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The Effects of Mixed Wire Types in Aircraft Electrical Wiring Interconnection Systems

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16. Abstract

Original aircraft manufacturers have designed and built aircraft with various wire types due to the improvement of technology, materials, and processing of wire. New aircraft may have multiple wire types in the same aircraft to meet various environmental zone requirements. Wiring sections may be modified or rewired with the same wire that was originally installed in the aircraft or with a newer, more advanced wire, thus mixing wire types in bundles. Little data has been generated and published indicating whether mixing wire types creates problems with the long-term integrity of the electrical wiring. The objective of this research was to assess past and current guidelines, to review prior research and test data, and to perform additional testing to determine the effects of mixed wire types in electrical wiring interconnection systems in aged aircraft. Where applicable, develop recommendations regarding the mixing of wire types in aircraft applications.

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LIST OF ACRONYMS

AC	Advisory Circular
CFR	Code of Federal Regulations
DWV	Dielectric withstand voltage
EWIS	Electrical wiring interconnect system
FAA	Federal Aviation Administration
IR	Insulation resistance
NAC	Naval Avionic Center
OAM	Original aircraft manufacturer
PI	Polyimide
PTFE	Polytetrafluoroethylene
PVC	Polyvinylchloride
XLETFE	Cross-linked ethylene-tetrafluoroethylene
XPI	Cross-linked polyalkene-imide

EXECUTIVE SUMMARY

Original aircraft manufacturers have designed and built aircraft with various wire types. This occurred because the technology, materials, and processing of wire has continually improved. New aircraft may have multiple wire types in the same aircraft to meet various environmental zone requirements. Wiring sections may be modified or rewired with the same wire that was originally installed in the aircraft or with a newer, more advanced wire, thus mixing wire types in bundles. Little data has been generated and published indicating whether mixing wire types creates problems with the long-term integrity of the electrical wiring.

An assessment of the past and current guidelines regarding the presence of multiple wire types was performed. Conclusions were made regarding the effects of multiple wire types mixed together in the electrical wiring interconnect system (EWIS), based on test results, and recommendations are made regarding the mixing of multiple wire types within the EWIS during design, repair, and maintenance of the EWIS.

None of the documents reviewed specifically addressed or restricted mixing of dissimilar wire types in bundles, but regulations stipulated that the wires selected must meet the environmental, application, interface, and design requirements.

Accelerated vibration testing of mixed and nonmixed wire bundles was performed both with and without hydraulic fluid and metal shavings contamination. The results indicated that none of the ten wire types tested exhibited accelerated wear characteristics in mixed bundles compared to nonmixed bundles. No electrical failures were attributed to mixing of wire types within a bundle during laboratory testing. Many of the wire types, however, exhibited significant wear from clamps and structure in both the contaminated and uncontaminated conditions.

Routine inspections of all wire types should continue in aging aircraft to ensure that the electrical wire maintains physical and electrical integrity and to monitor the wire for signs of wear from wires, clamps, and the aircraft structure. Inspection of the clamped areas should be emphasized, with the clamp to wire tightness being evaluated.

1. INTRODUCTION.

1.1 PURPOSE.

The purpose of this study was to determine the effects of mixing wire types in aged aircraft and to develop Federal Aviation Administration Advisory Circular (AC) or regulation recommendations as applicable to the mixing of wire types in aircraft applications.

1.2 BACKGROUND.

1.2.1 Wire Installation.

Original aircraft manufacturers (OAM) have designed and built aircraft with various wire types. This occurred because the technology, materials, and processing of wire has continually improved. Aircraft wiring is not subject to a service life and mandatory replacement. The airworthiness of aircraft wiring is managed through inspections and maintenance processes. Wiring sections may be modified or rewired with the same wire that was originally installed in the aircraft, or with a newer, more advanced wire, thus mixing wire types in bundles. As aircraft systems are modified or updated, the same airframe wire may not be available or desirable to use. During maintenance and repair, newer or different wire may be used to replace older wire. In these cases, different wire types may be placed together within a harness, or may be located in adjacent harnesses.

1.2.2 Design Options.

It is not uncommon to have multiple wire types used for a new aircraft design because of extreme environmental differences between aircraft zones. Some zones require more rugged wire types than general-purpose wire zones. The designer has the option to protect the general-purpose wire in the extreme zones or to use an alternate wire type. In many cases, the alternate wire type is a specialty wire used for enhanced performance or weight savings. The end result is mixed wire bundles for the life of the aircraft.

1.2.3 Investigation Reason.

Very little data has been generated or published indicating whether mixing wire types creates short- or long-term problems. Since recent Aging Transport Systems Rulemaking Advisory Committee aircraft inspections indicated mixed wire might be a problem [1], it was determined that an investigation was warranted for aged aircraft.

2. APPROACH.

The current requirements from various regulatory and military documents that have been used as guidance regarding the mixing of different wire types in electrical wiring interconnection system (EWIS) bundles were reviewed. Aircraft wiring practices referencing mixed wire types were also examined. Past test results, formal or informal, were analyzed. Based on the background information gathered, a test program was developed and executed to assess the actual interactions between different wire types within the same bundles or in adjacent harnesses in the EWIS.

3. REVIEW OF DOCUMENTATION.

A collection of information related to mixing of dissimilar wire types that was compiled through extensive research of military specifications, Federal Aviation Administration (FAA) regulations and advisory material, technical manuals, and other documentation are found in appendix A. It also summarizes the results of the search and provides a description of how, and to what extent, the subject is currently addressed in the aerospace industry.

3.1 REVIEW OF REGULATIONS, PROPOSED REGULATIONS, AND DESIGN SPECIFICATIONS.

FAA regulations, Title 14 Code of Federal Regulations (CFR), Airworthiness Directives, ACs, military and commercial design documents such as SAE AS50881 (formerly MIL-W-5088) and SAE ARP4404, and other documents were researched extensively for information related to the mixing of dissimilar wire types in bundles (as shown in appendix A).

Two major points are evident from the research. First, there are no specific statements in any of the documents that specifically address how mixing of dissimilar wire types in bundles should or should not be performed. Second, the documents imply that mixing different wire types is not restricted. However, regulations do stipulate that the wire selected for an application must meet the environmental and application requirements demanded of the wire, wiring components interface requirements, and design recommendations such as minimizing the number of components used in the EWIS.

3.2 AIRCRAFT WIRING PRACTICES.

3.2.1 Original Aircraft Manufacturers Wiring Practices.

OAM standard wiring practices were reviewed to identify guidelines related to mixing wire types in installation, maintenance, repair, and inspection of the EWIS. The wiring practices of the following OAMs, as described through the standard wiring practices manuals, were reviewed for material related to mixing of dissimilar wire types.

- Airbus Industrie Electrical Standard Practices Manual
- Boeing D6-54446 Standard Wiring Practices Manual (chapter 20)

Lockheed Martin also provided informal information but no documentation.

Only limited relevant processes and practices of the operators and the OAMs were provided, making it difficult to provide a clear picture of what the current commercial practices are in regard to mixing different wire types within the same wire bundles during installation, repair, modification, and routine maintenance.

It is generally accepted that the use of fewer parts on an aircraft will help to keep the overall costs down. The logistical costs of maintaining aircraft with multiple wire types and tooling are often cost prohibitive. OAMs prefer to use one wire type for all major wiring on the aircraft; however, special applications or environments may require that a different type of wire be used that can meet these special requirements. These various wire types will usually lay together in the same wiring runs and harnesses, or cross other wires. Since one wire length may pass through multiple areas of an aircraft with vastly different environmental conditions, the wire must be able to meet the most stringent of those application requirements.

3.2.2 Commercial Maintenance and Operator Wiring Practices.

Maintenance facilities and operators usually follow the instructions and recommendations of the OAM for a specific airframe. Some facilities attempt to decrease parts inventories through standard process initiatives and may substitute parts through that process. In areas where modifications are made to the EWIS, mixing of wire types will occur if substitute wire types are used. Many of the older aircraft have airframe wire that is no longer allowed in the new 14 CFR Part 25 aircraft and is discouraged from use in aerospace applications. When repairs are made to the EWIS, these wires or portions of these wires could be replaced with alternative wire types.

3.2.3 Modification Facilities.

Facilities that hold a Supplemental Type Certificate may perform modifications to the aircraft with different wire types than were originally used on the aircraft when approved by FAA authorities.

3.2.4 Military Maintenance and Operation Wiring Practices.

As with many military maintenance documents, NAVAIR 01-1A-505 and U.S. Air Force T.O. 1-1A-14 "Installation Practice Aircraft Electric and Electronic Wiring" manuals and other documents (listed in appendix A) do not specify that mixing of dissimilar wire types can or cannot take place in the aircraft. However, there is wire substitution information contained in NAVAIR 01-1A-505.2 concerning wire replacement for repair and maintenance. For example, work package 006 contains very specific instructions for replacing M81381 aromatic polyimide insulated wire types with M22759 cross-linked ethylene-tetrafluoroethylene (XLETFE) insulated wire types for single conductor repair. For aircraft that were originally manufactured with polyimide insulated wires, the instructions in the work package tacitly call for an eventual mixing of wire types over time as old polyimide is replaced with fluorocarbon-based wire during maintenance and repair actions.

The U.S. Air Force does not appear to have published policy related to specific replacement of wire across the board. However, specific platforms can and do make decisions, such that older wire types can be replaced with available alternative wire types. Over time, this will lead to the presence of mixed wire types in U.S. Air Force aircraft.

The Naval Aerospace Vehicle Wiring Action Group guideline, D5-GI-1188, assists maintenance personnel with replacement of polyvinylchloride (PVC) and aromatic and aliphatic-type polyimide insulated wire types. The guidance specifies the replacement of PVC insulated wire and aromatic and aliphatic polyimide insulated wire with XLETFE insulated wire. The guideline also provides wire substitutions for canceled wire specifications and for certain common wire types stored in wiring shops.

These directives and guidelines indicate that mixing of wire types in U.S. Navy and U.S. Air Force aircraft is a recognized practice that is necessary and acceptable.

3.3 REVIEW OF SERVICE DATA.

Review of field service data did not indicate that failures occur as a result of mixed wires. There were significant insulation abrasion failures reported that may or may not be attributed to mixed wire, but there was no indication by the repair actions that mixed wires were the issue (see appendix A).

3.4 REVIEW OF PRIOR RESEARCH AND TEST DATA (INDUSTRY, GOVERNMENT, MILITARY, ETC.).

Some parts of the military are presently looking at the issue of mixed wire, but the only formal report found is the Naval Avionic Center (NAC) report TR-2333 [2]. The results indicate that the dielectric characteristics of harder insulations are reduced significantly more than those of softer insulation types. In some cases, the withstand voltage capability was reduced nearly 50% from the initial values, but it should be understood that even at these reduced levels, the wire withstand voltage capability was still 15 times greater than the wire insulation-rated value. Another significant result from the report is that the withstand voltage began to level off between 250 and 512 hours of vibration conditioning. It is unknown whether the withstand voltage would continue to be unchanged after 512 hours of vibration. Visual observations from the study indicate that the reduction in withstand voltage capability was probably due to wire-to-wire wear.

