.025 in apart for current leakage measurements. One coupon was conformal coated - the other was not.

The conformal coating used on the test articles is a MIL-I-46058 acrylic with a dielectric strength of 1500 volts, a moisture resistance of 40 gigaohms and an operating temperature tolerance of -75°F to 270°F.

These test articles are identified in Table I by an asterisk. Table I data shows test article part number, or the military specification to which it was ordered. Table I lists the materials and finishes of the test article metal details used for comparing the effects of the carrier environment with the test environment.

TABLE I TEST ARTICLES

Test Article	Part No. or Specification	Finish	Material
4 Pin Connector*			
● Plug	PT02E-8-r4D	Chromate Conversion Coated Cadmium	6061 Al Alloy
● Receptacle	PT06CP-8-45	Chromate Conversion Coated Cadmium	6061 Al Alloy
10 Pin Connector			
● Plug	MIL-C-2642	Electroless Nickel	6061 Al Alloy
● Receptacle	MIL-C-2642	Electroless Nickel	6061 Al Alloy
61 Pin Connector			
● Plug	PT00CP-24-61P	Chromate Conversion Coated Cadmium	6061 Al Alloy
● Receptacle	PT00CP-24-61S	Chromate Conversion Coated Cadmium	6061 Al Alloy
66 Pin Connector			
● Plug	MS38999P Series II	Chromate Conversion Coated Cadmium	6061 Al Alloy
● Receptacle	MS38999S Series II	Chromate Conversion Coated Cadmium	6061 Al Alloy
● Pin	MS27493-22D	Bright Dipped	Copper
● Pin	MS27493-22D	Electroplated Tin	Copper
● Pin	MS27493-22-D	Electroplated Gold	Copper
● Socket	MS27491-22D	Bright Dipped	Copper
● Socket	MS27491-22D	Electroplated Tin	Copper
● Socket	MS27491-22D	Electroplated Gold	Copper
Coaxial Connector			
● Right Angled Plug	M39012/05-0503	Electroplated Nickel	Brass
● Connector	M39012/03-0503	Electroplated Nickel	Brass
Test Circuit Coupon*	A69G0210-2	Solvent Clean	Copper
Fixed Resistor*	MIL-R-39017	Lead/Tin Electroplated	Copper
Variable Resistor	JANTXZN2219A	Passivated	Stainless Steel
Toggle Switch	MIL-STD-202	Cadmium Plated	Steel
Circuit Board*	MS24525	Tin Plated	Copper
● TA Capacitor*	39003/01-2327	Tin/Nickel Plated	Stainless Steel
● Mica Capacitor*	39014/01-256	(Leads) Tin Plated	Kovar
● Transistor*	12464-A69D0809	Nickel Plated	Steel
Track Socket Module	CXT3841	Electroplated Nickel	Stainless Steel

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● = Assembly details

*Baseline and Demonstration Test Articles

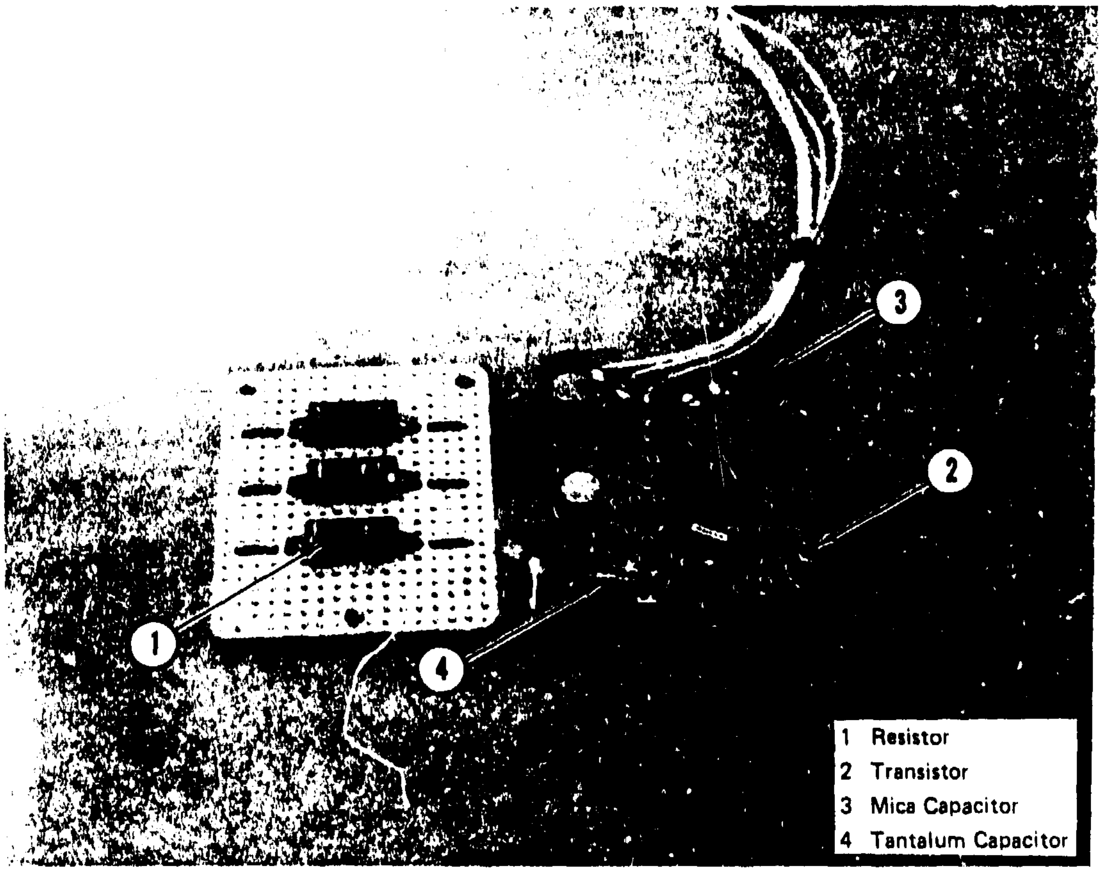

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Figure 3 Resistors and Circuit Board

2.1.2 Verification Test Articles - The final screening test in the second increment of the program was used to verify the performance of the two most successful test methods and to select the winning candidate. To broaden the data base for making the test selection, all 25 test articles listed in Table I were exposed to the two test environments and compared to their aircraft carrier exposed replicas.

The extra test articles added the following material/finish combinations to those of the baseline test articles; electroless nickel plated aluminum, tin and gold plated copper, passivated stainless steel, nickel plated brass and nickel plated stainless steel.

2.1.3 Test Article Fabrication

Electrical Connectors - All electrical connectors were wired in the production facilities using military aircraft procedures and materials. Connectors are assembled by crimping M22759/11 wire to attach the wires to the gold plated sockets in the plug and to attach wires to the gold plated pins in the receptacle. The contact assembly is then inserted into connector grommets which act as a dielectric material to prevent shorting. This contact assembly is then pushed into a connector shell until the grommet snaps into place. The cavity behind the grommet is sealed by potting with MIL-S-8516 class 3 sealing compound to a minimum height of 0.25 in. above the ends of the crimped area of the pin and socket contacts. The connector wires are protected by a polyester braided jacket which extends 6 in. from the connector back shell to within a few inches of the ring tongue terminals. Selfbonding silicon tape is wrapped over the backshell and extends for approximately 6 inches above the jacket.

The connector and wire bundle assembly with 66 circuits (pins) was not standard in that although 22 pins had standard gold plated pins, 22 were tin plated, and 22 were unplated copper. This was done to determine the effect of the test and carrier environments on the contact resistance between the pins and sockets with the three different finishes.

The coaxial connectors were assembled with back shells and radio frequency coaxial cables with an extruded polyetherfluroethlyne dielectric around the central copper wire conductor. The cables were fitted with standard nickel plated brass receptacle and a right angle plug.

Circuit Boards - The circuit boards shown in Figure 3 were made from a copper clad laminate by etching away all copper not used for the circuits, then tin plating the circuits. All components were mounted on the circuit board by hand-soldering. Finally, six 12 in Teflon coated 22 AWG lead wires were soldered to the solder pads to permit electrical tests on the capacitors.

No electrical tests were planned for the transistors, the intent being to display the corrosiveness of an environment by the amount of corrosion on the transistor cases.

The test circuit coupons, like the circuit boards, are fabricated from copper clad laminate. The etched copper circuitry is especially designed to test the dielectric properties of the board by energizing two parallel circuits spaced 0.025 in. apart. No fabrication was required beyond conformal coating the designated coupons. None of the other test articles required any in-house operations beyond mounting them on fiberglass boards for support during the testing.

2.2 GALVANIC BATTERY

2.2.1 Galvanic Battery Fabrication - Five galvanic batteries were fabricated and calibrated as tools for expediting the optimization of three winning baseline test environments in the second increment of the program. The schematic in Figure 4 illustrates their assembly. Anodes, 0.020 in. thick, were fabricated from QQ-A-250/1, 1100-H14 aluminum, cathodes from QQ-C-276 copper, 0.020 in. thick, and 0.004 mil Mylar sheet was used as insulation. Aluminum was chosen as the anode material because, in the corrosive environments used in the test program, steel or zinc anodes would produce voluminous corrosion products which could produce spurious readings. Copper was chosen as the cathode because increased sensitivity provided by more aggressive cathodes such as silver or platinum was not necessary in the aggressive test environments.

Mylar sheet, 0.004 in. in thickness was chosen as the insulating material for its durability. Galvanic action between the anodes and adjacent cathodes is initiated when an electrolyte, such as a moisture film, bridges across the Mylar insulation to produce an ionic path between anode and cathode. As a result, the sensitivity of the battery to relative humidity is affected by the thickness of the Mylar because the thinner the insulation, the thinner the moisture film needed for battery activation.

Each individual metal ply was manually deburred to eliminate any electrical shorts and then the electrodes and the Mylar were drilled for the Nylon bolts and deburred. They were assembled by alternately stacking copper, Mylar, aluminum, Mylar, copper, etc. as shown in Figure 4. The copper plies extended beyond the aluminum on one end of the battery so that a copper bolt could be inserted in the holes to form the cathode terminal. The aluminum plies were also bolted in like manner to form the anode terminal.

The working faces of the batteries were surface ground and polished to a bright finish and until all edge faces were of uniform height. Considerable additional effort was expended in eliminating any electrical shorts detected with an ohmmeter.

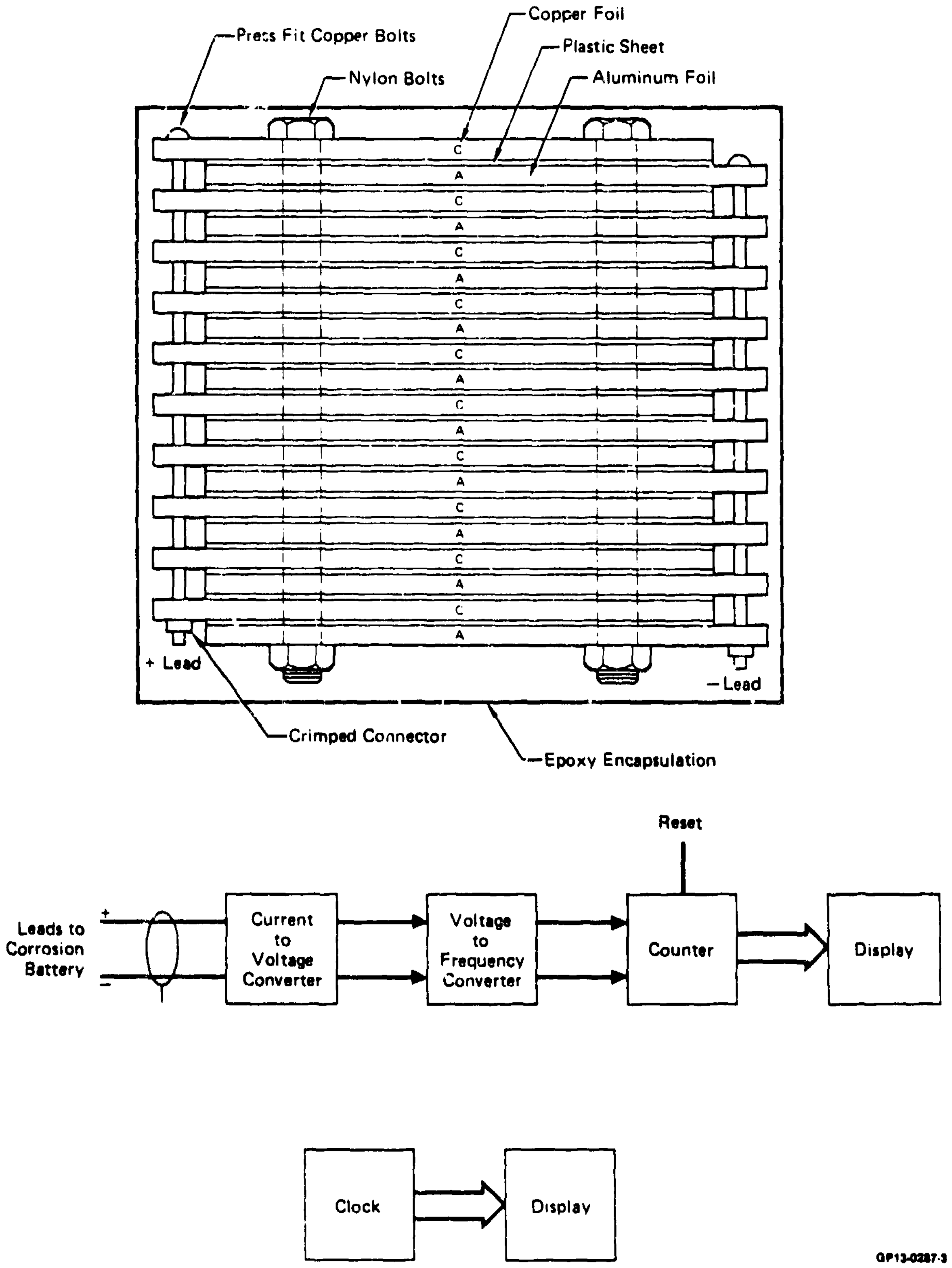

Figure 4 Schematic of a Copper-Aluminum Galvanic Battery and Digital Coulomb Counter Components

The resistance of the batteries was determined at various stages of assembly with a General Radio Company Megohmeter (Serial No. 1373) while applying 50 volts DC across the copper bolt terminals after the Nylon bolts had been tightened. The resistances ranged from 240 x 10^6 to 500 x 10^6 ohms.

2.2.2 Digital Coulometer Fabrication - The coulometer has two basic circuits as shown in Figure 4. One circuit is an elapsed time clock; the other is a coulomb measuring device. In this latter circuit, a small current (i.e., from the galvanic battery) is converted to a proportional voltage. This voltage is then converted into square wave pulses with frequency proportional to the input voltage. These pulses are counted and displayed. An important feature of the current-to-voltage converter is a low input impedance. This is necessary so that the battery operation is not inhibited by circuit impedance. The basic component of this circuit is a precision operational amplifier (LM108AL) which has an extremely low offset voltage (0.3mV). The conversion equation for this current is V (volts) = i (amperes) x R (ohms), where R is the value of the feedback resistor. The i-to-V converter operates in either of two ranges, wet or dry, by switching between different feedback resistors.

To test the accuracy of the coulomb counter, several long term calibrations were performed by connecting the coulometer to a Kiethly 261 Picoampere source for several weeks. At the end of each run the total current on the display was compared to calculated value. This test was repeated using several different current levels. The accuracy checked out within 0.5 percent.

2.2.3 Battery Calibration - The batteries were calibrated in several media in pairs to see which medium gave the most consistent results. The resultant data is tabulated below. Because both the anode and cathode area of the battery is 1 square inch, the coulometer reading was in coulombs per square inch which could be converted to milliamperes (mA) per square inch by dividing by the time over which the current was measured in seconds.

CALIBRATION MEDIA	AVERAGE CORROSION CURRENT IN MA/IN^2		HOURS OF EXPOSURE
	Battery 1	Battery 2	
Distilled Water	0.0124	0.0115	400
5% Salt Fog	1.36	1.41	9
5% NaCl Immersion	1.37	1.40	12
Substitute Ocean Water Immersion	0.274	0.144	32
185°F/95% RH Oven	1.26	1.29	19
185° /95% RH Oven after 6 hr SO_2/SF exposure without cleaning	1.26	1.29	17

During 24 hours of substitute ocean water (SOW) immersion, battery output was at its highest level during the first hour of exposure; then it gradually dropped to the stable output shown in the table.

The corrosion current data in the above table shows good agreement between the batteries except for the substitute ocean water immersion. It is theorized that battery No. 2 built up a protective film of corrosion products on the aluminum anodes which inhibited battery output.

After calibration in each of the above media the batteries were exposed to the SO_2/SF environment to see which of the medium provided the most stable output.

It was found that the batteries stabilized in a shorter time and gave more consistent results when used in a test environment after calibration in a 185°F cabinet with a relative humidity of 95%. Apparently, this type of conditioning produced a surface film that promoted a more uniform attack on the aluminum anodes by the SO_2/SF exposure. Under magnification, the surface of the battery appeared to be more uniformly pitted by the SO_2/SF exposure when conditioned in the humidity cabinet as opposed to distilled water calibration.

2.3 <u>AIRCRAFT CARRIER EXPOSURE</u> - Twenty-three of the test articles listed in Table I were exposed on aircraft carriers to provide authentic test standards by which identical sets of test articles which had been exposed to laboratory environments could be measured.

All test articles marked with an asterisk in Table I except the 4-pin connectors were installed in an avionic box prior to exposure on the Constellation because they are the type of component that would be in an avionics box for service use. The aluminum avionics box, is about 5" long x 2.5" high x 2.5" wide. The box has 4 ventilation slots in the front simulating an F-18 design and has a hole for the wire bundle. This box with the test articles secured inside was sent to the Naval Air Development Center (NADC) where it was fastened to their expanded steel exposure rack.

The other Constellation test articles shown in Figure 5 were supported by bolting them to a fiberglass support board. The electrical connectors shown in Figure 5 were prepared for Constellation exposure by bolting the receptacle flange to the board with the receptacle extending through the hole so that the plug could be assembled to it by means of the bayonet coupling. The fiberglass board was bolted to the steel rack.

Connector #1 in Figure 5 is the 4-pin connector, #2 is the 61-pin connector and #3 is the 66-pin connector with the mixture of gold plated pins, tin plated pins, and bare copper pins.

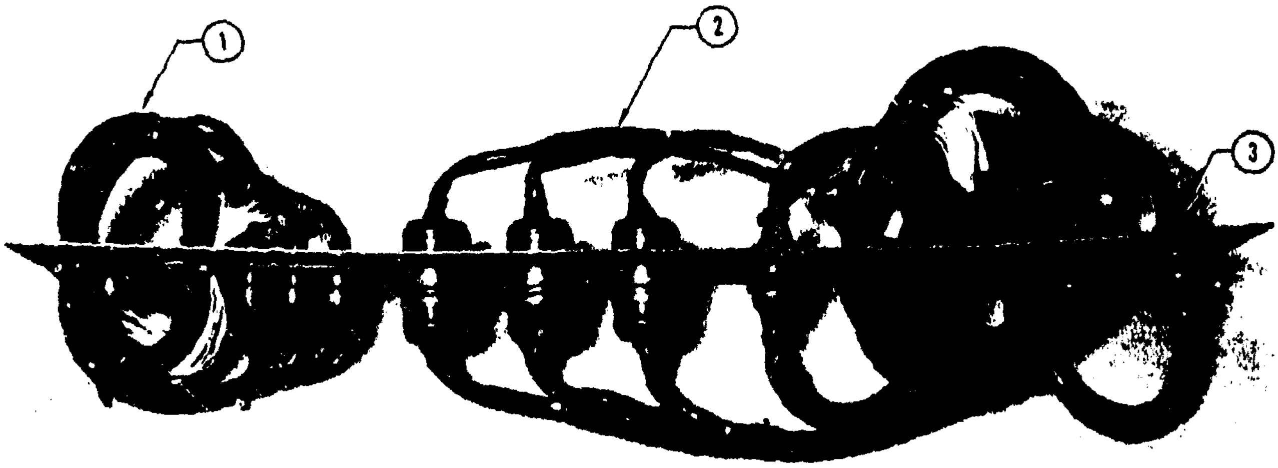

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Figure 5 Electrical Connectors Mounted for Carrier Exposure

These connectors and the avionic box and contents were fastened to the radar mast of the oil fueled carrier Constellation on 18 February 1980. They were recovered 9 months later on 20 November 1980 after the carrier returned from the Indian Ocean by way of the Pacific Ocean.

The remaining test articles listed in Table I except the track module and the 10-pin connector were mounted on fiberglass boards as described above, bolted to the NADC test rack and installed on the radar mast of the nuclear carrier Nimitz about 14 ft. above deck level on 24 July 1979. The test articles were recovered 10 months later on 24 May 1980 after cruising the Mediterranean Sea and Indian Ocean. The Nimitz also carried a set of coated and uncoated transistors as a comparison reference with the Constellation.

2.3.1 Corrosion Exposure Data - The entire Constellation test package including the plastic board on which test articles were mounted had a light salt deposit on it. As shown in Figure 6, the 4-pin (1) and 61-pin (2) connector shells were heavily coated with a white powder - mostly cadmium corrosion products with some crystalline salt. When the shells were washed and brushed, numerous pits extending into the aluminum substrate became visible. The uncoated transistor cans in Figure 7 had a greenish appearance and each can had at least a 100 sites where there was a buildup of corrosion products about the size of a pinhead. The conformal coated transistor cans had a narrow band of corrosion products around the base interface. All uncoated printed circuits were corroded. Conformal coated circuit boards still had a bright shiny appearance while the coated test coupon circuit had black corrosion products beginning at the through-hole at the end of the circuit and continuing for 10% of its length. One coaxial connector had to be cut with a saw before it could be disassembled because of corrosion products in the joint interface. This problem was caused by a defective seal. The 66-pin connector shown in Figure 8 had corrosion products on some of the tin plated pins. The bare copper pins had a dark tarnish. This data is tabulated in Table II for use as correlation criteria to evaluate laboratory test candidates.

Data derived by a visual examination of the Nimitz exposed test articles and documented in Table II can be summarized as follows:

- All cadmium plated parts were corroded but not as severely as the Constellation parts. The salt deposit was not nearly as heavy on the corroded surfaces.

- The most severe corrosion occurred on the cadmium plated toggle switch jam nuts and the uncoated transistors which were mounted outside the avionics box. See Figure 9. 50% of this area was covered by a rust stain.

Figure 6 Electrical Connector Corrosion After Carrier Exposure

Figure 7 Circuit Board Printed Circuit and Transistor Corrosion After Carrier Exposure

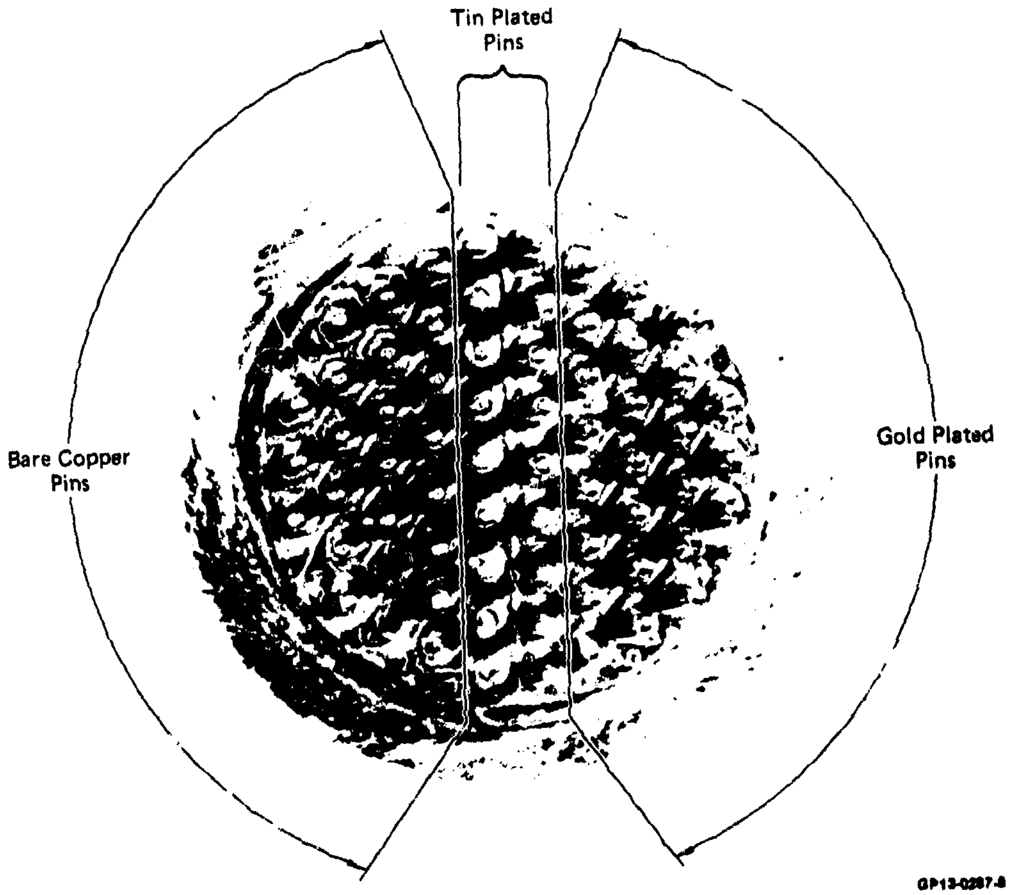

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Figure 8 Corrosion on Tin Plated Pins of the 66 Pin Connector After Carrier Exposure