3.5 DOCUMENTATION REVIEW SUMMARY.

There is limited documentation in the commercial industry (OAMs, wire manufacturers, etc.), academia, military, and government agencies that define the current state of knowledge of the effects of mixed wire in the aircraft EWIS. Maintenance and service (accident/incident) reports examined for specific effects of the mixing of wire types yielded no data. Overall, the documentation indicates that it is standard practice to mix wire types in new aircraft, aged aircraft, and in repair actions, although the general consensus (ATSRAC WG-6 report [3]) is to refrain from mixing different wire types unless necessary. The review also indicates that only limited tests were performed to determine the long-term impact of mixing wire types in an aircraft.

4. TEST PROGRAM.

A limited test program was designed to expand on previous testing performed in this area and to answer a number of questions related to the effects of mixing wire types within the EWIS in an aircraft environment.

The test program was developed from previous Raytheon testing experiences and a review of the test procedures from the NAC TR-2333 report and Douglas Corporation report MDC J1530/01 [4]. Some of the fixtures and equipment from the NAC testing program were used for the test program. The basis of the tests was that physical interactions are accelerated by vibration of mixed wire bundles. The vibration causes the motion of the wires against each other to occur at a quick rate, accelerating the physical contact and degradation mechanisms. The mixed wire bundles were baselined to bundles with only one wire type. Foreign object debris and a known chemical were also used to simulate other aircraft environments.

4.1 TEST PLAN.

A test plan was established to evaluate the baseline wire bundles (one wire type) and the mixed wire combinations at specified intervals. The following summarizes the test plan:

- Groups I and II

  - Baseline dry insulation resistance (500 Vdc, 1000 megohms pass/fail threshold, 1 second dwell time)

  - Baseline dry dielectric withstand voltage (1000 Vac, 1 milliamp (mA) leakage current, 1 second dwell time)

  - Random vibration exposure (23.88 grms; see figure B-1 in appendix B), two or three subcycles:

    - Visual inspection on mounted bundles after each subcycle
    - Dry insulation resistance after each subcycle
    - Dry dielectric withstand voltage after each subcycle

  - Wet insulation resistance (500 Vdc, 1000 megohms pass/fail threshold, 1 minute dwell time)

  - Wet dielectric withstand voltage (1000 Vac, 1 mA leakage current, 1 minute dwell time)

  - Visual inspection of unassembled tested bundles

- Group III

  - Crush test

Group I consisted of 48 wire combinations that were subjected to a total of 500 hours of vibration conditioning, with the conditioning paused after 100 and 250 hours for the performance of visual and electrical evaluations.

Group II was similar to group I, except only 24 of the original combinations were selected. One set of the 24 wire combinations was soaked in hydraulic fluid prior to vibration conditioning (group IIF), and a similar set was contaminated with metal shavings (group IIM). Since these bundles were contaminated, the vibration exposure was reduced to 250 hours, and a visual inspection was performed after 100 hours.

Group III consisted of a crush test on the same 24 combinations as tested in group II. Single wires were placed perpendicular to each other, and a load was applied to determine which insulation exhibited the most damage. For each combination of wire selected, four tests were performed with a load of 80 pounds, and four tests with a load of 120 pounds. The wires were evaluated by quantifying the degree of permanent deformation to the insulation of each wire type in the pairs tested. (The complete details of the test plan are in appendix B.)

4.2 SPECIMEN DESCRIPTION.

The wire types chosen for this test program represent typical wire families used in aged aircraft, though there are various construction types within a wire family. For example, PVC/glass/nylon differs from PVC/nylon in that it uses glass fiber braid between the layers of insulation. Since this is not the exterior of the wire, the major difference is the extra stiffness that it imparts on the wire sample. As a sample wears, the glass fiber may become exposed and have an impact on the wires it contacts. Ten wire constructions commonly used in aircraft wiring applications were selected for the test program and were included in both single and twisted pair configurations. The wire types and their combinations with other wire types are shown in table 1. Seven of the wire types tested are general-purpose types designed for use in open wiring (airframe) applications based on AS 50881. The other three insulation types, mineral-filled polytetrafluoroethylene (PTFE), PTFE with glass braid, and PVC/glass/nylon, are generally for applications with especially high abrasion stresses.

The wires tested were 22 gauge, with the exception of the modified and XLETFE and cross-linked polyalkene-imide (XPI) alloy insulated wires that were 24 gauge. These wire sizes are typical of open wiring applications that use 22-gauge wire with an annealed copper conductor or 24 gauge with a higher tensile strength copper alloy conductor. The original objective was for all the wires to have the same conductor size, but the two 24-gauge wires were added to the program because of the high usage of that wire size in aircraft. It was also expected that these small-gauge wires, with thinner insulation and smaller wire-to-wire contact areas, would exhibit pronounced damage more quickly.

TABLE 1. WIRE TYPES EVALUATED

Wire Code*	Description
1	PVC/glass/nylon—Annealed copper conductor insulated with an extruded PVC covered by a glass fiber braid, then coated with an extruded Polyamide per MIL-W-5086/2-22.
2	Polyimide—Annealed copper conductor insulated with a tape-wrapped aromatic polyimide, and coated with an extruded aromatic polyimide resin, per BMS13-51T08.
3	XPI, alloy—Copper alloy conductor insulated with a cross-linked extruded aliphatic polyimide, per Raychem Spec 88A, 24 AWG.
4	XLETFE—Annealed copper conductor insulated with a modified and cross-linked extruded XLETFE, per BMS13-48T08.
5	XLETFE, alloy—Copper alloy conductor insulated with a modified and cross-linked extruded XLETFE, per MIL-W-22759/42-24.
6	PTFE—Annealed copper conductor insulated with polytetrafluoroethylene (PTFE), per MIL-W-22759/9-22.
7	MF-PTFE—Annealed copper conductor insulated with a mineral-filled PTFE, per MIL-W-22759/8-22.
9	PTFE/glass—Annealed copper conductor insulated with multilayered PTFE and covered with a glass fiber braid, per MIL-W-22759/1-22.
10	PI/PTFE—Annealed copper conductor insulated with a tape-wrapped aromatic polyimide, and covered with a tape-wrapped PTFE, per BMS13-60T19G22.
11	PI/PTFE Alloy—Copper alloy conductor insulated with a tape-wrapped aromatic polyimide and covered with a tape-wrapped PTFE, per BMS13-60T04G22.

*Tape wrap PTFE (M16878), wire code 8, was originally considered for the program, but was removed since it is not typically used in open wire applications.

4.3 WIRE BUNDLE CONFIGURATIONS.

Each wire bundle in Groups I and II consisted of 20 wires of either the same wire type or 10 wires of two different wire types. Each bundle contained 12 single wires and 4 twisted pair wires, which provided the opportunity to evaluate the interactions between single-end wires, twisted pair wires, and between twisted pairs and single-end wires in each bundle. For bundles containing two wire types, half of the singles and half of the twisted pairs were of each wire type. Tiedown straps, lacing string, and cushion clamps were used on the bundles to contain the wires and secure them to the vibration fixtures. Detailed descriptions of the wire bundles are in appendix B.

4.4 WIRE BUNDLE COMBINATIONS.

Since 10 wire types were selected for the program, up to 55 different wire combinations could be evaluated, including each wire type in a nonmixed condition. However, due to the limitations of the program funding and vibration test fixturing, the 48 combinations represented by the unshaded blocks in table 2 were selected for group I.

TABLE 2. WIRE COMBINATIONS TESTED IN GROUP I

Wire Type	1 PVC/ G/N	2 PI	3 XPI Alloy	4 XLETFE	5 XLETFE Alloy	6 PTFE	7 MF-PTFE	9 PTFE/ Glass	10 PI/PTFE	11 PI/PTFE Alloy
1 PVC/ G/N										
2 PI										
3 XPI Alloy										
4 XLETFE										
5 XLETFE Alloy										
6 PTFE										
7 MF-PTFE										
9 PTFE/ Glass										
10 PI/PTFE										
11 PI/PTFE Alloy										

The rationale for selecting the combinations for group I included:

- Selecting a type that would give the most encompassing data when several wire types had similar characteristics (e.g., wire with copper alloy conductor is stiffer than wire with annealed copper conductor, and may lead to different results).

- Excluding specific wire combinations that would not be expected in an application. For example, many of the older aircraft are wired using PVC/glass/nylon insulated wire and are repaired using the same wire type, but it is not typically used for modifications. Also, the use of PVC/glass/nylon in combination with polyimide, XPI, PTFE, or composite (wrapped aromatic polyimide (PI) and PTFE) insulated wire is expected to be minimal.

- Selecting types with which aircraft are typically wired, including in specific applications and during modifications or repairs. For example, a combination of PVC/glass/nylon with the mineral-filled PTFE, which is often used as an abrasion-resistant wire construction in many aircraft, was included. The combination of PTFE and PI/PTFE composite insulated wire was excluded, since the abrasion resistance variety is more common.

Forty-eight wire bundles were also tested in group II, but since two contamination variables (metal shavings and hydraulic fluid) were introduced, the number of different wire combinations tested for each contamination type had to be reduced to the twenty-four unshaded combinations shown in table 3.

TABLE 3. WIRE COMBINATIONS TESTED IN GROUP II

Wire Type	1 PVC/ G/N	2 PI	3 XPI Alloy	4 XLETFE	7 MF-PTFE	9 PTFE/ Glass	10 PI/PTFE	11 PI/PTFE Alloy
1 PVC/ G/N								
2 PI								
3 XPI Alloy								
4 XLETFE								
7 MF-PTFE								
9 PTFE/ Glass								
10 PI/PTFE								
11 PI/PTFE Alloy								

The rationale used in selecting the wire combinations for group II was similar to that used for group I, but also included

- selecting the types most commonly used in aircraft applications.
- removing XLETFE insulated copper alloy conductor wire since the difference between the alloy and annealed versions was evaluated in the first test group.
- deleting combinations with the PTFE/glass fiber braid type insulated wire, except for the one mixed with XLETFE insulated wire.
- removing combinations with the PI/PTFE alloy conductor wire, except for the ones with either XLETFE or the PI/PTFE annealed copper conductor type.

4.5 CRUSH TEST WIRE COMBINATIONS.

The group III crush test was performed on single wires of the same 24 combinations as shown in table 3.

5. DISCUSSION AND RESULTS.

Potential risks associated with simulation testing are common in most test situations. These risks include (1) whether the testing realistically simulates the actual conditions seen in operation, (2) whether there is control over as many variables as possible, and (3) the variability of test measurements and observations. To mitigate these risks, previous research, test data, and procedures were consulted prior to finalizing the test plan. For comparison, mixed wire bundles were tested with baseline nonmixed wire bundles.

The primary scope of this program was to determine the impact of mixing different wire insulation types within the same bundle in an aircraft. The test data generated in this program included electrical measurements, wire-to-wire wear, wear from support components, wear from contaminants, and resistance to crushing. Summaries and comparisons of the test data permitted conclusions to be drawn as to the role the variables played in the interactions between the same wire and different wire types (The data generated for this test program is compiled in appendix C).