TABLE II AIRCRAFT CARRIER AND SERVICE CORROSION DATA

Test Article	Area Examined	Corrosion Data
4 Pin Connector	Mated Shell Exterior	Cadmium Severely Corroded Over 100% of Surface. Nickel Undercoat Visible in Numerous Pitted Areas
● 10 Pin Connector	Mated Shell Exterior	Electroless Nickel Blistered-Substrate Corroded
61 Pin Connector	Mated Shell Exterior	Same as 4 Pin
66 Pin Connector Ag/P Wire	Mated Shell Exterior	Cadmium Corroded Over 100% of Surface. Large Corrosion Deposits Between Coupling Ring and Shell Made it Necessary to Saw the Ring in Two to Disassemble the Connector
	Contact Pins	Gold Still Shines, Copper Dulled, Tin Corrosion
Coaxial Connector	Mated Shell Exterior	Bright Polished Finish Reduced to Dull Grey
Uncoated Test Coupon	Printed Circuits	Coated with Black Corrosion Products Over 100% of Area
Conformal Coated Test Coupon	Printed Circuits	Coated with Black Corrosion Products Over 12% of Area
Uncoated Ta Capacitor	Lead/Tin Plated Leads	Coated with Black Corrosion Products Over 100% of Area
Conformally Coated Ta Capacitor	Lead/Tin Plated Leads	Coated with Thin Grey Film Over 100% of Area
Uncoated Transistor (Exposed)	Case	Rust Stains Over 25% of Area at Base Joint
Uncoated Transistor	Case	Scattered Sites with Green Corrosion Product Buildup. Greenish Tinge Overall
Conformal Coated Transistor (Box)	Case	Some Green Corrosion Products Around Base of Case
Variable Resistors	Case	No Corrosion
Toggle Switch	Housing and Toggle	Cadmium Corroded. Heavy Rust where Mounting Nut Contacts Mount
Uncoated Circuit Board	Printed Circuits	White Corrosion Products Except for Black Spots where Substrate is Exposed
Coated Circuit Board	Printed Circuits	No Corrosion
Circuit Breaker	Nut and Threaded Portion of Housing	Coated with Uniform Film of Green Corrosion Products
● Track Socket Module	Entire Surface	Coated with Light Film of Green Corrosion Products

● = Service history data

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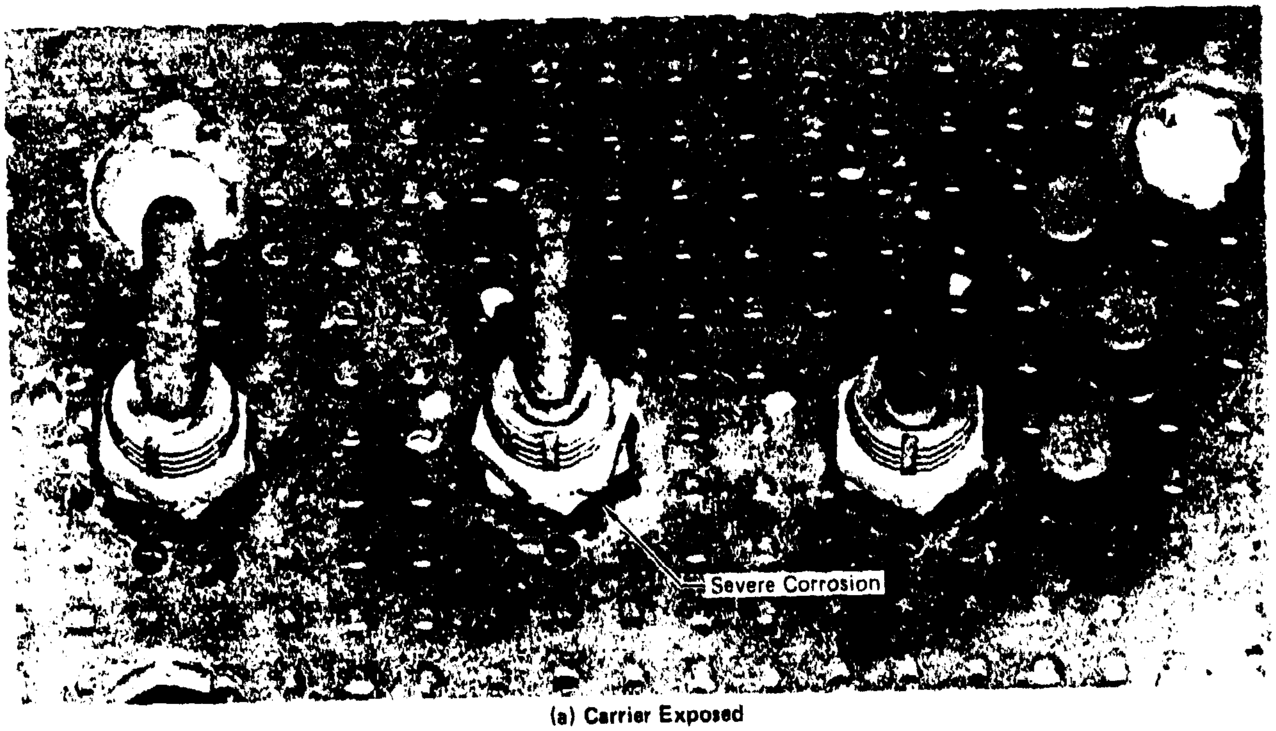
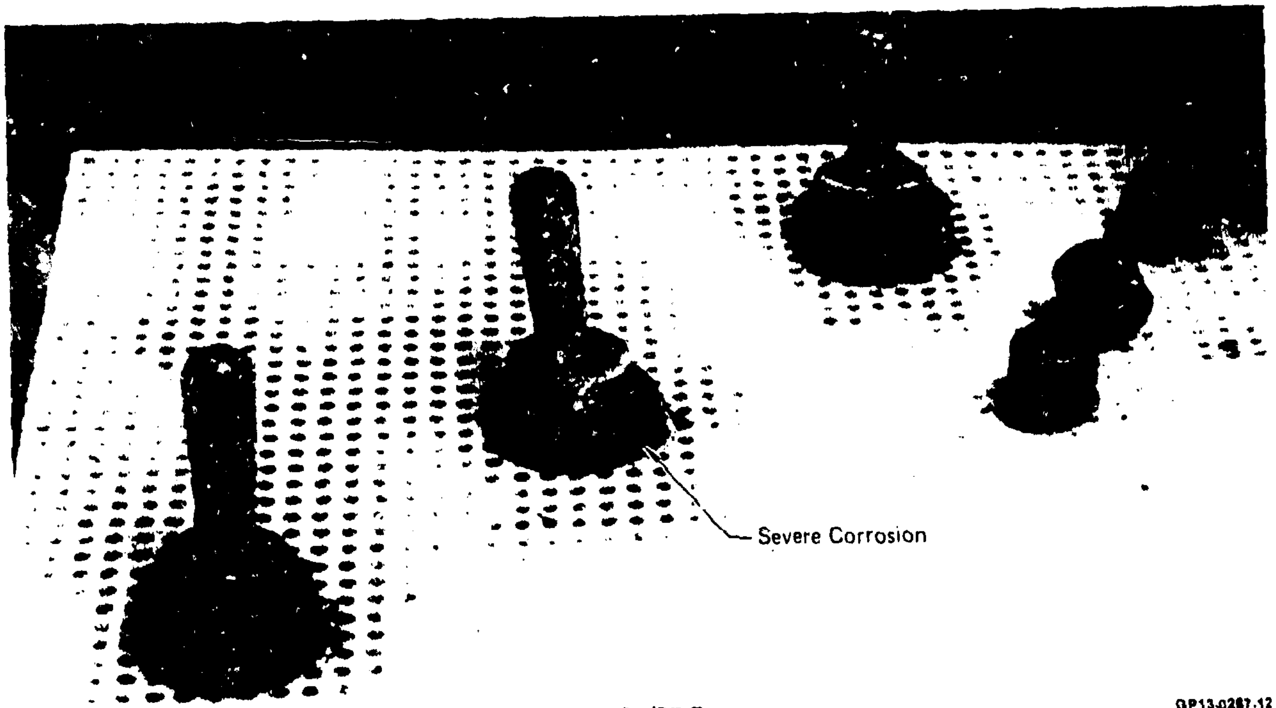


(a) Carrier Exposed



(b) After SO_2/SF Exposure

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Figure 9 Comparison of Toggle Switches and Transistors (A) Exposed During Nine Month Carrier Cruise and (B) Those Exposed to One Week SO_2/SF Test

- As compared to the condition of the transistor described above, the uncoated transistor in the avionics box had only 1% of the area at the base coated with a rust stain, but had the remainder of the surface dotted with green corrosion products

2.3.2 Electrical Exposure Data - Electrical property tests were carried out on the carrier exposed test articles. No significant difference was noted between the before and after circuit board and electrical connector insulation resistance measurements of the Constellation Package. This is attributed to a delay that meant the electrical tests were not carried out until weeks after the exposure rack was removed from the carrier. Evaporation of accumulated moisture before testing would restore any loss in dielectric properties of insulation materials. Corrosion damage to the tin plated contacts of the 66-pin connector shown in Figure 8 caused high contact resistance on 25% of the pins. Copper pins and the gold pins were not affected.

Electrical tests on the Nimitz package showed that circuit breaker performance suffered serious deterioration. The time to trip under 200% of rated current increased from an average of 8.1 sec. before exposure to an average of 31 seconds after exposure.

Another significant change in performance was the increase in contact resistance of two out of three toggle switches from 5 mΩ before exposure to 520 mΩ after exposure.

2.4 BASELINE ACCELERATED CORROSION TESTS

2.4.1 Environments - the baseline tests are listed in Table III. They include three variations of three types of environments for a total of 9 test methods. The test duration was 500 hrs. for all nine tests.

(a) Type A Environments - The MIL-STD-810 salt fog tests listed in Table III as Type A, variation 1 (A1) is the only recognized qualification test method for evaluating the effect of a marine environment on avionic equipment. For example, it is called out in the Electrical Connector Specification MIL-C-38999, in MIL-STD-202, Method 102, and in MIL-STD-1344, Method 1001.1.

This test was included in the program so that a comparison could be made between test data derived from this standard test method, the experimental test methods and the carrier environments. The salt fog test method requires the atomization of three quarts of 5% salt solution per 10 cubic foot of chamber volume every 24 hours. The solution is atomized by compressed air humidified by bubbling through 115°F distilled water. The cabinet temperature is held at 95°F.

TABLE III BASELINE TEST MATRIX

Variation Number	Type A Environment (Salt Fog)	Type B Environment (SO_2/Salt Fog and Humidity)	Type C Environment (Sulfur Monochloride/Humidity)
1	MIL-STD-810, Method 509.1, Salt Fog	MIL-I-46058 Thermal Humidity Aging and 6 hr per Week SO_2/Salt Fog Exposure	Sulfur Monochloride (350 ppm) in 185°F and 95% Relative Humidity Environment; 4 hr Daily Room Temperature Cool
2	NADC SO_2/Salt Fog Continuous Salt Fog and a SO_2 Injection for 1 hr every 6 hr	MIL-STD-1344, Method 1002.2, Type III, Humidity Cycle and 6 hr per Week SO_2/Salt Fog Exposure	Sulfur Monochloride (3.5 ppm) 185°F and 95% Relative Humidity Environment; 5 min Daily Room Temperature Cool
3	Cyclic SO_2/Salt Fog. 20 min Salt Fog and SO_2 Injection Followed by 23 hr 40 min Air Purge	77°F and 96% Relative Humidity Test Followed by Daily 185°F Oven Bake for 3 hr	Sulfur Monochloride (2,100 ppm) in 185°F and 95% Relative Humidity Environment; 5 min Daily Room Temperature Cool

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The Type A2 NADC sulfur dioxide salt fog test method has been very successful in simulating corrosion mechanisms, paint failures and sealant failures that sometimes occur on the moldlines of carrier based aircraft. Its success is attributed to the fact that in addition to salt fog, it utilizes periodic injections of sulfur dioxide which create the acidic conditions characteristic of oil burning carrier environments.

The fog generation and cabinet temperature meet the requirements of MIL-STD-810 except that ASTM D1141 substitute ocean water (SOW) is used to produce the fog. Sulfur dioxide from a pressurized source, controlled by a needle valve and flow meter is introduced through the wall of the chamber and dispersed through the cabinet via 8 holes in the baffle at the top of the dispersion tower as described in Reference 2. A cam and timing mechanism is used to introduce the gas for 1 hour every 6 hours at a rate of 1.0 ± 0.2 cm^3/minute/ft^3 of cabinet volume.