5.1 GROUP I TEST RESULTS.

5.1.1 Visual Observations on Mounted Bundles.

Upon completion of 100, 250, and 500 hours of vibration exposure, the wire bundles were visually inspected while still mounted on the test fixtures. General observations after 100 hours of vibration included rotation of the heads of the straps; twisted pairs separating from the bundles; wear marks on the fixtures from wires, straps; and lacing string; and slippage of bundles in the cushion clamps. After 250 hours of vibration, additional observations included the presence of white residue from wire insulation or cushion clamp, lacing string cutting into the insulation, and wearing of the black wire stripe marking. The same types of conditions were observed after 500 hours of testing as after 250 hours, but the severity of the conditions had increased. (The complete results from the inspections are shown in appendix C.)

5.1.2 Electrical Testing.

Following 100, 250, and 500 hours of vibration exposure, the test bundles were electrically tested for insulation resistance (IR) and dielectric withstand voltage (DWV) in the dry condition. After 500 hours of vibration, the bundles were submerged in a saltwater bath for wet electrical testing.

No dry IR or DWV failures were detected after 100 hours of vibration conditioning. However, failures were observed following 250 and 500 hours of vibration exposure. Not as many failures were detected during dry electrical testing as during wet testing. This might be due to the position of the wear on a wire, whether from other wires, support hardware, or the test fixture, could be such that it was isolated from other circuits. During the wet electrical testing, the individual wires were immersed in a saltwater bath so that the complete external surface of the wire could be tested for failures. For this analysis, a wire was not considered to have failed if it passed the DWV test, even if the IR was below the selected pass/fail threshold. No electrical failures were detected on the PVC/glass/nylon, PI, XLETFE, or PI/PTFE alloy wire types (codes 1, 2, 4, and 11 in table 1) in either the mixed or nonmixed bundles.

Only one dry electrical test failure was confirmed by wet electrical testing; however, all wet electrical failures were confirmed through visual examination of the test bundles. For this reason, the dry electrical results were considered suspect. Occasional DWV failures related to wire aging is expected. This was not considered significant unless several instances occurred in one bundle or moderate to severe wear was noted during visual examination. (A complete summary of the dry and wet IR and DWV failures is provided in appendix C, tables C-2 through C-4.)

5.1.3 Wire-to-Wire Wear.

The visual examination data from the unassembled bundles is compiled in appendix C, table C-5. The results are summarized by wire type in table C-6 of appendix C so that wire-to-wire wear data for each type, in mixed and nonmixed bundles, could be analyzed. Each column in table C-6 provides a comparison of the nonmixed bundle to the mixed bundle combinations selected. The table also identifies which bundles were slipping within the cushion clamps after 100 hours of vibration, provides a damage rating for the wires rubbing against the fixture plate, and quantifies the electrical failures that were detected.

A graphical representation of the group I wire-to-wire wear for each wire type in mixed and nonmixed configurations is provided in figures 1 through 10. The damage severity ratings of 0, 1, 2, and 3 in the charts correspond to none, low, moderate, and severe ratings, respectively, and were assigned based upon subjective visual observations**.** No bars shown for a particular wire code indicates that the combination was not tested.

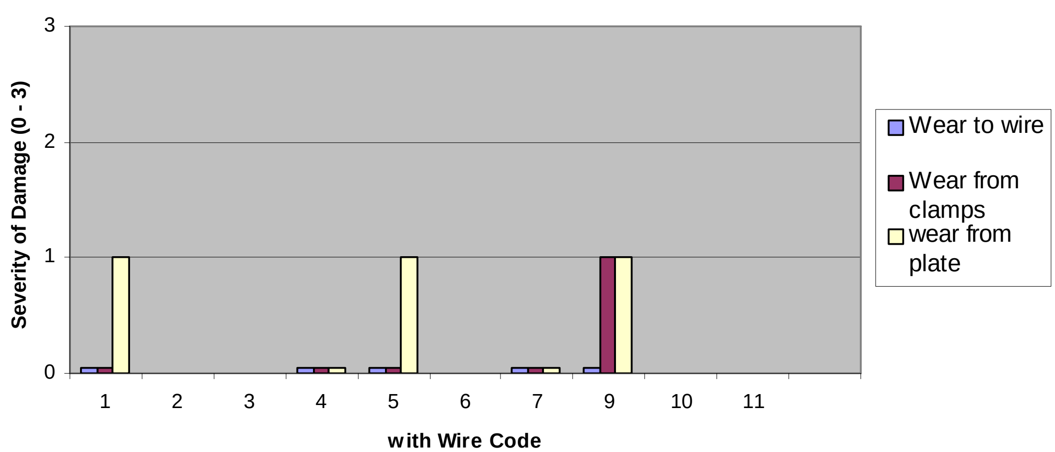

FIGURE 1. GROUP I TESTING: PVC/GLASS/NYLON (WIRE CODE 1) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

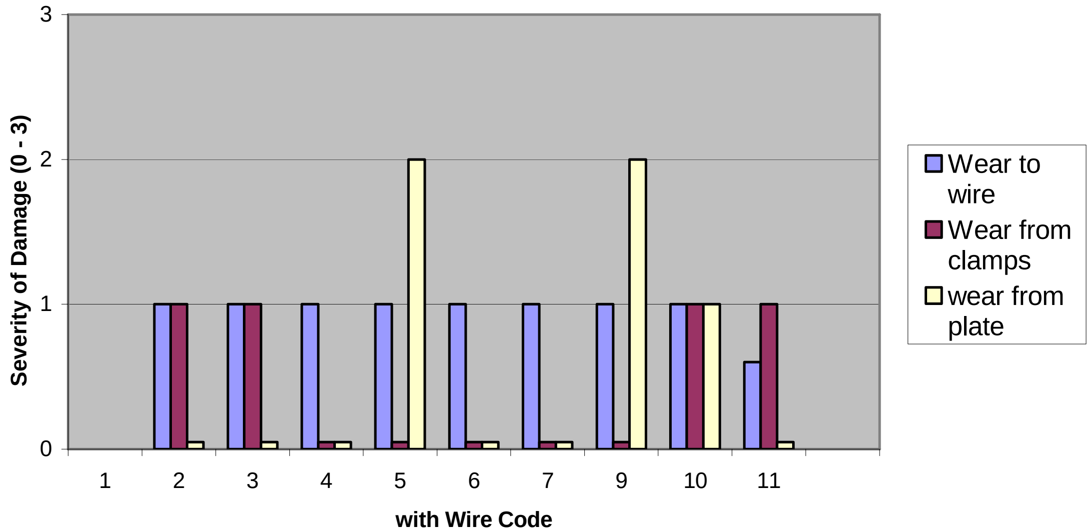

FIGURE 2. GROUP I TESTING: PI (WIRE CODE 2) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

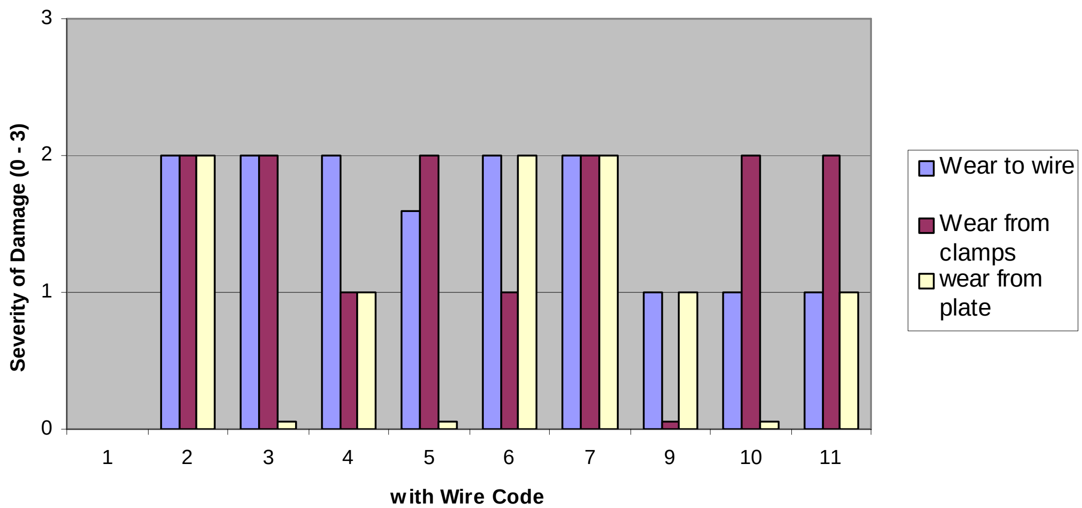

FIGURE 3. GROUP I TESTING: ALIPHATIC PI, ALLOY (WIRE CODE 3) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

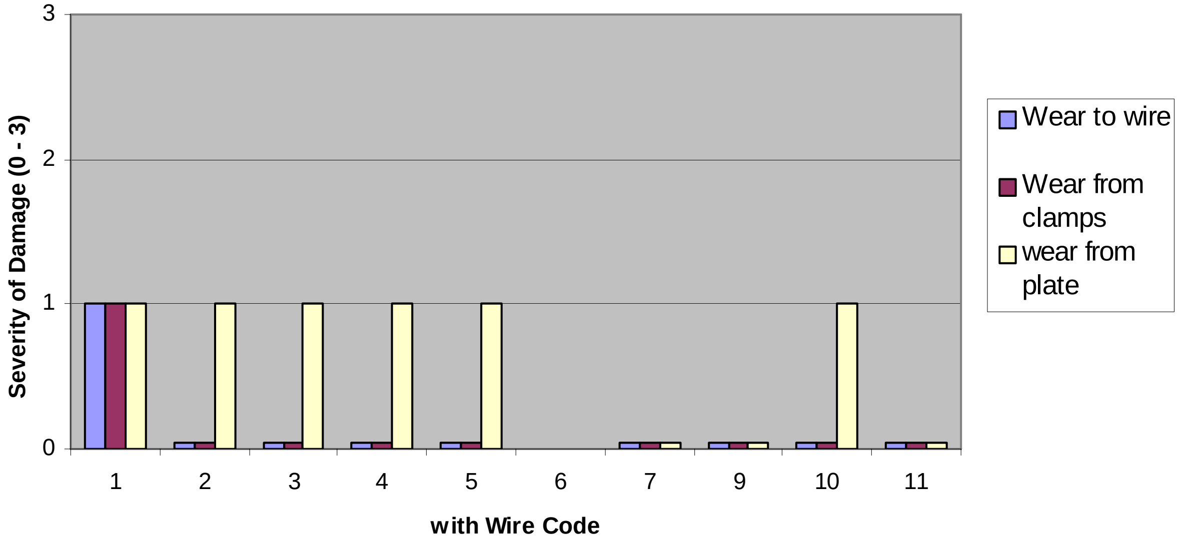

FIGURE 4. GROUP I TESTING: XLETFE (WIRE CODE 4) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

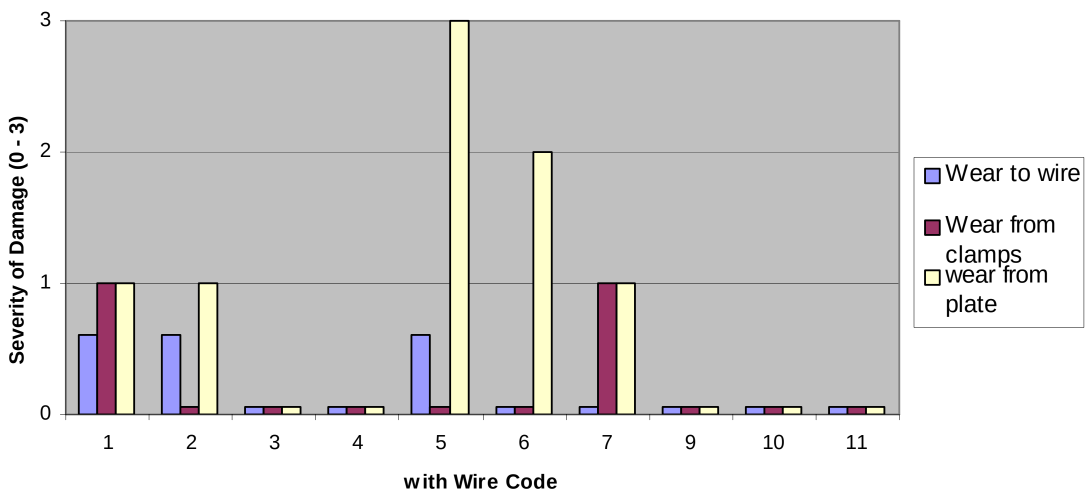

FIGURE 5. GROUP I TESTING: XLETFE, ALLOY (WIRE CODE 5) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

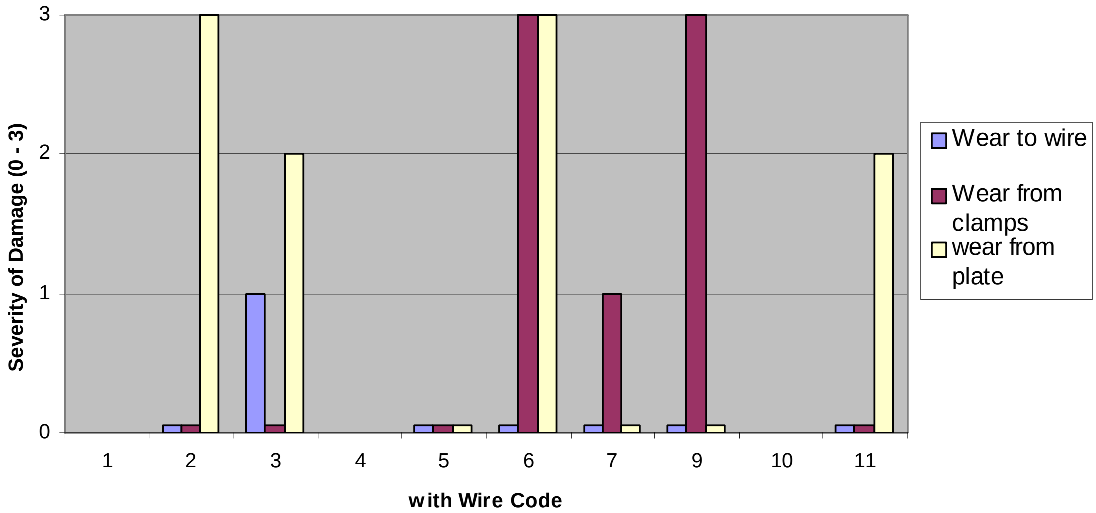

FIGURE 6. GROUP I TESTING: PTFE (WIRE CODE 6) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

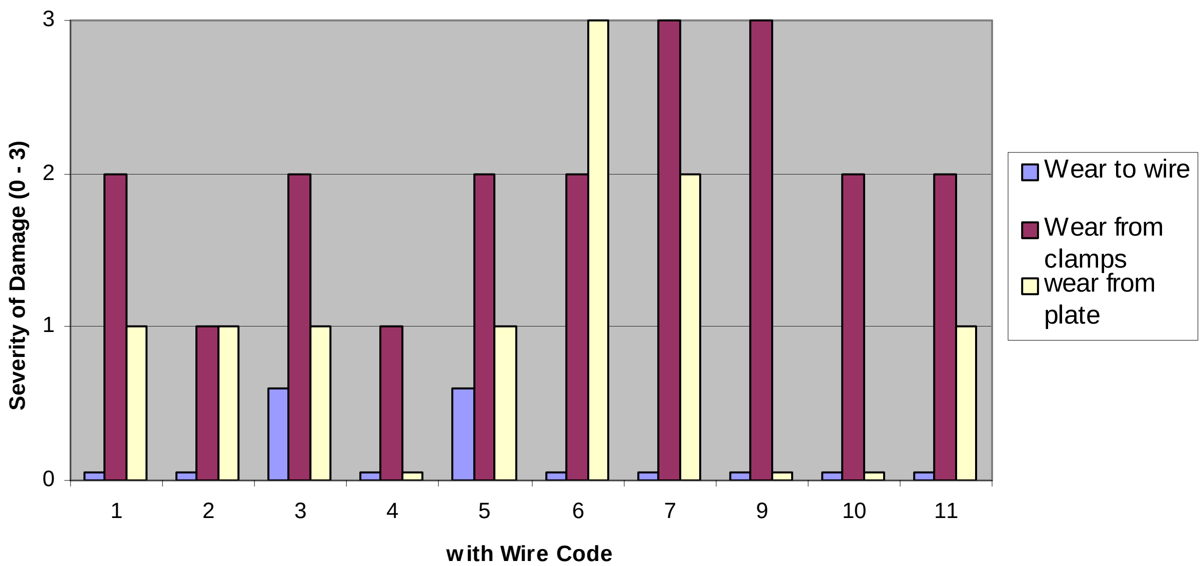

FIGURE 7. GROUP I TESTING: PTFE, MINERAL-FILLED (WIRE CODE 7) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

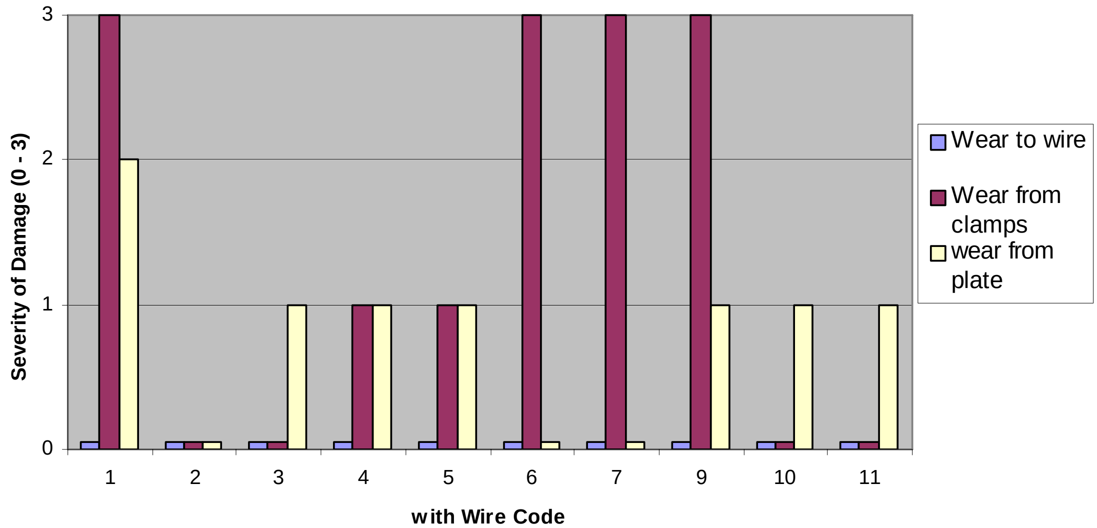

FIGURE 8. GROUP I TESTING: PTFE/GLASS BRAID (WIRE CODE 9) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

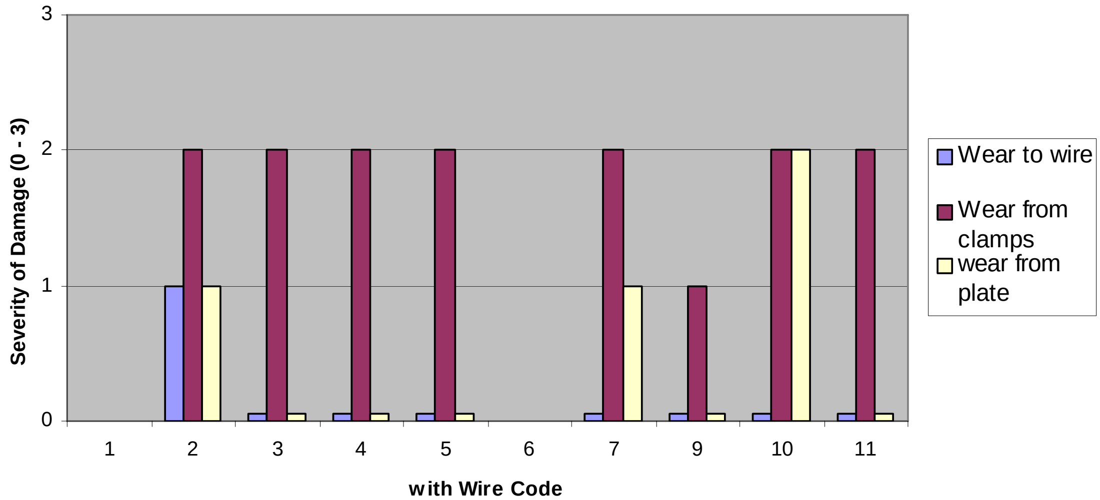

FIGURE 9. GROUP I TESTING: PI/PTFE (WIRE CODE 10) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

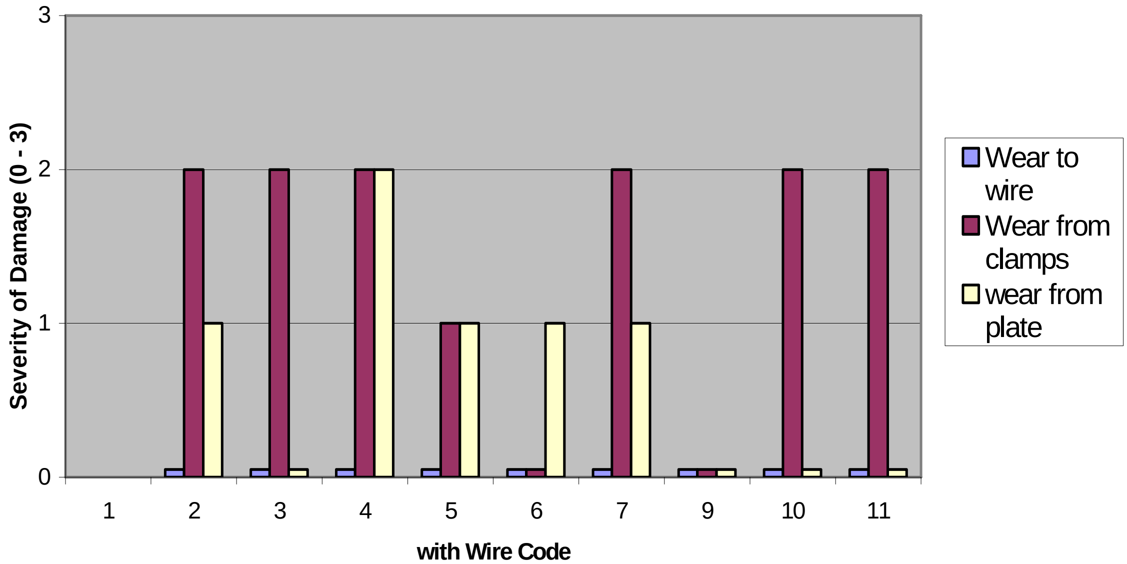

FIGURE 10. GROUP I TESTING: PI/PTFE, ALLOY (WIRE CODE 11) WIRE DAMAGE AFTER 500 HOURS OF VIBRATION CONDITIONING

Figure 1 indicates that negligible wire-to-wire wear occurs with PVC/glass/nylon wire, whether in a mixed or nonmixed bundle.