In the type A3 cyclic sulfur dioxide/salt fog experimental environment, both the SOW fog and the sulfur dioxide were injected at the same temperature and concentration as in the Type A2, test. Unlike the other Type A tests which utilize continuously generated salt fog environments, the A3 test utilizes a 30-minute injection of salt fog and sulfur dioxide gas at the same input rate as that used in the Type A2, test. This is followed by a three-hour stagnant air period, a three-hour air purge and then a 17 1/2-hr stagnant air period. This daily cycle is repeated for 21 days.

In this test the cabinet temperature is kept at 140°F, i.e., 45°F above that used in the standard test, to induce more rapid diffusion of the corrodents. The salt fog spray is at ambient temperature instead of 115°F to cool down the specimens during the spray cycle so that a negative air pressure condition will be created in partially sealed air spaces. This condition is created during the salt spray and sulfur dioxide injection when a maximum concentration of corrodents surrounds the test articles.

(b) Type B Environments - Type B salt fog and high temperature-high humidity test sequence contaminates the surface with salt and sulfur dioxide to simulate the accumulation of corrodents which occur in a service environment and then uses a high temperature/humidity environment to accelerate both corrosion reactions and the diffusion of corrodents and moisture into dielectric materials and organic environmental seals. The temperature is either cycled in the exposure chamber test or the test articles are removed and cooled to room temperature. These temperature differentials produce contraction and expansion of the air inside partially sealed enclosures (such as the inside of connector shells) to aid the intrusion of corrodents. In aircraft service pressure differentials occur naturally as a result of altitude changes and changes in ambient temperatures during flight and ground deployment.

During the type B1 weekly cycles, the test articles are exposed for six hours to the NADC SO_2/SF environment and then transferred to a humidity cabinet maintained at 185°F and 95% RH. The 185°F/95% RH conditions are specified in MIL-I-46085 for qualifying conformal coatings for printed circuit boards. Once a day, the test articles are removed from the humidity cabinet to a laboratory bench to cool and dry for 2 hours. The weekly cycle is repeated four times.

The type B2 test calls for the test articles to be contaminated for 6 hours in the SO_2/salt fog test and then placed in the humidity chamber to undergo the humidity cycle for the remainder of the week. The test environment used in this test is specified in MIL-STD-210, Figure 2, as the Type III Humidity cycle. During a 24 hour cycle, the temperature is raised from 82°F to 160°F over a two hour period, held for 6 hours at 160°F and 95% RH and then allowed to cool back to 82°F for the remaining 16 hours.

In the type B3 test, after a weekly 6 hour exposure to the SO_2 salt fog test, the test articles are exposed to a daily cycle which includes a 77°F and 96% RH environment for 21 hours followed by a drying cycle in a 185°F oven for three hours. This relatively low temperature humidity-soak followed by the high-temperature bake cycle was designed to draw humid air into partially sealed air spaces (such as the inside of connectors) by heating the articles in an oven and letting them cool in the 77°F 96% RH environment.

(c) Type C Environments - Exposure to sulfur monochloride vapor as part of a high temperature-high humidity environment was included in the baseline tests because preliminary tests indicate it is capable of reproducing service environment effects such as exfoliation and stress corrosion of aluminum and it does not require the elaborate atomizing equipment used in salt fog generation.

Sulfur monochloride (S_2Cl_2) in contact with moisture dissociates to form hydrochloric acid, sulfur dioxide and hydrogen sulfide:

$$S_2Cl_2 + 2H_2O \rightarrow 2HCl + SO_2 + H_2S$$

Sulfur dioxide and hydrogen sulfide are common air pollutants. The fact that the chloride is in the form of an acid instead of a salt makes it more corrosive but should not change the type of corrosion reactions generated by natural environment chlorides.

A 9 liter desiccator was used as a sealed environmental chamber for the three S_2Cl_2 tests. An evaporating dish full of distilled water provided 100% RH. A 185°F temperature was maintained by placing the desiccator in an oven. In the original test method, a glass bottle containing liquid S_2Cl_2 was also placed in the oven to act as a vapor generator. The S_2Cl_2 flow rate to the generator through glass tubing was controlled by a Corning Rotoflow adjustable valve. However, although considerable effort was expanded, the attempt to develop a gas analysis technique with the sensitivity needed to quantify the concentration of SO_2 and Cl_2 in the parts per million (PPM) range was unsuccessful. The tests were repeated using a calibrated eye dropper that delivers a drop of S_2Cl_2 weighing 0.02885 gm.

The type C1 test was designed to expose the test articles to a 350 PPM concentration of S_2Cl_2. Calculations show that at 185°F, 1 drop (0.02885 gm) of S_2Cl_2 produces a 350 PPM concentration in the 9 liter airspace. The actual concentration would be less because of corrosion reaction consumption. After the initial cycle in which the test articles, the distilled water and 1 drop of S_2Cl_2 were placed in the desiccator, and the desiccator placed in the oven, the following daily routine was followed:

a) Remove the desiccator from the oven
b) Allow the desiccator to cool on a bench for 4 hours
c) Remove the lid to dispel residual S_2Cl_2
d) Add 1 drop of S_2Cl_2
e) Replace the desiccator in the 185°F oven for 20 hours.

The type C2 test method is similar to that described above except that the S_2Cl_2 was diluted with 10 parts by volume with ether to produce a concentration of 3.5 PPM and the room cool time was reduced to 5 minutes.

The type C3 test method was identical to that used for the type C Series 2 test except that 6 drops of S_2Cl_2 were added daily to provide a calculated concentration of 2100 PPM of the S_2Cl_2 vapor.

2.4.2 Corrosion Data - When the accelerated tests were completed, the carrier exposed articles were not yet available for correlation. Selection of the environments for continuation into the second increment of the program was therefore based upon service experience reported from various sources and by engineering judgement. When the baseline test articles from the Constellation became available, the preliminary assessments were confirmed.

The amount of corrosion produced by the nine test environments after 500 hrs of exposure was compared to the 9 month carrier exposure data shown in Table IV. The results of this comparison are recorded in Table V. An "L" in the tabulation indicates less corrosion than that produced by the carrier exposure, "S" the same and "M" more corrosion than the carrier. Test methods with the best carrier correlation were identified by totaling the S's. For example, A2, the NADC sulfur dioxide environment, and C2, the 3.5 PPM sulfur monochloride environment, provided the best correlation (8 S's out of 11 possible). The standard test for qualifying aircraft and aircraft equipment for

TABLE IV CORROSION CORRELATION CRITERIA
(BASELINE TEST ARTICLES)

Test Article	Area Examined	Carrier Corrosion Data
4 Pin Connector	Mated Shell Exterior	Cadmium Severely Corroded Over 100% of Surface. Nickel Undercoat Visible in Numerous Pitted Areas
Uncoated Test Coupon	Printed Circuits	Coated with Black Corrosion Products Over 100% of Area
Coated Test Coupon	Printed Circuits	Coated with Black Corrosion Products Over 12% of Area
Uncoated Resistors	Lead/Tin Plated Leads	Coated with Black Corrosion Products Over 100% of Area
Coated Resistors	Lead/Tin Plated Leads	Coated with Thin Grey Film Over 100% of Area
Uncoated Ta Capacitor	Housing,Leads	No Corrosion
Coated Ta Capacitor	Housing,Leads	No Corrosion
Uncoated Transistor	Case	Scattered Sites with Green Corrosion Product Buildup. Greenish Tinge Over All
Coated Transistor	Case	Some Green Corrosion Products Around Base of Case
Uncoated Circuit Board	Printed Circuits	White Corrosion Products Except for Black Spots where Substrate is Exposed
Coated Circuit Board	Printed Circuits	No Corrosion

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TABLE V AIRCRAFT CARRIER/BASELINE TESTS CORROSION DAMAGE CORRELATION

Test Article	Area Examined	Baseline Tests/Carrier Correlation								
		A1	A2	A3	B1	B2	B3	C1	C2	C3
4 Pin Connector	Mated Shell Exterior	L	M	L	M	M	L	M	L	L
Uncoated Test Coupon	Printed Circuits	L	S	L	S	L	L	L	L	L
Coated Test Coupon	Printed Circuits	L	M	L	L	L	L	S	S	L
Uncoated Resistors	Lead/Tin Plated Leads	L	S	S	M	M	L	M	S	L
Coated Resistors	Lead/Tin Plated Leads	L	M	L	L	M	L	M	S	L
Uncoated Ta Capacitor	Housing Leads	S	S	S	S	S	S	M	S	S
Coated Ta Capacitor	Housing	S	S	S	S	S	S	M	S	M
Uncoated Transistor	Case	L	S	L	L	S	L	L	S	L
Coated Transistor	Case	L	S	L	L	S	L	L	L	S
Uncoated Circuit Board	Printed Circuits	L	S	L	S	M	L	S	S	L
Coated Circuit Board	Printed Circuits	S	S	S	S	S	S	S	S	M
Rating		3	8	4	5	5	3	3	8	2

Notes: L = Less corroded than carrier test article
S = Same amount of corrosion
M = More corroded than carrier test article

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marine deployment - the Type A1 MIL-STD-810 salt fog test - showed very poor correlation - 3 out of 11. As shown by the L designation in Table V, 8 test articles were more severely corroded during the carrier exposure than those exposed to 500 hrs. of the salt fog environment. In other words, a 3 week MIL-STD-810 salt fog exposure is not as severe as a nine month carrier cruise where deck stowage of aircraft is standard procedure.

The photograph in Figure 10 shows the corrosion caused by Type A and B environments on the 4-pin connector shells. Comparing Figure 10 and 6 shows the standard salt fog caused too little corrosion, Type A2, Type B1 and Type B2 caused too much corrosion because the Connector shells broke during disassembly as a result of corrosion products in the plug - receptacle interface.

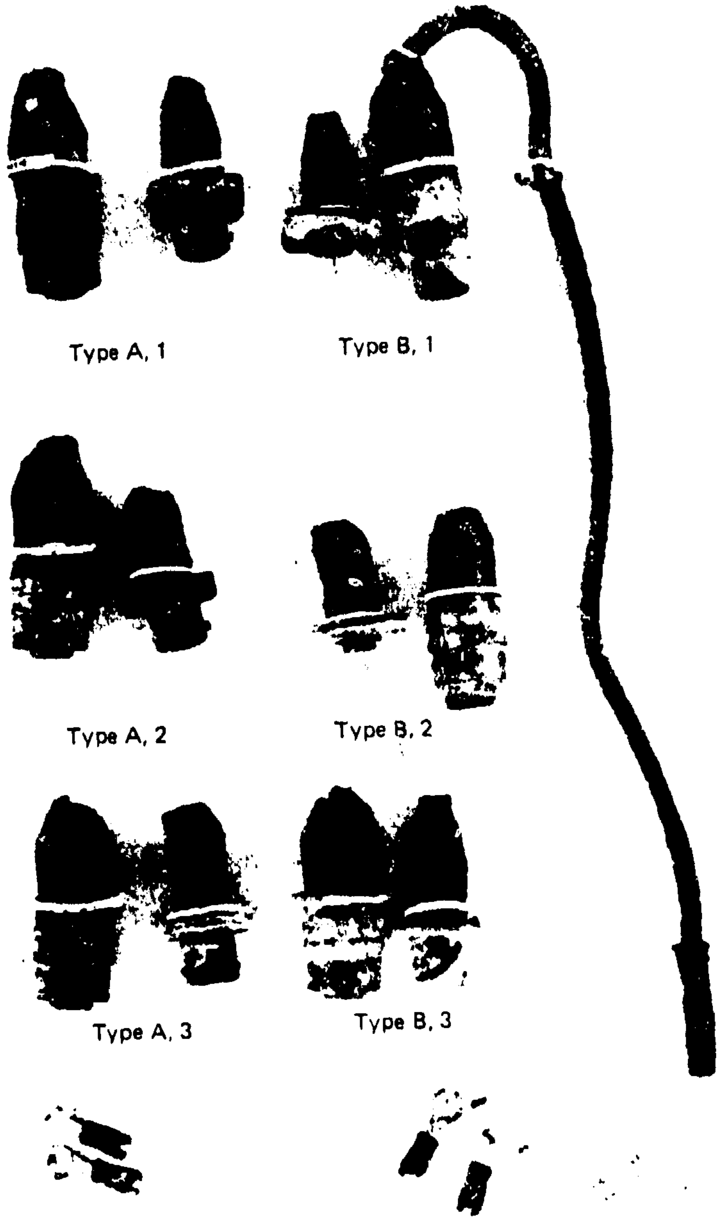

Figure 10 Electrical Connectors After 500 Hr Exposure to Salt, Fog, and SO_2/SF - Humidity Tests

2.4.3 Baseline Electrical Data - The test articles were electrically tested before and after exposure in order to apply the correlation criteria in Table VI. The electrical correlation criteria for the connector was based on service history data which shows a high failure rate because of "shorts" which are caused by the electrical insulation resistance falling from 10^5 megohms to less than 10^3 megohms. The criteria on the other test articles were established on the arbitrary basis that conformal coated component should meet military specification requirements whereas uncoated components should fail. The results of applying these correlation criteria are shown in Table VII. The NADC SO_2/SF (A2), the low temperature humidity/ high temperature bake (B3) and the 3.5 PPM S_2Cl_2/humidity test (C2) showed the best correlation. As in the corrosion correlation evaluation, the standard MIL-STD-810 salt fog test (A1) produced poor electrical correlation results. Only one other test environment (B2) had a lower correlation score.

TABLE VI ELECTRICAL CORRELATION CRITERIA (BASELINE TEST ARTICLES)

Test Article	Electric Property Tested	Correlation Criteria
Connector	Insulation Resistance Between Circuits	Resistance must be < 1,000 megohms MIL-STD-1344 Method 3003.1
	Insulation Resistance Between Circuits and Shell	Resistance must be < 1,000 megohms MIL-STD-1344
Uncoated Test Coupon	Leakage Between Printed Circuits	i must be > 2.00 MA MIL-STD-2753
Coated Test Coupon	Same as Above	i must be < 2.00 MA MIL-STD-2753
Uncoated Resistors	Resistor Resistance	Change in Before and After Exposure R must be > 10% MIL-STD-202, Method 303
Coated Resistors	Resistor Resistance	Change in Before and After Exposure R must be < 10%
Uncoated Capacitor No. 1	Capacitance	Change in Before and After Exposure Capacitance must be > 25%
	Leakage	> 0.01
Uncoated Capacitor No. 2	Capacitance	Same as 1
	Leakage	Same as 1
Coated Capacitor No. 1	Capacitance	Change in Before and After Capacitance must be 25%
	Leakage	< 0.01
Coated Capacitor No. 2	Capacitance	Same as 1
	Leakage	Same as 1

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TABLE VII BASELINE TESTS/ELECTRICAL CRITERIA CORRELATION

Test Article	Electrical Property Tested	Baseline Test/Electrical Criteria Correlation								
		A1	A2	A3	B1	B2	B3	C1	C2	C3
Connector	Insulation Resistance Between Circuits	L	L	L	S	L	L	L	S	S
	Insulation Resistance Between Circuits and Shell	L	L	L	S	L	L	S	S	L
Uncoated Test Coupon	Leakage Between Printed Circuits	S	L	L	L	L	L	S	S	S
Coated Test Coupon	Same as Above	M	S	S	M	M	S	M	M	M
Uncoated Resistors	Resistor Resistance	L	L	L	S	L	L	S	S	A
Coated Resistors	Resistor Resistance	S	S	S	M	S	S	M	F	F
Uncoated Ta Capacitor	Capacitance	L	L	L	S	L	S	S	S	L
	Leakage	S	S	L	S	L	S	S	S	S
Uncoated Ceramic Capacitor	Capacitance	L	L	L	L	L	L	L	L	L
	Leakage	S	S	L	S	S	S	L	S	S
Coated Ta Capacitor	Capacitance	S	S	S	M	L	S	M	M	S
	Leakage	M	S	S	M	S	M	M	M	M
Coated Ceramic Capacitor	Capacitance	S	S	S	S	S	S	S	S	S
	Leakage	M	S	S	M	S	S	S	M	M
	Total	6	8	6	7	5	8	7	8	7

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Notes:

L = Less severe (failed to promote electrical failure)

S = Same (meets correlation criteria)

M = More severe (promoted electrical failure of conformal coated component)

3. SECOND INCREMENT ACTIVITIES

The program plan requires that one baseline test method from each of the three types be optimized to improve its ability to simulate service environment effects.

Data from Tables V and VII were combined in Table VIII to provide the necessary data base for the test method selection. All L designations mean corrosion or electrical effects are less than that required for correlation with Tables IV and VI criteria, S means correlation and M means the environmental effects are too severe for correlation.

Table VIII Baseline Test Correlation Summary

	A_1			A_2			A_3			B_1			B_2			B_3			C_1			C_2			C_3		
	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M
Corr.	8	3	0	0	8	3	7	4	0	4	5	2	2	5	4	8	3	0	3	3	5	3	8	0	7	2	2
Elec.	5	6	3	6	8	0	8	6	0	2	7	5	8	5	1	5	8	1	3	7	4	1	8	5	3	7	4
Total	13	9	3	6	16	3	15	10	0	4	5	7	10	10	5	13	11	1	6	10	9	4	16	5	10	9	6

The L and M totals, 6 and 3 respectively, for the A2 test method show that in order to obtain a perfect correlation score, the test environment must be changed to produce six more electrical failures and three less corrosion failures.

The approach taken to implement this objective was to experiment with higher test temperatures to speed up moisture diffusion to increase electrical failures and to experiment with salt fog and sulfur dioxide concentrations to reduce the test exposure time to two weeks or less and still obtain acceptable correlation.

The sulfur monochloride test chosen for optimization (C2) also had a correlation factor of 16 but requirements for optimization are reversed as compared to A2. A shorter exposure will reduce electrical failures and an increase in the concentration of S_2Cl_2 will increase corrosion failures for better correlation.

Whereas, A2 and C2 had a correlation factor of 64% ($\frac{16}{25}$), the best Type B correlation was only 40%. The reason for designing the Type B tests to use both an SO_2/SF and a humidity exposure is the inherent ease of changing the exposure times of one or other of the exposures to obtain the required corrosion failure/humidity failure balance.

However, the poor performance of the Type B tests compared to the other tests showed that the corrosion-humidity balance could be achieved with a single test environment. Also because of the inconvenience of having to tie up a humidity cabinet as well as a salt fog chamber to run the test it was decided not to try to optimize a Type B test. Instead a test method with a new approach using hydrochloric and sulfurous acids was substituted.

3.1 SULFUR DIOXIDE/SALT FOG OPTIMIZATION - As a first step in the optimization attempt, a galvanic battery was used to establish the corrosivity of the standard NADC SO_2/salt fog test to provide a standard by which attempts at optimizing the test could be compared. The galvanic battery was then used to measure the effect of different combinations of salt fog and sulfur dioxide injections on corrosivity to provide a data base for test parameter development.

In order to use battery data to compare the relative corrosivity of environments produced by exploratory test parameter changes with that of the baseline Type A2 environment, it was necessary to calculate an average battery reading. For example, the Type A2 test method calls for 5 hours of salt fog and 1 hour of combined salt fog and sulfur dioxide gas. The average battery reading for the 6 hour cycle is calculated by multiplying the battery reading during fog generation by 5, adding the average battery reading during the 1 hour combined SO_2/fog generation and dividing by 6. Because these tests were cyclic, the batteries were connected to a strip chart recorder to provide a graphic picture of battery output.

In the first test of the series shown in Table IX, the cabinet was purged of SO_2, and a galvanic battery was used to measure the corrosivity when the cabinet is operated in accordance with the NADC procedure. As shown in the Table, the average battery output when exposed to the salt fog is 2.1 mA/in^2 and 4.3 mA/in^2 when exposed to the combined effects of salt fog and sulfur dioxide. This averages out to a reading of 2.5 mA for the 6 hour repetitive cycle.

In the second test, a battery was used to measure the corrosivity of distilled water at the 90°F cabinet temperature and the corrosivity of SO_2 when not accompanied by salt fog. Table IX data shows that sulfur dioxide by itself generates almost the same battery output - 4.2 mA vs. 4.3 mA - as it does when accompanied by salt fog.

A 6 hour cycle consisting of 5 hours of salt fog followed by turning off the fog and injecting SO_2 for an hour at the NADC flow rate produces an average battery output of 2.4 mA as compared to 2.5 mA for the standard cycle.

The objective of test number 3 was to measure output when a battery not contaminated by exposure to salt fog is exposed to SO_2 and then to salt fog. Table IX data show that when a battery

TABLE IX SULFUR DIOXIDE/SALT-FOG PARAMETER MANIPULATION

Test Number	Cabinet Temperature	Tower Temperature	Cabinet Operating Conditions	Battery Reading (mA)	Average* Reading (mA)	Remarks
1 (Type A2)	90°F	115°F	Fog On, SO_2 Off	2.1		Started Test with Clean battery
			Fog and SO_2 On	4.3	2.5	Output Increased from 2.1 to 4.3 in 10 min
2	90°F	115°F	Chamber Free of Fog and SO_2, Battery Allowed 30 min to Reach Chamber Temperature	0.1		Battery Face Wet with Distilled Water Before Placing in Chamber
			Fog On, SO_2 Off	2.0		
			Fog Off, SO_2 On	4.2		Took 25 min to Reach Steady Output
			SO_2 Off	1.8	2.4	Took 30 min to Reach Steady Output
3	90°F	115°F	SO_2 On	3.9		
			Fog On	2.3	2.6	
4	140°F	135°F	Fog On	0.4		Humidity too Low
			SO_2 On	4.3		Batteries Sloshed with Chamber Condensate
				1.9		Battery Coated with Salt Deposits Because of Evaporation
			SO_2 Off	0.7		
			Fog On	2.7		
5	120°F	135°F	Synthetic Ocean Water Diluted with 10 Parts Water for Fog Generation Chamber Free of Fog and SO_2	0.4		
			Fog On	1.2		Battery Output Increased Gradually as Compared to Normal Fog Effect
			SO_2 On	4.4		Took 25 min for Battery Output to Stabilize
			SO_2 Off	2.2	1.8	

*Average reading is average over entire test.

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with a clean surface is exposed to sulfur dioxide, the output is about 10% lower than when the battery has been previously exposed to salt fog. On the other hand, when the battery was exposed to salt fog following the SO_2 exposure, its output is higher (2.3 vs 2.1).

In the fourth test, both the chamber and bubble tower thermostats were set for maximum temperature to increase moisture diffusion rates so that electrical failures could be produced in a shorter exposure time frame. The other test parameters remained the same. Because the cabinet reached a higher temperature than the bubble tower, the resulting low humidity produced in a salt build-up on the surface of the battery because of evaporation. As a result, battery output dropped to 0.4 mA.

Test 5 overcame the difficulties experienced in Test 4. Chamber temperature was lowered to 120°F to provide sufficient spread between bubble tower temperature and cabinet temperature to prevent salt deposit formation because of evaporation.

The NADC SO_2/SF environment produces corrosion failures in a shorter time than electrical failures as compared to a service environment. Therefore synthetic ocean water (SOW) used for fog generation was diluted to 1 part SOW to 10 parts water to reduce corrosivity. As shown by Table IX data, the average battery reading dropped from 2.1 when standard fog was used to 1.2 mA when diluted fog was atomized. However, the combined effects of the diluted SOW and the sulfur dioxide salt fog test produced a 4.4 mA battery output which is the same as the standard test. The average battery output calculated for a 6 hr cycle is a 1.8 mA or a 28% reduction compared to that of the baseline NADC environment.

In order to reduce the corrosivity of the environment more than 28%, it was decided to reduce the duration of the SO_2 injection from 1 hour to 1/2 hour. It was anticipated the higher temperature and lower corrositivity would balance corrosion and moisture related effects to correlate with those produced by carrier exposure. These concepts are incorporated in the following test cycle:

a. The ASTM D1141 synthetic ocean water (SOW) for generation was diluted with 10 parts distilled water to reduce corrosivity.

b. Cabinet temperature was increased from the ASTM B117 standard 95°F to 120°F to increase moisture absorption by dielectric materials used for insulation.

c. The bubble tower temperature was increased from 115°F to 135°F.

d. Fog generation was changed from continuous to 5 hour on, 1 hour off.

e. SO_2 was introduced when the fog was off to prevent it being carried to the bottom of the chamber with the fog.

f. SO_2 flow rate remained the same at 1.0 ± 2.0 cm^3/minute per cubic foot of cabinet environment but the duration of the flow was reduced from 1 hour to 0.5 hours every 6 hours to reduce corrosivity.

After the chamber was run using the above cycle for 24 hours for stabilization, three test circuit coupons and three cadmium plated connector shells were placed in the chamber. The test was terminated after a 2 week exposure period.

At the completion of the exposure, visual examinations showed that the flange surfaces on the receptacle were more severely corroded than the same connector surfaces exposed during the cruise of the Constellation. Other surfaces on both the plug and receptacle shells were slightly less corroded than equivalent surfaces exposed to the carrier environment.

The amount of corrosion on the test coupon printed circuits was comparable to that produced by carrier exposure except that there were localized areas where the normally white corrosion produces had a greenish tinge. Since these test results are satisfactory, these parameters were retained for the demonstration test.

3.2 HYDROCHLORIC ACID/SULFUROUS ACID OPTIMIZATION - As stated earlier, it was decided not to optimize a Type B environment but to try a different approach that would require the use of only one environmental cabinet. For example, if the make-up water used to generate water vapor in humidity cabinets was replaced by a solution of hydrochloric acid in sulfurous acid, the solution would volatize producing chloride ions and sulfur dioxide which are the most common marine corrodents. Because chlorides in the form of vapor are better able to penetrate partially sealed air spaces than as salt fog, hydrochloric acid vapor can in a few hours penetrate air space enclosures that would require a longer exposure in salt fog to obtain the same effect.