Figure 2 indicates that PI wire consistently exhibits low wire-to-wire wear whether in a mixed or nonmixed bundle.

Figure 3 indicates that XPI alloy wire exhibits moderate wire-to-wire wear in the nonmixed and mixed bundles, except in combinations with PTFE/glass (code 9), PI/PTFE (code 10), and PI/PTFE alloy (code 11), where a low amount of wear was observed.

Figure 4 indicates that XLETFE wire has negligible wire-to-wire wear in the nonmixed and mixed bundles, except in combination with PVC/glass/nylon, where a low level of wear was noted.

Figure 5 indicates that XLETFE alloy wire exhibits low wire-to-wire wear in the nonmixed bundle and in combination with PVC/glass/nylon (code 1) and PI (code 2). Negligible wear was observed when mixed with other wire types.

Figure 6 indicates that PTFE wire exhibits low wire-to-wire wear when mixed with XPI wire (code 3), and negligible wear in all other combinations and in the nonmixed bundle.

Figure 7 indicates that mineral-filled PTFE wire exhibits negligible or very low wire-to-wire wear in the nonmixed and mixed bundles.

Figure 8 indicates that negligible wire-to-wire wear was observed on PTFE/glass wire, whether in mixed or nonmixed bundles.

Figure 9 indicates that PI/PTFE exhibits low wire-to-wire wear when mixed with PI wire (code 2) only. This is likely caused by the PI insulation being more abrasive than the outer PTFE layer of the PI/PTFE wire. In the nonmixed bundle, and in all other combinations, negligible wear was observed.

Figure 10 indicates that there was negligible wire-to-wire wear of PI/PTFE alloy in the nonmixed and mixed bundles. The slight difference in the results between the same insulation types in figures 9 and 10 may be due to the subjectivity of the visual examinations.

Figure 11 provides a summary of five mixed wire bundle combinations in which one of the wires exhibited more severe wire-to-wire wear than in the nonmixed bundle. The wire types exhibiting more wear are XLETFE, PTFE, MF-PTFE, and PI/PTFE (codes 4, 6, 7, and 10, respectively). However, in these combinations, the differences in wear were slight and could be attributed to the subjectivity of the data. The following observations were made on these combinations:

- 1, 4 (PVC/glass/nylon, XLETFE): The XLETFE exhibited more damage when mixed in a bundle with the glass fiber with nylon than in the nonmixed bundle.

- 3, 6 and 3, 7 (XPI, PTFE and XPI, MF-PTFE): The XPI caused a little more damage on both of the PTFE insulated wire types in the mixed bundles, but the damage was slightly less on the abrasion-resistant MF-PTFE. Neither of the PTFE wire types caused additional damage to the XPI wire. The XPI had poor resistance to abrasion regardless of the other wire type.

- 5, 7 (XLETFE alloy, MF-ETFE): The XLETFE alloy showed slightly less damage when mixed with MF-PTFE than in its baseline bundle, but the MF-PTFE showed slightly more damage in the mixed configuration.

- 2, 10 (PI, PI/PTFE): The PI/PTFE showed a little more damage in the mixed configuration due to the PTFE outer coating being softer than the PI coating.

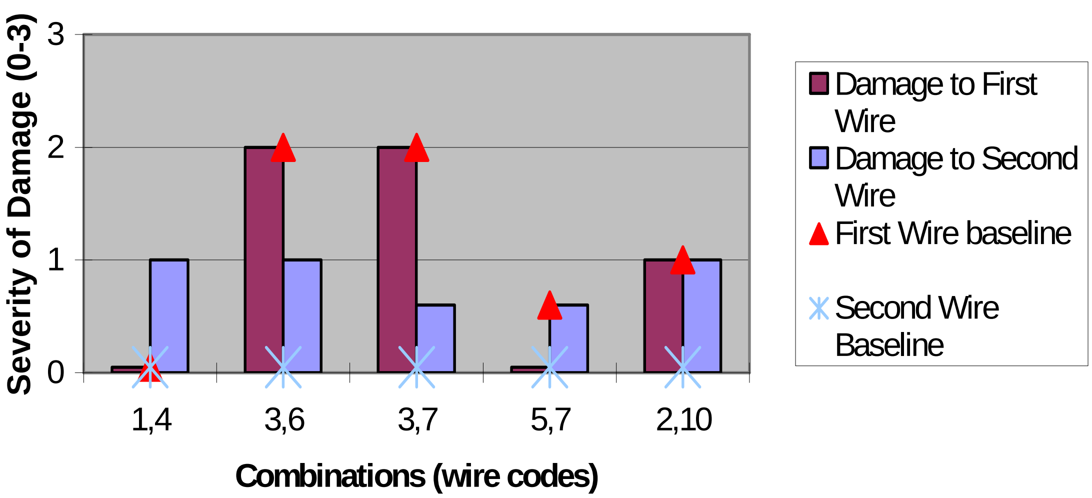

FIGURE 11. WIRE INTERACTIONS IN GROUP I MIXED BUNDLES

Overall, the results indicated that within the subjectivity of the data, wire-to-wire wear is not significant in mixed or nonmixed bundles on the wire types tested, with the possible exception of XPI wire (code 3) that exhibited moderate wear in both the mixed and nonmixed bundles (see figures 12 and 13). The vibration level chosen for the program is similar to the high vibration levels expected in U.S. Navy aircraft, so it can be presumed that at lower levels, the wear would be less. The vibration profile used in this test program may be different from the vibration levels experienced by the EWIS in commercial aircraft.

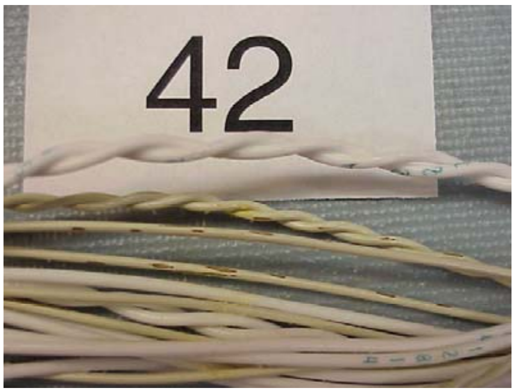

FIGURE 12. MODERATE WIRE-TO-WIRE WEAR ON GROUP I XPI IN BUNDLE MIXED WITH PTFE

FIGURE 13. MODERATE WIRE-TO-WIRE WEAR IN GROUP I NONMIXED XPI BUNDLE

5.1.4 Wire Wear From Clamps.

The visual examination data from the unassembled bundles are also summarized in appendix C, table C-6 so that the data regarding wire wear from the clamps for each wire type could be analyzed. Each column in table C-6 provides a comparison of the nonmixed bundle to the mixed bundle combinations selected. The table also indicates whether the bundle was slipping within the cushion clamps after 100 hours of vibration, provides a damage rating for the wires rubbing against the fixture plate, and quantifies the electrical failures.

The graphical representation of the wire wear from clamps in mixed and nonmixed conditions for each wire type is shown in figures 1 through 10.

Figures 1, 4, and 5 show that only the PVC/glass/nylon, XLETFE, and XLETFE alloy wire types (codes 1, 4, and 5, respectively) exhibited more wear from the clamps in certain mixed bundles than in the nonmixed bundle. It was also noted that the XPI, PTFE, MF-PTFE, PTFE/glass, PI/PTFE, and PI/PTFE alloy wires (codes 3, 6, 7, 9, 10, and 11) all exhibited moderate or severe wear from the clamps, but the wear was similar in the mixed and nonmixed bundles (see figures 14 and 15 and additional figures D-1 through D-7 in appendix D).

The one XPI wire that failed the wet DWV test was determined to be from a combination of wear from wire-to-wire interaction and wear from the clamps in the nonmixed bundle (see figure 14).

FIGURE 14. MODERATE WIRE WEAR FROM CLAMPS ON NONMIXED XPI BUNDLE IN GROUP I

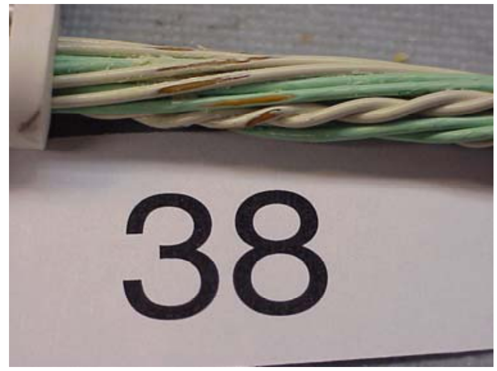

FIGURE 15. MODERATE WIRE WEAR FROM CLAMP ON PI/PTFE AND XPI IN GROUP I

The wire types with the most electrical failures were the PTFE/glass and PTFE (codes 9 and 6, respectively); however, all the failures were attributed to the severe wear from the clamps (see figures D-1, D-2, D-3, and D-5 in appendix D).

The PI/PTFE wire (code 10) exhibited one DWV failure in a bundle mixed with MF-PTFE (code 7), which was attributed to moderate wear from the clamps (see appendix D, figure D-8) and wear from the vibration fixture plate. No wire-to-wire wear was evident in the bundle.

Data was also plotted to analyze whether the clamp diameter and bundle diameter difference or slippage in the clamps after 100 hours of vibration exposure had a direct correlation to the severity of wire-to-wire or wire from clamp damage.

Figure 16 indicates that a higher difference between the bundle and clamp diameters was not the only factor in determining the severity of the wire-to-wire wear. The figure also indicates that slipping in the clamps did not cause the wire-to-wire damage to be more severe.

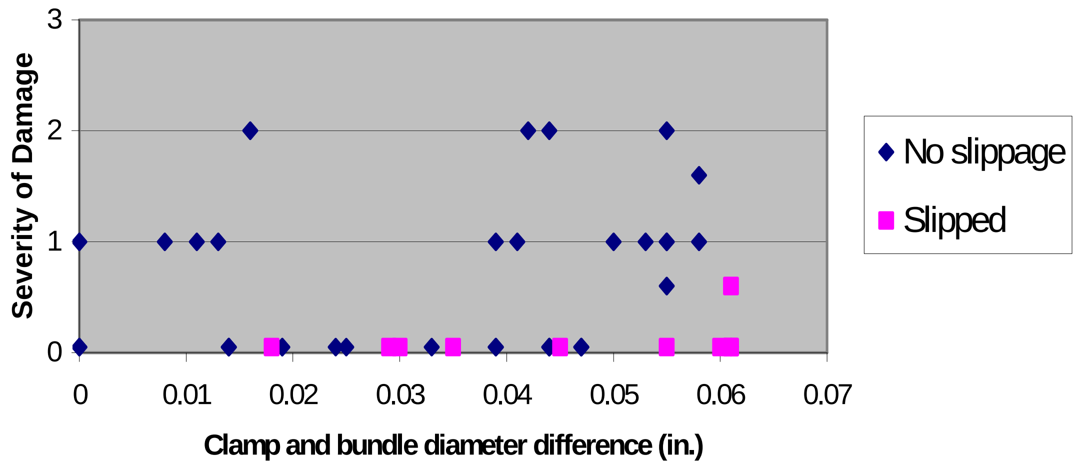

FIGURE 16. GROUP I: TIGHTNESS OF CLAMP VS WEAR FROM WIRE

Figure 17 indicates that a higher difference between the bundle and clamp diameters was not the only factor in determining the severity of the wire wear from the clamps. The figure also indicates that slipping in the clamps did not necessarily cause the wire wear from clamps to be more severe.

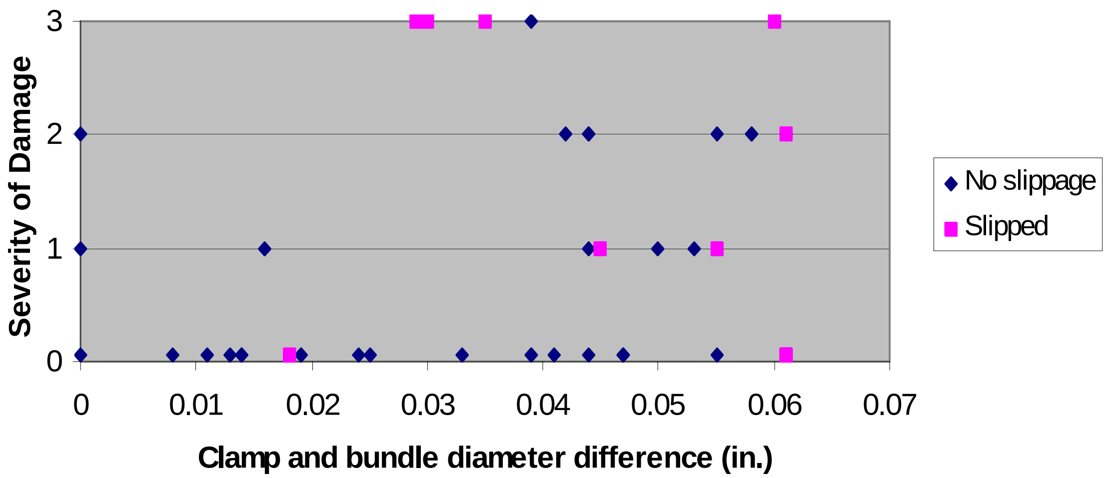

FIGURE 17. GROUP I: TIGHTNESS OF CLAMP VS WEAR FROM CLAMP

These results were not expected, since it is generally an industry standard practice to tightly clamp wire bundles to minimize wire movement and wear from the clamps and other wires. More investigation is needed to determine the appropriate level of clamping required to minimize wire wear.

5.1.5 Wire Wear From Straps and Lacing String.

Visual examination results from unassembled bundles were also reviewed to determine the amount of damage that the wires sustained from the straps and lacing string. (A summary of the results is provided in appendix C, table C-5.)

The results indicate that all the wire types displayed little or no wear at the straps, whether the bundles were nonmixed or mixed wire types. The PI wire (code 2) had a little wear when mixed with PTFE/glass (code 9), whereas there was none in the PI nonmixed bundle. The XLETFE alloy wire (code 5) had a little wear with the XPI, PTFE, and PI/PTFE wire type (codes 3, 6, and 10, respectively), but none in the nonmixed. The PI/PTFE wire (code 10) had a little wear with the XPI, XLETFE, XLETFE alloy, and MF-PTFE wire types (codes 3, 4, 5, and 7,respectively), but none in the nonmixed.

Only the PI, MF-PTFE, and PI/PTFE alloy wire types (codes 2, 7, and 11, respectively) showed any wear from the lacing string, and this was just in one case each in a mixed wire bundle.

Overall, within the subjectivity of the visual examinations performed, the results indicate no significant wire wear occurred from the straps or lacing string in group I.

5.1.6 Wire Wear From Vibration Fixture Plate.

A number of wire types suffered abrasion from the aluminum test fixture during vibration, which may have contributed to electrical failures. Figures 1 through 10 provide a graphical representation of the wire wear from the plate for each wire type in the mixed and nonmixed configurations.

The two electrical failures detected on the XLETFE alloy wire (code 5) in the nonmixed bundle were attributed to the severe wire wear from rubbing against the vibration fixture (see appendix D, figure D-9). A little wire-to-wire wear was also observed on this wire type in the nonmixed configuration.

One electrical failure was also detected on the XLETFE alloy wire (code 5) in a bundle mixed with MF-PTFE (code 7), but visual examination of the bundle indicated that the failure was caused by wire wear from the plate or clamps since no wire-to-wire wear was noted.

5.1.7 Wear of Support Components.

The clamps were the only support components (clamps, straps, and lacing string) that exhibited moderate wear. In these cases, either PVC/glass/nylon or PTFE/glass wires were in the bundles (see figures 18 and 19). This might be explained by the abrasive nature of the glass component within the PTFE/glass insulation and the slightly harder outer coating of the PVC/glass/nylon wire.

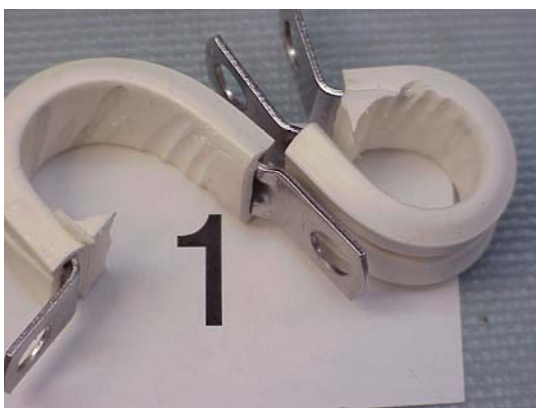

FIGURE 18. MODERATE WEAR ON CLAMP FROM PVC/GLASS/NYLON AND MF-PTFE GROUP I BUNDLE

FIGURE 19. MODERATE WEAR OF CLAMP FROM NONMIXED PTFE/GLASS BUNDLE IN GROUP I

5.1.8 Wear of Single Wires vs Twisted Pairs.

It was noted that nearly twice as many wet electrical failures were detected on twisted pairs than single wires in group I. This was likely due to the high points of the twisted pairs being subjected to concentrated frictional forces from wires rubbing against each other.

5.2 GROUP II TEST RESULTS.

5.2.1 Visual Observations.

Upon completion of 100 and 250 hours of vibration exposure, the wire bundles were visually inspected while still mounted on the test fixtures. General observations after 100 hours of vibration included rotation of the heads of the straps; twisted pairs separating from the bundles; wear marks on the fixtures from wires, straps, and lacing string; the presence of residue on the bundles from the clamp or wire insulation; slippage of bundles in the cushion clamps; and splatter marks on bundles from the fluid contamination. After 250 hours of vibration, additional observations included lacing string cutting into insulation and wearing of the black wire stripe marking. The results from the inspection are shown in appendix C, table C-7.

5.2.2 Electrical Testing.

No dry insulation resistance or DWV failures were detected after 100 hours of vibration conditioning in group II. Furthermore, no dry DWV failures were observed following 250 hours of vibration exposure. However, some wires failed to meet the IR pass/fail threshold selected for the program. As in group I, a wire was not considered to have failed if it passed the DWV test, even if IR did not exceed the selected pass/fail threshold. Electrical failures were detected on the PTFE/glass and PI/PTFE wires only (codes 7 and 10, respectively). (A complete summary of the dry and wet IR and DWV failures is provided in appendix C, tables C-8 and C-9. Specific electrical failures are discussed in conjunction with the wire wear paragraphs.)

Only one dry DWV test failure was confirmed by wet testing; however, all wet DWV failures were confirmed through visual examination of the test bundles. For this reason, the dry electrical results are considered suspect.

5.2.3 Wire-to-Wire Wear.

The visual examination results of the group II unassembled bundles are compiled in appendix C, tables C-10 and C-11. The results are summarized in table C-12 so that the wire-to-wire wear data for each type, mixed and unmixed, could be analyzed and the different wire types could be compared. Each column in table C-12 provides a comparison of the nonmixed bundle to the mixed bundle combinations selected. The table also indicates whether the bundle was slipping within the cushion clamps after 100 hours of vibration, provides a damage rating for the wires rubbing against the fixture plate, and quantifies the electrical failures that were detected.

5.2.3.1 Group IIF Fluid-Soaked Bundles.

Figures 20 through 27 provide graphic representations of the wire-to-wire wear for each wire type in mixed and nonmixed bundles.

Figure 20 indicates that negligible wire-to-wire wear occurs with PVC/glass/nylon wire, whether in a mixed or nonmixed bundle.

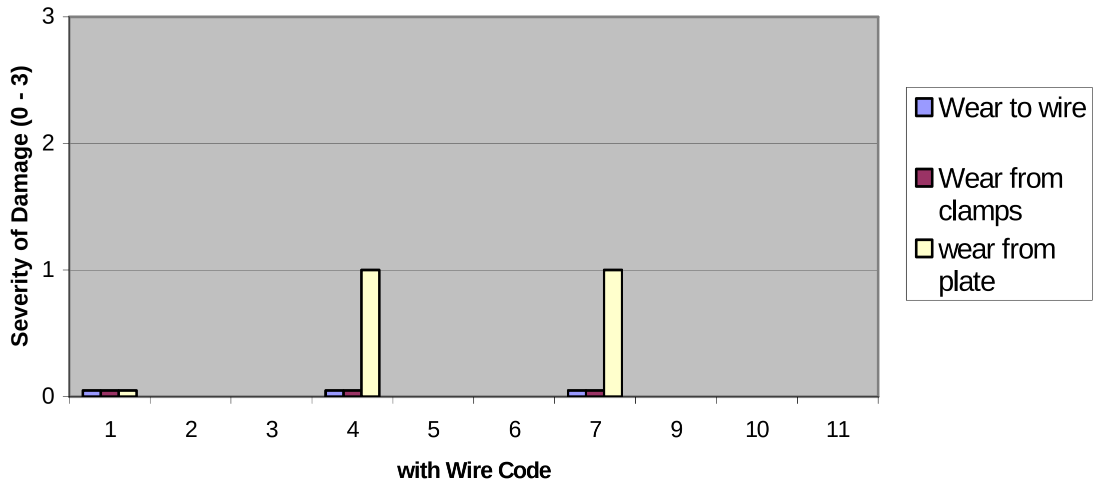

FIGURE 20. GROUP IIF TESTING: PVC/GLASS/NYLON (WIRE CODE 1) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

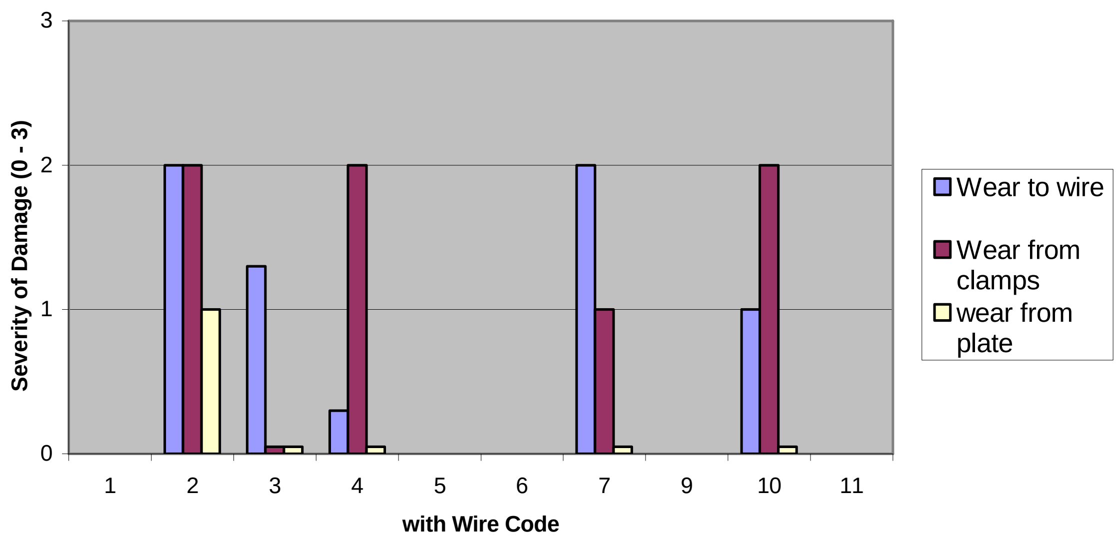

FIGURE 21. GROUP IIF TESTING: PI (WIRE CODE 2) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