If this test method were used on a regular basis, a humidity cabinet could be set aside for its exclusive use. However, in this exploratory phase, instead of taking the risk of contaminating a cabinet, optimization tests were carried out in a sealed container.

Sealed 1 liter beakers were used as environmental chambers. 25 ml of the following liquids were absorbed on cheese cloth and placed around the inside walls of the beakers to provide a large evaporating surface: distilled water, saturated sulfurous acid, and a 50-50 solution of saturated sulfurous and 3% hydrochloric acids. The test articles placed in each beaker included 2 mated electrical connector shells and 3 printed circuit test coupons. The beakers were placed in a 180°F oven.

Calibrated corrosion batteries were used to monitor the corrosivity of the humidity cabinet environment as well as the sealed beaker environments. The batteries were exposed in the humidity chamber at 195°F/95% RH for temperature and surface film stabilization. Battery readings are shown in Table X along with a description of the test articles after a 14 day exposure.

Table X Hydrochloric - Sulfurous Acid Exposure Data

Test Environment	Test Coupon Corrosion	Connectors		Galvanic Battery mA/in^2
		Shell Corrosion	* Shell Disconnect	
Oven at 185°F and 90% RH				1.4
Beaker at 185°F and 100% RH	Nil	Nil	Passed	0.016
Same as 2 + H_2SO_3 Vapor	Slight	Moderate	Passed	0.25
Same as 2 + H_2SO_3 and HCl	Severe	Severe	Passed	3.4

*To pass shell disconnect criteria, connectors had to be disassembled using hand pressure.

The most surprising result was the 100 to 1 ratio between the galvanic battery readings generated by the oven environment and the distilled water-sealed beaker environment. The most obvious difference is the rapid air movement in the oven produced by the high volume fan and the stagnant condition in the beaker.

The galvanic battery reading (0.25 mA/in^2) generated by the sulfurous acid environment is only one tenth as high as that generated by salt fog. Lack of aggressive behavior is also demonstrated by the lack of serious corrosion of the connector shells and the printed circuits of the test coupons.

On the other hand, corrosion produced by the hydrochloric/sulfurous acid environment produced severe corrosion of the test articles and generated a battery current of 3.5 mA as compared to the 2.5 mA average generated by the NADC SO_2/SF environment.

The severe corrosion produced by the hydrochloric acid/sulfurous acid solution in the last test indicated the concentration of these corrodents was too high. In the next attempt, it was decided to obtain better control at lower concentration by injection of HCl and SO_2 in the gaseous form. A 9 liter dessicator with holes drilled in the lid for the galvanic battery leads and the syringe for HCl and SO_2 injections was used as the environmental chamber. Water, 2 printed circuit coupons and 2 electrical connector shells were placed in the chamber. The lid was sealed after the chamber reached temperature equilibrium in a 185°F oven. Daily additions of 0.45 ml of HCl and 0.45 ml of SO_2 were injected to provide a concentration of 50 ppm of each corrodent. The lid was removed daily prior to the injection so that residual gases could be dissipated.

The galvanic battery was calibrated in a 185°F/95% RH environment until the reading stabilized at 0.150 mA prior to use. During the first 19 hours battery output averaged 3-6 mA but fell to an average of 0.5 mA for the next two days. During the final week of the test, the average reading was less than 0.1 mA in spite of an increase in daily HCl and SO_2 injections from 0.45 ml to 0.90 ml. The drop in corrosivity was substantiated by the uncorroded condition of the test articles. Examination of the test articles after 4 weeks of exposure revealed that the printed circuits of the test coupons were not as corroded as the Constellation exposed coupons. The connector shells were slightly discolored but not corroded.

3.3 SULFUR MONOCHLORIDE OPTIMIZATION - As shown in Table VII, the sulfur monochloride test (C2) chosen for optimization caused 5 too many electrical failures and three too few corrosion failures for correlation. To correct these problems, the test duration was shortened from 4 weeks to 2 weeks to reduce electrical failures and the sulfur monochloride concentration was increased from 3.5 ppm to 14 ppm to increase corrosion failures.

Three printed circuit test coupons, three mated connector shells and a 50 ml beaker of distilled water were placed in a sealed 1 liter container. A drop of a solution of 1 part S_2Cl_2 to ten parts of ether from a calibrated eye dropper was added daily through a hole drilled in the lid. The container was placed in a 185°F oven. The corrosivity of the environment was monitored by means of a calibrated galvanic battery. The average battery output during the first week was 0.56 mA/in^2 and 1.6 during the second week. The 2 week average output of 1.08 mA/in^2 is only half the target 2.0 mA/in^2. This target was based on the fact that the SO_2/SF test was too corrosive when it generated a 2.5 mA/in^2 average battery output. The overall average battery current of 1 mA did not meet the target of 2.0 mA/in^2. The lack of corrosivity indicated by the battery data was confirmed by the fact that the connector shells were not corroded by the two week exposure. Time did not permit additional optimization tests prior to the demonstration test.

3.4 DEMONSTRATION TEST METHOD - The objective was to expose test articles to the optimized Type A, B and C test environments and based on how well the data correlated with the Constellation corrosion criteria in Table IV and the electrical criteria in Table VI, eliminate the least desirable test method from further consideration.

The following test articles were exposed to each of the three environments:

Four pin connector assemblies (wired)
*Uncoated circuit board assemblies
*Conformally coated circuit board assemblies
*Uncoated test circuit coupons
*Conformally coated test circuit coupons
*Uncoated resistors
*Conformally coated resistors
*Unwired but sealed 31-pin connector assemblies

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*Electronic test articles exposed in an avionic box

The following test parameters were used:

Environment A - Modified Sulfur Dioxide/Salt Fog Test

a) SOW diluted with 10 parts water for fog generation
b) Bubble tower at 135°F - 140°F
c) Cabinet at 120°F
d) The following 6 hr cycle was used:

5 hr salt fog
1/4 hr of SO_2 gas flow to start immediately after fog shuts off
3/4 hr rest period with fog and SO_2 off

Environment B - High Temperature Corrosion/Humidity Test

a) A sealed 9 liter container was placed in a 185°F oven and allowed to come to temperature.

b) HCl and SO_2 gases were injected to produce a concentration in the container of 100 ppm HCl, 50 ppm SO_2 and a relative humidity of 100%.

c) Batteries were placed in the bell jar with leads sealed through a hole in the cover and output was monitored with the chart recorder until the battery output stabilized.

d) The concentration of SO_2 and HCl was adjusted as required to produce a battery output of 1.0 mA/in^2.

e) Prior to the daily gas addition, the container was opened to dissipate residual HCl and SO_2 vapor.

Environment C - Sulfur Monochloride/Humidity Test

a) A 9 liter dessicator containing distilled water was placed in a 185°F oven and allowed to come to temperature.

b) S_2Cl_2 was diluted with 10 parts by volume of ether. 1 drop of the mixture was added three times a day at 8 AM, 12 noon and 4 PM. Disregarding loss by corrosion reactions this would provide a 105 PPM concentration. Before the first daily addition was made, the dessicator was opened to dissipate any residual vapor produced by the previous day's additions.

In preparation for exposure, a set of the electronic test articles was installed in each of the three avionic boxes. The boxes were exposed to the environments in a horizontal position with the lid side up. The connector assemblies were supported by the wire harness with the plug above the receptacle as specified in MIL-C-38999. The galvanic batteries were calibrated in a humidity cabinet at 185°F until the output stabilized at 1.26 mA/in^2.

Exposure to the three environments continued until a visual examination showed that the majority of the test articles were corroded to the same extent as the Constellation test articles or until the exposure duration lasted 4 weeks. The SO_2/SF environment produced good correlation in 2 weeks, the HCl/H_2SO_3 and S_2Cl_2 tests were terminated after 4 weeks.

3.4.1 Exposure Data - The results of the corrosion evaluation is shown in Table XI. The test articles were given an L, S or M rating depending on whether the test environment produced less, the same or more corrosion than the carrier correlation criteria in Table IV. The modified sulfur dioxide/salt fog test showed the best correlation with the carrier exposed test articles with a total of eight test articles correlating and three not. The hydrochloric acid/sulfurous acid environment was second best with six test articles showing correlation and five showing less corrosion than the carrier exposed test articles. The sulfur monochloride environment was too benign for good correlation.

The results obtained by comparing electrical test data obtained after the exposure with criteria in Table VI are shown in Table XII. The modified SO_2 salt fog test produced a drop in the average insulation resistance from 16,000 to 9000 megohms but this is well above the 1000 maximum megohms set as the failure criterion. Hence the 'L' rating. On the other hand, the HCl/H_2SO_3 environment received an 'S' rating because it produced circuit to circuit failure in all three connectors and degraded the circuit-to-shell before test insulation resistance of 14,000 megohms, to 4500 megohms. The S_2Cl_2 environment reduced the circuit-to-circuit resistance from 16,000 megohms to 7,000 megohms in one connector but had no effect on the other two. The shell-to-shell insulation was reduced from 20,000 to 6,700 megohms - not enough to rate a failure.

None of the tests caused a leakage current failure of the uncoated test circuit coupons and therefore were given an L rating.

TABLE XI DEMONSTRATION TEST CORROSION CORRELATION DATA

Test Article	Area Examined	Test/Carrier Correlation								
		SO_2/SF			HCl/H_2SO_3			S_2Cl_2		
		L	S	M	L	S	M	L	S	M
4 Pin Connector	Mated Shell Exterior		✓		✓			✓		
Uncoated Test Coupon	Printed Circuits		✓			✓		✓		
Coated Test Coupon	Printed Circuits		✓			✓			✓	
Uncoated Resistors	Lead/Tin Plated Leads	✓			✓			✓		
Coated Resistors	Lead/Tin Plated Leads		✓			✓			✓	
Uncoated Ta Capacitor	Housing and Leads	✓			✓			✓		
Coated Ta Capacitor	Housing and Leads		✓			✓			✓	
Uncoated Transistor	Case			✓	✓			✓		
Coated Transistor	Case		✓			✓		✓		
Uncoated Circuit Board	Printed Circuits		✓		✓			✓		
Coated Circuit Board	Printed Circuits		✓			✓		✓		
Total		2	8	1	5	6	0	8	3	0

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TABLE XII DEMONSTRATION TEST ELECTRICAL CORRELATION DATA

Test Article	Electrical Property Tested	Test/Carrier Correlation								
		SO_2/Salt Fog			HCl/H_2SO_3			S_2 Cl_2		
		L	S	M	L	S	M	L	S	M
4 Pin Connector	Insulation Resistance between Circuits	✓				✓		✓		
	Insulation resistance between Circuits and Shell	✓			✓			✓		
Uncoated Test Coupon	Leakage between Printed Circuits	✓			✓			✓		
Coated Test Coupon	Leakage between Printed Circuits		✓			✓			✓	
Uncoated Resistors	Resistor Resistance	✓				✓			✓	
Coated Resistors	Resistor Resistance		✓				✓		✓	
Uncoated Capacitor No. 1	Capacitance	✓			✓			✓		
	Leakage	✓			✓			✓		
Uncoated Capacitor No. 2	Capacitance	✓			✓			✓		
	Leakage	✓				✓			✓	
Coated Capacitor No. 1	Capacitance		✓			✓			✓	
	Leakage		✓			✓			✓	
Coated Capacitor No. 2	Capacitance		✓			✓			✓	
	Leakage		✓			✓			✓	
Total		8	6	0	5	8	1	6	8	0

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The S_2Cl_2 test was the only one which had a perfect resistor correlation score in that it failed the set of three uncoated resistors but not the conformal coated set. The SO_2/SF test did not fail either resistor set while the HCl/H_2SO_3 test failed both sets. None of the tests caused a capacitance output failure of the capacitors. Both the HCl/H_2SO_3 and the S_2Cl_2 test produced a current leakage failure of the ceramic capacitor.

The HCl/H_2SO_3 environment and the S_2Cl_2 environment, as expected, produced more electrical failures than the modified sulfur dioxide test because the higher temperature - 185°F as compared to 120°F - promoted faster moisture permeation of the dielectric materials.

In summary, the two tests chosen for the verification were the SO_2/SF and the HCl/H_2SO_3 tests. The SO_2/SF test was chosen because it had the highest correlation score. The HCl/H_2SO_3 test was chosen because it had a higher correlation score than the S_2Cl_2 test, and because the S_2Cl_2 test produced orange colored cadmium sulfide corrosion products on cadmium plated parts instead of the white corrosion products characteristic of service exposure.

3.5 VERIFICATION - The program plan calls for a total of 25 test articles, including the test articles used for the baseline tests, to be exposed to the two most effective test methods. This requirement widens the scope of the materials and finishes exposed to the test environments including nickel plated stainless steel, nickel plated brass, stainless steel and electroless nickel plated aluminum connectors. All test articles exposed to the carrier environment and listed in Table I, plus two test articles with service corrosion problems at land bases were used for the verification test.

3.5.1 Verification Test Methods - Because the SO_2/SF demonstration test produced two too few corrosion failures and eight too few electrical failures, it was decided to increase the SO_2 injection duration from 15 to 30 minutes every 6 hours and increase the bubble tower temperature during the verification test. Since the bubble tower temperature control was already set at maximum, it was necessary to insulate the glass bubble tower to raise the temperature. The modified SO_2/SF test parameters were as follows:

- SOW diluted with 10 parts distilled water
- Bubble tower 140 - 145°F
- Cabinet at 120°F
- 5 hours salt fog every 6 hours
- 30 minutes SO_2 injection to begin 15 min before fog shuts off and continue for another 15 min after shut-off

The reason the SO_2 was started 15 minutes before the fog generation was shut down was to acidify the fog that condensed on the parts. The 15 min period of SO_2 input after the fog shut down was to keep the fog from absorbing the SO_2 and carrying it to the bottom of the cabinet. Without the fog, the SO_2 maintains its concentration longer and is therefore better able to penetrate interfaces and partially sealed air spaces.

Because the HCl vapor/SO_2 gas method used in the demonstration test produced an environment that was too benign, it was decided to use cheesecloth saturated with a 3% solution of HCl in concentrated sulfurous acid to generate the environment. It was intended to increase the volume of the solution if the galvanic battery reading was below 2.0 mA/in^2.

For both the SO_2/SF test, and the HCl/H_2SO_3 test, the 25 Table I test articles were placed in the chambers with connectors mounted on plastic boards as they were in the carrier exposure tests and with the electronic components in an avionic box. The tests were terminated after a 7 day exposure.

In the HCl/H_2SO_3 test, the test articles were placed in a plastic container with the saturated cheesecloth fastened around the circumference of the inside wall. The test articles, prepared as described above, were placed in the container and the lid sealed. The container was then placed in a 185°F oven. For the first three days the cheese cloth was saturated with 150 ml of the HCl/H_2SO_3 solution. This was increased to 250 ml when it was found that the cheese cloth was dry when the container was opened. When it was also dry after another three days of operation, it was realized that the container must be leaking. After saturating cheese cloth with 250 ml of the corrodents, the lid was sealed with high temperature tape instead of the silicone sealant previously used. When the container was opened after three days, the cheese cloth was still moist. The cheese cloth was replaced with cheese cloth containing another 250 ml of HCl/H_2SO_3 solution. The test was terminated after a total of 13 days but the desired level of corrodents was only achieved for 7 days so the effective test period was 7 days.

3.5.2 Exposure Data - Examination of the exposed test articles shown in Figure 11 after the modified SO_2/salt fog test shows the connector shells had the same amount of corrosion as the carrier exposed connectors in Figure 6. The connectors are identified by the same number in both figures. Number 1 is the 4-pin connector; number 2 is the 61-pin connector and number 3 is the 66-pin connector. Connectors in Figure 6 appear to have a heavier deposit of corrosion products on the cadmium plated surfaces than those in Figure 11. However, about 25% of the deposit on the carrier exposed test articles is salt whereas there is little or no salt deposit on the test articles exposed to the modified SO_2/SF test. Connector number 4, the electroless nickel plated connector was more severely corroded than the cadmium plated connectors. The nickel plating was missing from approximately 80% of the surface. Where the nickel plating was missing, there was a noticeable loss of cross sectional thickness of the aluminum shell due to corrosion. The nickel plating that was intact was a dull grey color.

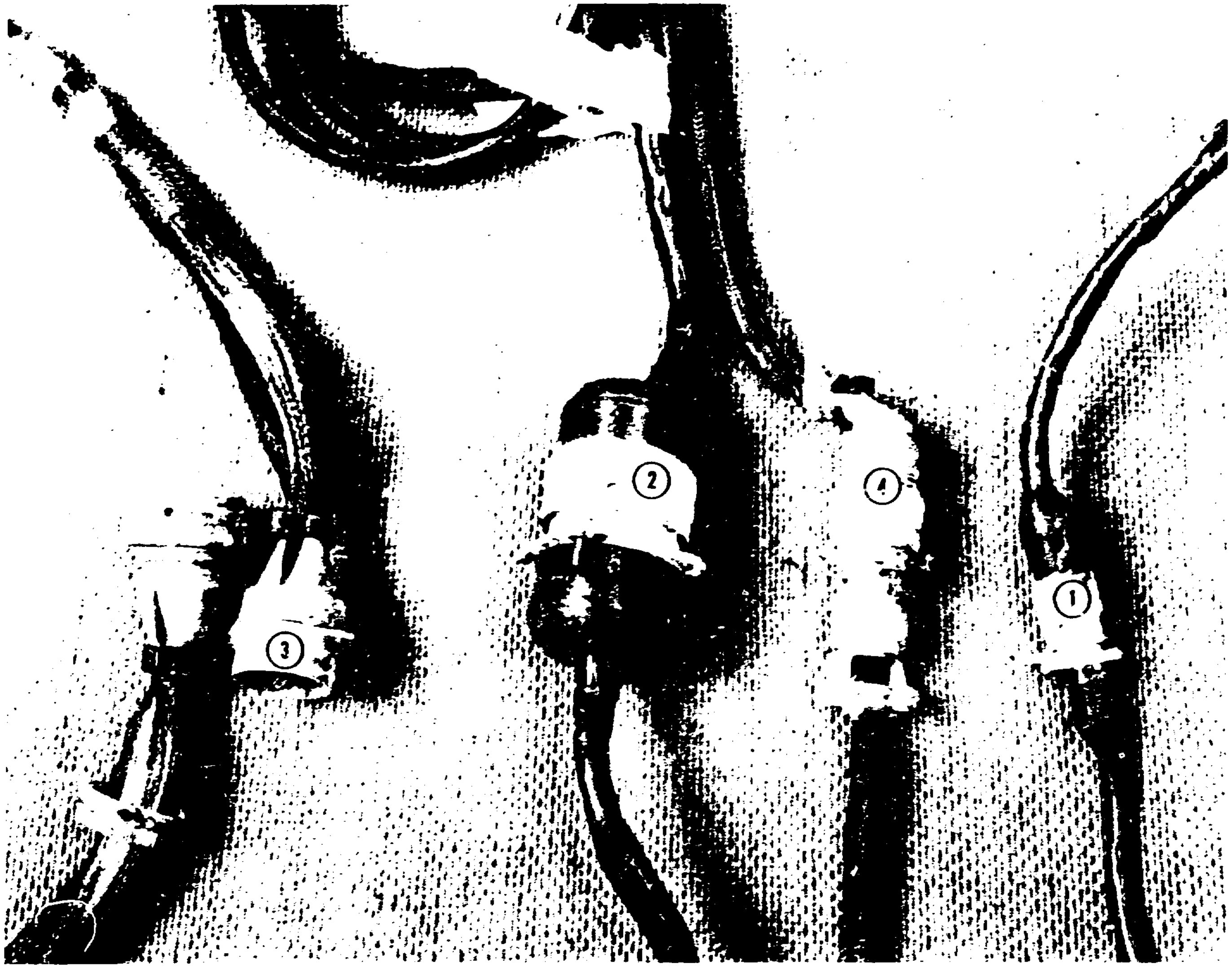

Figure 11 Electrical Connectors After One Week SO_2/SF Exposure

In contrast, the electroless nickel plated 10 pin connectors exposed to the HCl/H_2SO_3 environment showed only minor pitting and a speckling of green corrosion products. The chromate finish of the cadmium plated connectors was bleached by the HCl/H_2SO_3 exposure but there was no corrosion.

When the circuit boards, test coupons and resistor packages were removed from the avionic boxes, visual examination showed that the corrosion produced by the SO_2/SF exposure correlated with that produced by the carrier exposure. This is illustrated by the photograph of the uncoated circuit board in Figure 12. It shows that the SO_2/SF exposed board on the left has the same rust stains at the base of the case and the same green corrosion products on the remainder of the case as the uncoated board in Figure 7. The HCl/H_2SO_3 exposed circuit board has a green patina but no significant build up of corrosion products or rust stains.

The corrosion of the tin plated contacts of the 66-pin connector, shown in Figure 8 after the carrier exposure, was not reproduced by either of the laboratory environments. However, the SO_2/SF test did darken the bare copper contacts to the same extent as on the carrier exposed connector. The gold plated pins were not affected by the carrier or the laboratory environments.

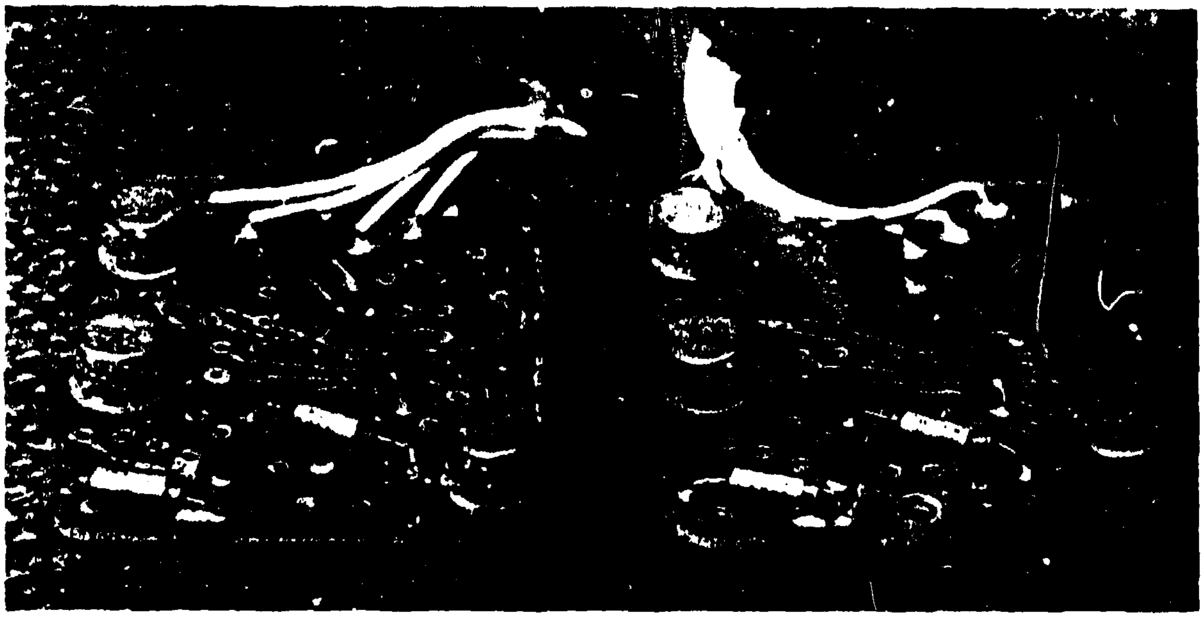

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Figure 12 Circuit Board on Left After One Week SO_2/SF and Circuit Board on Right After Four Weeks HCl/H_2SO_3 Exposure Tests

The results of the visual comparison of the carrier exposed test articles and those exposed to the verification test environments are summarized in Table XIII. As shown by this data, the modified SO_2/SF test produced the same degree and type of corrosion as the carrier exposure on 16 of the test articles. It produced less corrosion on the tin plated pins of the 66-pin connector and on the tin plated printed circuits of the uncoated circuit boards. It produced more corrosion on transistor cases that were not protected by the avionics box and on the cadmium plated toggle switch mounting nuts.

The HCl/H_2SO_3 test provided correlation with 10 of the carrier test articles, less corrosion on 8 and too much on the stainless steel variable resistor and nickel plated brass coaxial connector. Based on the tabulated corrosion data, the modified SO_2/SF test is superior to the HCl/H_2SO_3 test method.

TABLE XIII VERIFICATION TEST CORROSION CORRELATION DATA

Test Article	Area Examined	SO_2/Salt Fog			HCl/H_2SO_3		
		L	S	M	L	S	M
4 Pin Connector	Mated Shell Exterior		X		X		
10 Pin Connector	Mated Shell Exterior		X		X		
61 Pin Connector	Mated Shell Exterior		X		X		
66 Pin Connector Ag/P Wire	Copper Pins		X			X	
	Tin Plated Pins	X			X		
	Gold Plated Pins		X			X	
Coaxial Connector	Mated Shell Exterior		X				X
Uncoated Test Coupon	Printed Circuits		X		X		
Conformal Coated Test Coupon	Printed Circuits		X			X	
Uncoated Resistors	Lead-Tin Plated Leads		X			X	
Conformally Coated Resistors	Lead-Tin Plated Leads		X			X	
Uncoated Transistors (Exposed)	Case			X		X	
Uncoated Transistors (Box)	Case		X		X		
Conformal Coated Transistors (Box)	Case		X		X		
Variable Resistors	Stainless Steel Housing		X				X
Toggle Switch	Toggle and Mounting Nut			X		X	
Uncoated Circuit Board	Circuits	X			X		
Conformal Coated Circuit Board	Circuits		X			X	
Circuit Breaker	Housing Thread and Jam Nut		X			X	
Stainless Steel Track Module	Nickel Electroplate		X			X	
Total		2	16	2	8	10	2

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Electrical tests were carried out on the test articles before and after the exposure tests to detect any significant change in electric characteristics or performance. Data derived by tests made after the exposure were compared to the Table XIV electrical correlation criteria. The results of this comparison are shown in Table XV. The data show that both tests failed to produce failure of some of the connectors and circuit board components.