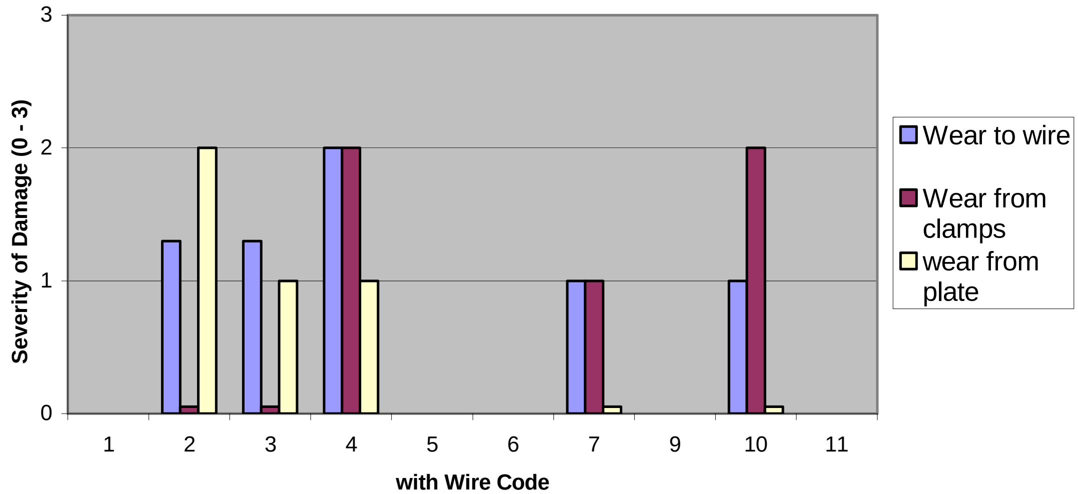

FIGURE 22. GROUP IIF TESTING: ALIPHATIC PI, ALLOY (WIRE CODE 3) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

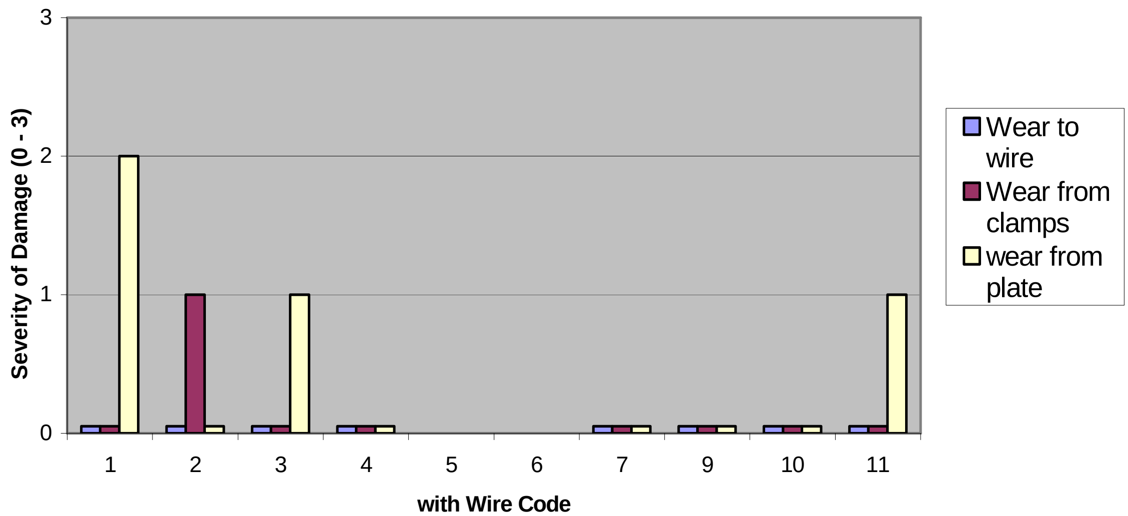

FIGURE 23. GROUP IIF TESTING: XLETFE (WIRE CODE 4) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

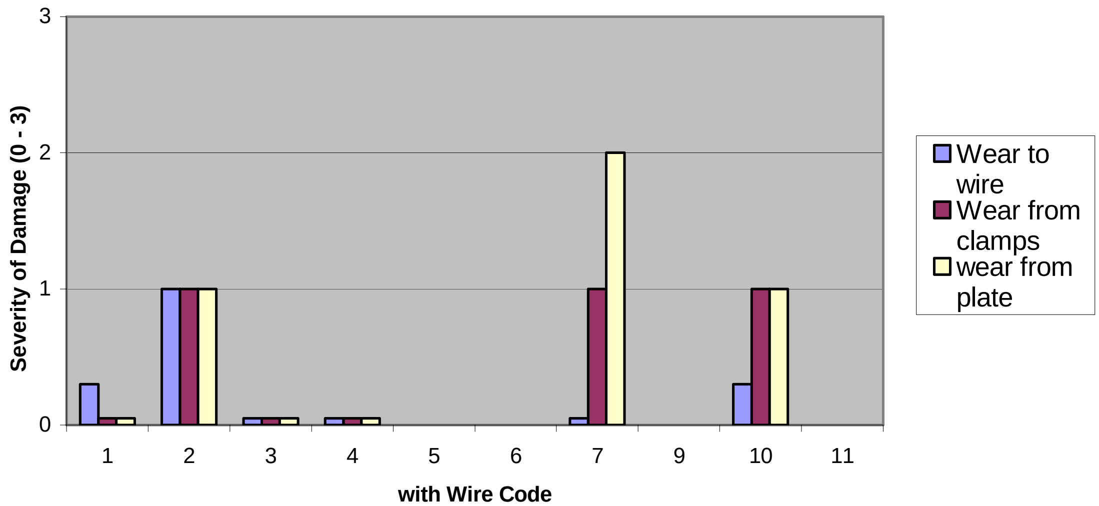

FIGURE 24. GROUP IIF TESTING: PTFE, MINERAL-FILLED (WIRE CODE 7) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

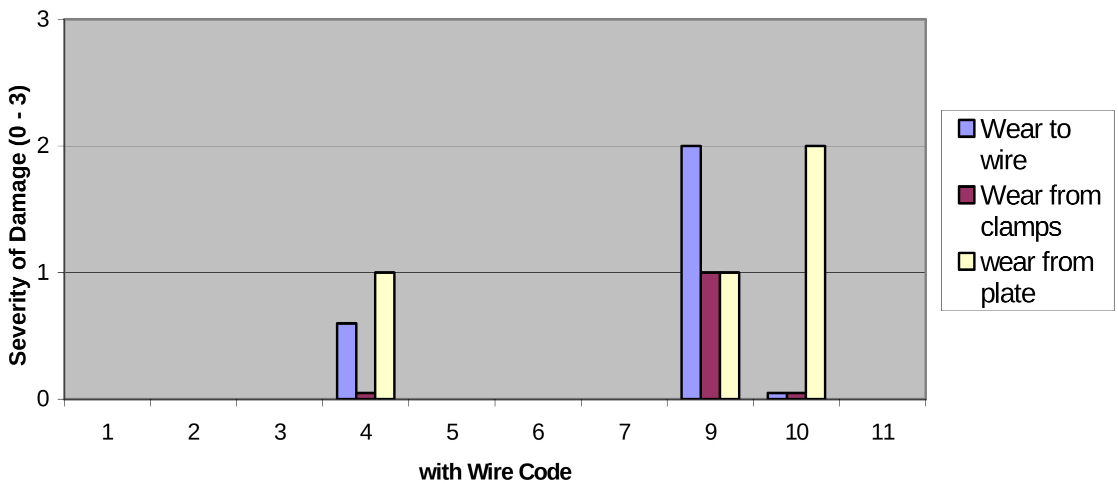

FIGURE 25. GROUP IIF TESTING: PTFE/GLASS BRAID (WIRE CODE 9) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

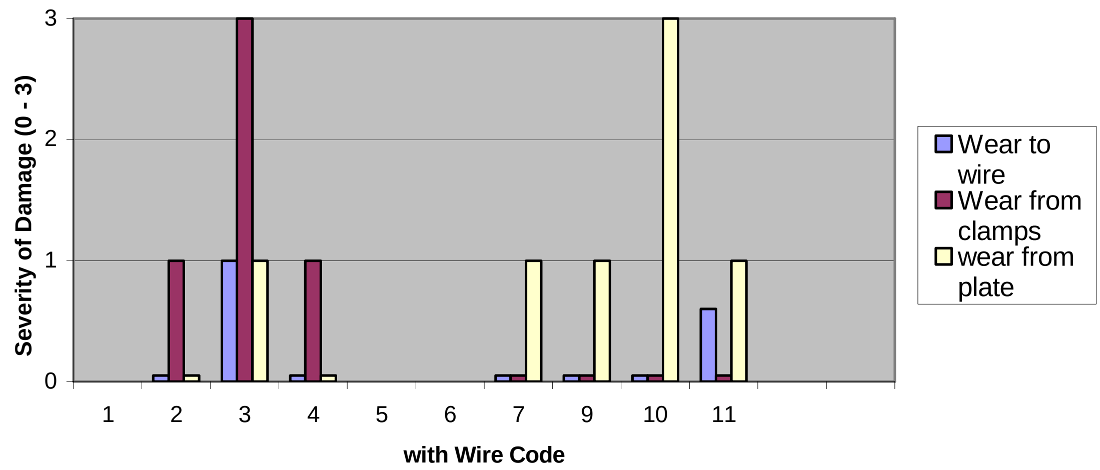

FIGURE 26. GROUP IIF TESTING: PI/PTFE (WIRE CODE 10) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