However, the SO_2/SF test did produce failure of the 4-pin and 61-pin electrical connectors and the circuit breaker. The connectors have a history of corrosion failures and the circuit breaker failed due to the carrier exposure. The other connectors do not have a history of service failure. The modified SO_2/SF test also increased pin/socket contact resistance as did the carrier exposure.

The Table XIV criteria that requires the test circuit coupons to fail may be unrealistic. So based on solid service history and carrier data the modified SO_2/SF test produced the required response in all test articles.

3.5.3 Galvanic Battery Data - Because the corrosion current generated by a galvanic battery changes with fluctuations in environmental corrosivity, it provides a method of tracking the dynamics of a rapidly changing environment. For example the duplication of superimposed chart recordings in Figure 13 shows that the battery senses the increase in corrosivity produced by the injection of SO_2 and shows the drop off in corrosivity about 30 minutes after the injection is terminated. Note that the chart pen recorded from right to left so the time scale "0" is at the far right end of the abscissa. Figure 13 data shows that although the modified SO_2/SF injection duration is only 30 minutes as compared to 60 in the NADC test, the effect of the injection lasts about the same length of time. This is because the salt fog is off for the last 15 minutes of the modified test and therefore does not absorb the SO_2 and carry it to the bottom of the chamber. The recording in Figure 14 shows the rapid increase in corrosivity when the sealed container with cheese cloth saturated with the HCl/H_2SO_3 solution is placed in a 185°F oven and gradual decrease in corrosivity of the HCl/H_2SO_3 environment as the active ingredients are depleted. This information indicates that for this environment to work successfully, the HCl/H_2SO_3 solution has to be introduced at more frequent intervals to produce sufficient corrosion to correlate with a carrier environment.

TABLE XIV ELECTRICAL CORRELATION CRITERIA (VERIFICATION TEST)

Test Article	Electrical Property Tested	Correlation Criteria	Criteria Basis	Test Method
4 Pin Connector	Insulation Resistance (C-C)	Must Be Less Than 1,000 megohms	History of Service Failure by Shorting	MIL-STD-202, Method 302 (3,000 VDC)
	Insulation Resistance (C-S)	↓	↓	↓
10 Pin Connector	Insulation Resistance (C-C)	↓	↓	↓
	Insulation Resistance (C-S)	↓	↓	↓
61 Pin Connector	Insulation Resistance (C-C)	↓	↓	↓
	Insulation Resistance (C-S)	↓	↓	↓
66 Pin Connector Ag/P Wire	Contact Resistance Cu	No Significant Change	↓	MIL-STD-202, Method 302
	Contact Resistance Sn	↓	Carrier Data	Test Current 125 mA
	Contact Resistance Au	↓	↓	↓
Coaxial Connector	Insulation Resistance	↓	↓	MIL-STD-1344, Method 3003.1 (500 VDC)
Uncoated Test Coupon	11 Circuit Leakage	>2.00 mA	Arbitrary	MIL-STD-2753
Conformal Coated Test Coupon	11 Circuit Leakage	<2.00 mA	↓	MIL-STD-2753
Uncoated Capacitor (Ta)	Capacitance	> 25% Change in Capacitance	↓	↓
	Leakage	>0.01	↓	↓
Conformally Coated Capacitor (Ta)	Capacitance	<25% Change in Capacitance	↓	↓
	Leakage	No Change in Leakage	↓	↓
Uncoated Resistor	Resistance	>10% Change in Output	↓	MIL-STD-202, Method 303
Conformally Coated Resistor	Resistance	<10% Change in Output	↓	MIL-STD-202, Method 303
Variable Resistors	Resistance	<10% Change in Output	Carrier	MIL-STD-202, Method 303
Toggle Switch	Contact Resistance	<1.0 mΩ	Carrier Data	Voltage Drop Measured Using 100 mA Test Current
Circuit Breaker	Trip Time at 200% OL	Must Take Longer than 20 sec	Carrier Data	Trip Time Measured Using 10 A at 24 VDC

C-C Circuit-to-Circuit
C-S Circuit-to-Shell

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TABLE XV VERIFICATION TEST ELECTRICAL CORRELATION DATA

Test Article	Electrical Property Tested	SO_2/SF			HCl/H_2SO_3		
		L	S	M	L	S	M
4 Pin Connector	Insulation Resistance (C-C)		√		√		
	Insulation Resistance (C-S)	√			√		
10 Pin Connector	Insulation Resistance (C-C)	√			√		
	Insulation Resistance (C-S)	√			√		
61 Pin Connector	Insulation Resistance (C-C)		√			√	
	Insulation Resistance (C-S)		√			√	
66 Pin Connector Ag/P Wire	Contact Resistance Cu		√			√	
	Contact Resistance Sn		√			√	
	Contact Resistance Au		√			√	
Coaxial Connector	Insulation Resistance		√		√		
Uncoated Test Coupon	11 Circuit Leakage	√			√		
Conformal Coated Test Coupon	11 Circuit Leakage	√			√		
Uncoated Ta Capacitor	Capacitance	√				√	
	Leakage		√			√	
Conformally Coated Ta Capacitor	Capacitane	√				√	
	Leakage		√				√
Uncoated Resistor	Resistance	√			√		
Conformally Coated Resistor	Resistance		√			√	
Variable Resistors	Resistance		√			√	
Toggle Switch	Contact Resistance	√				√	
Circuit Breaker	Trip Time at 200% OL		√		√		
Total		9	12	0	9	11	1

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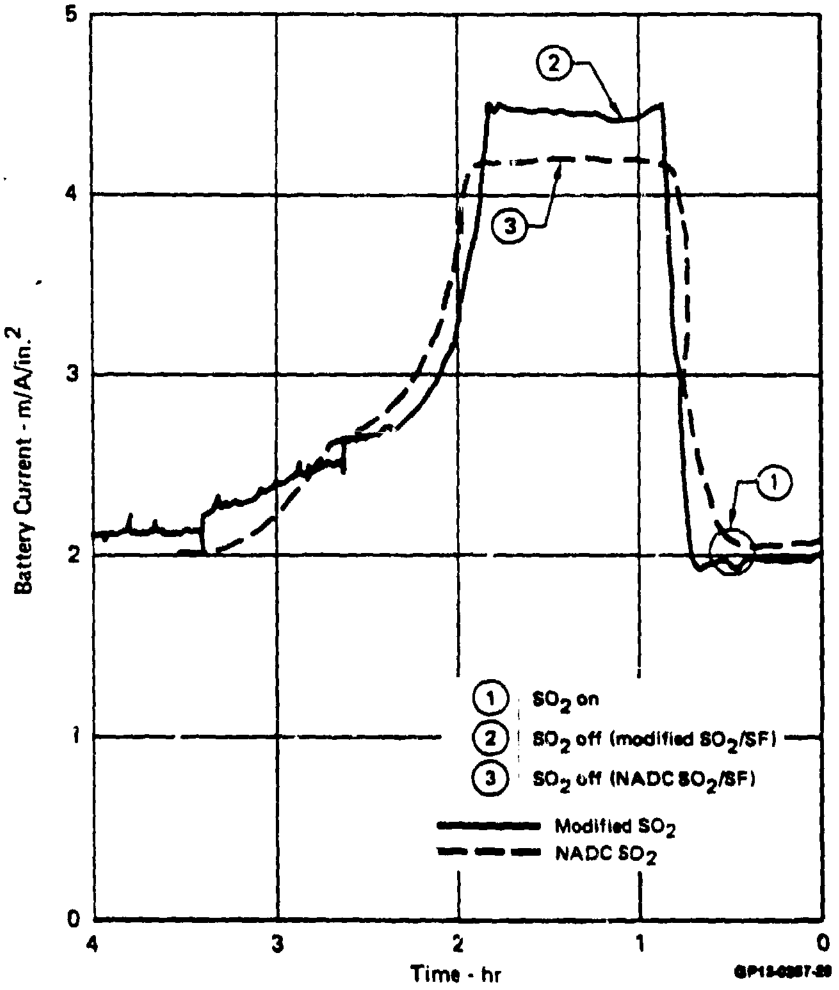

Figure 13 Galvanic Battery Chart Recording During Exposure to the NADC and the Modified SO$_2$/SF Test

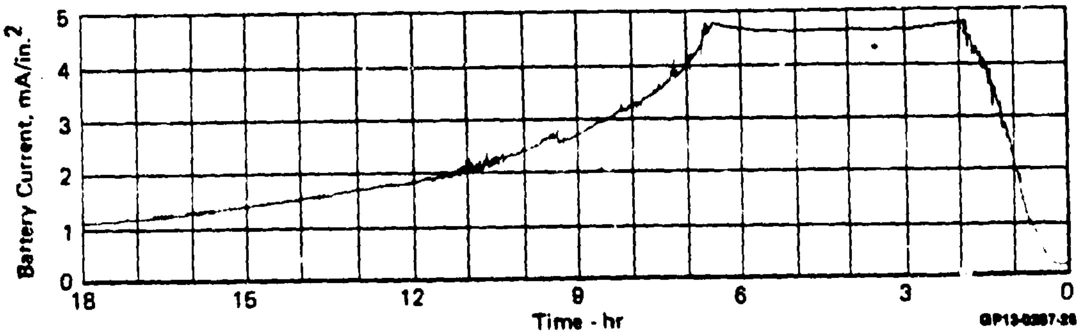

Figure 14 Galvanic Battery Chart Recording of HCl/H$_2$SO$_3$ 185°F Environment

3.6 DISCUSSION OF RESULTS - The modified SO_2/SF test produced the same amount of corrosion on 16 of the 20 test articles as the carrier exposure. Two test articles were more corroded and two were less corroded than the carrier test articles. This is considered to be as high a correlation score as is practicable. A perfect correlation score is not possible using such a wide variety of test articles because the results of the carrier exposure will vary depending on the operating area, the time of year and the weather conditions. Therefore, since the test standards are to some degree a variable as are the results of sequential laboratory tests, the test method should be expected to provide good but not perfect correlation.

Wherever there is moisture to act as an electrolyte, there is a danger that corrosion can occur. Therefore to be effective, a corrosion test must have the same ability to force moisture to penetrate partially sealed components such as connector interiors as the service environment. The high temperature SO_2/SF test meets this criteria because it caused insulation failure of the 4-pin connector and tarnished the copper pins inside the 61-pin connector. The Mil-STD-810 5% neutral Salt Fog test and the NADC sulfur dioxide operate at a cabinet temperature at 95°F. This temperature is too low to produce the moisture diffusion and intrusion phenomena that occur during long term avionics deployment.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS - As a result of the data developed by the program, the following conclusions are presented:

- The Mil-STD-810 (ASTM B117) neutral salt fog test is inadequate for qualifying avionic components for marine service.
- The program objective of developing a avionic corrosion test method that can be used for component certification has been accomplished.
- The program objective has been exceeded in the sense that the high temperature SO_2/SF test can be used as a humidity test as well as a corrosion test.
- The galvanic battery is a valuable addition to the analytical tools required in corrosion research and development.

4.2 RECOMMENDATIONS - It is recommended that:

- Additional tests be carried out using the high temperature sulfur dioxide/salt fog test by more than one laboratory using line replaceable units with known corrosion problems to determine if this test method will duplicate the service problems. The following test parameters are recommended for running these tests:

  a) Cabinet temperature 120-125°F.
  b) Bubble tower temperatures 135-140°F (it may be necessary to insulate the tower to meet the temperature requirements).
  c) Make up salt solution for fog generation by adding 1 part of the ASTM D1141 solution to 10 parts distilled water.
  d) Fog generation in accordance with ASTM B117 except that the Fog is discontinuous - 5 hrs. on and 1 hr. off every 6 hrs.
  e) Sulfur dioxide dispersed throughout the cabinet as shown in Figure 1 of Reference 2.
  f) The flowrate of sulfur dioxide and flow rate control equipment should be in accordance with Reference 2.
  g) The cam controlled solenoid valve should be set to start the SO_2 flow 15 minutes before the salt fog is shutoff and should continue for 15 minutes after the fog is shut off for a total of 30 minutes of input every 6 hrs.

- Feasibility studies be made using galvanic batteries to establish aircraft wash schedules based on galvanic battery output.

5. REFERENCES

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