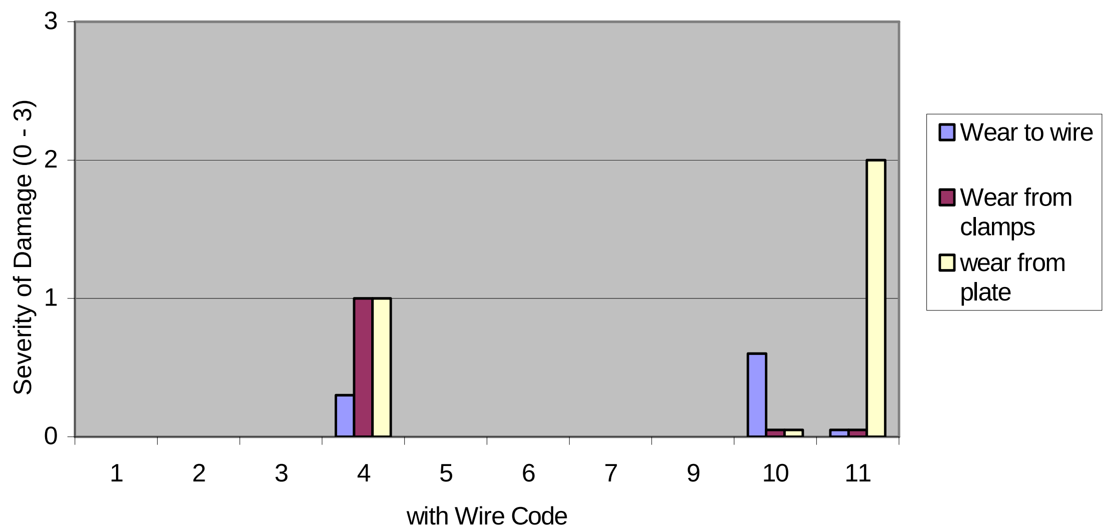

FIGURE 27. GROUP IIF TESTING: PI/PTFE, ALLOY (WIRE CODE 11) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

Figure 21 indicates moderate wire-to-wire wear of PI wire in the nonmixed bundle and moderate or low wear in the mixed bundles.

Figure 22 indicates that XPI wire exhibits low wire-to-wire wear in all combinations except with XLETFE (code 4), in which case, the wear is moderate.

Figure 23 indicates that negligible wire-to-wire wear was observed on XLETFE wire in the nonmixed and mixed bundles.

Figure 24 indicates that MF-PTFE wire exhibits negligible wire-to-wire wear in the nonmixed bundle, but slightly more wear when mixed with PVC/glass/nylon (code 1), PI (code 2), or PI/PTFE wire (code 10).

Figure 25 indicates that PTFE/glass wire exhibits moderate wire-to-wire wear in the nonmixed condition, but low or negligible wear in the other combinations tested.

Figure 26 indicates that negligible wear was observed in the PI/PTFE nonmixed bundle, and low wear when mixed with XPI (code 3) or PI/PTFE (code 10) wire.

Figure 27 indicates that PI/PTFE alloy wire has negligible wire-to-wire wear in the nonmixed bundle, but slightly more when mixed with XLETFE or PI/PTFE.

Figure 28 provides a summary of seven mixed wire bundle combinations from Group IIF in which at least one of the wires exhibited more severe wire-to-wire wear than in the nonmixed bundle. These wire types are XPI, MF-PTFE, PI/PTFE, and PI/PTFE alloy wire types (codes 3, 7, 10, and 11, respectively). The wear on the XPI wire type (code 3) was moderate when mixed with XLETFE (code 4) (see figure D-10 in appendix D) compared to a low amount of wear in the nonmixed bundle. The wear on the MF-PTFE, PI/PTFE, and PI/PTFE alloy wires was low in both the mixed and nonmixed conditions. These combinations are discussed below.

- 3, 4 (XPI, XLETFE): XPI is slightly more damaged in the mixed configuration than in the baseline bundle.

- 1, 7 (PVC/glass/nylon, MF-PTFE): Both wires showed very little damage, but the MF-PTFE had slightly more damage in the mixed bundle.

- 2, 7 (PI, MF-PTFE): MF-PTFE is damage more than in its baseline, but the damage rating on the PI is higher for both the mixed and nonmixed bundles.

- 7, 10 (MF-PTFE, PI/PTFE): Both wires showed very little damage, but the MF-PTFE had slightly more damage in the mixed bundle.

- 3, 10 (XPI, PI/PTFE): XPI in the mixed configuration exhibited slightly less damage than in the nonmixed bundle, but PI/PTFE suffered slightly more than in the nonmixed bundle.

- 4, 11 (XLETFE, PI/PTFE alloy): Both wires showed very little damage, but the PI/PTFE alloy had slightly more damage in the mixed bundle.

- 10, 11 (PI/PTFE, PI/PTFE alloy): Both wire types showed a slight increase in the damage when mixed together. When compared to each other, the two wire types showed similar wear, whether in the mixed or nonmixed bundles.

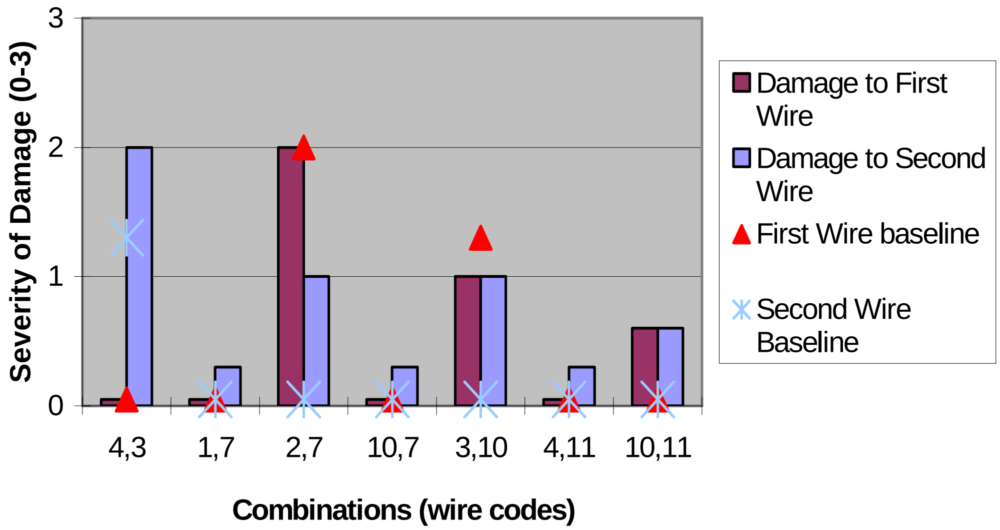

FIGURE 28. WIRE INTERACTIONS IN GROUP IIF MIXED BUNDLES

Overall, PI, XPI, and PTFE/glass wire types (codes 2, 3, and 9, respectively) exhibited moderate wear on the bundles soaked in hydraulic fluid, but the wear was similar or less severe in the mixed bundle than in the nonmixed bundle for PI and PTFE/glass wires (see figures 21, 25, 29, and 30, and figure D-11 in appendix D). The wear on the XPI wire in the bundle with XLETFE was slightly worse than in the nonmixed bundle (see figure 22).

FIGURE 29. MODERATE WIRE-TO-WIRE WEAR IN GROUP IIF NONMIXED PI BUNDLE

FIGURE 30. MODERATE WIRE-TO-WIRE WEAR ON PI WHEN MIXED WITH MF-PTFE IN GROUP IIF

5.2.3.2 Group IIM Metal Shavings Bundles.

For the bundles containing metal shavings, figures 31 through 38 provide graphical representations of the wire-to-wire wear for each wire type when mixed with other types.

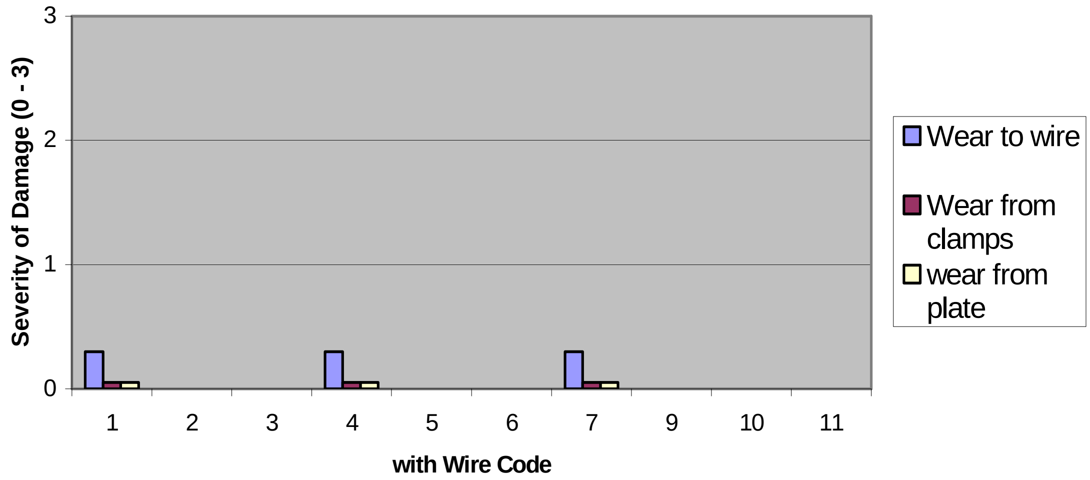

FIGURE 31. GROUP IIM TESTING: PVC/GLASS/NYLON (WIRE CODE 1) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

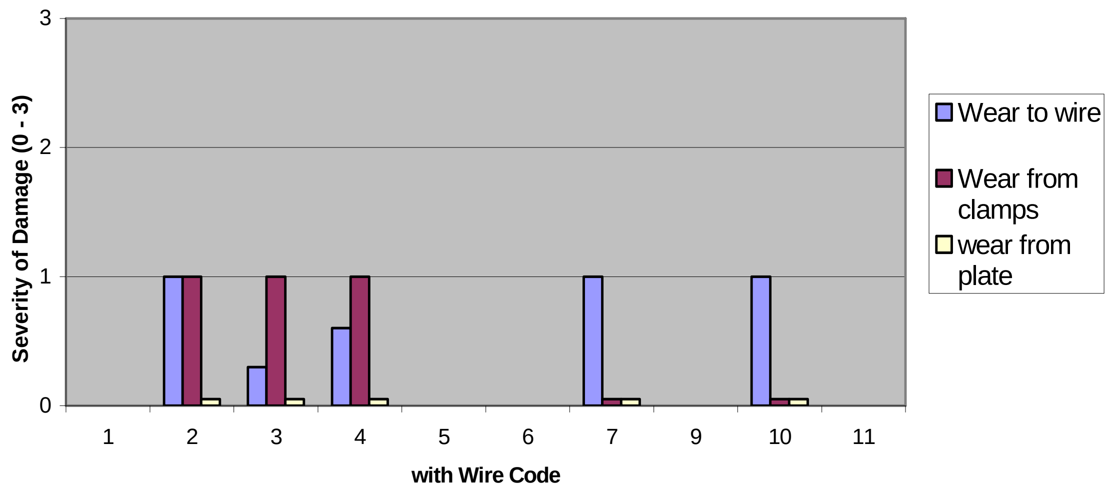

FIGURE 32. GROUP IIM TESTING: PI (WIRE CODE 2) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

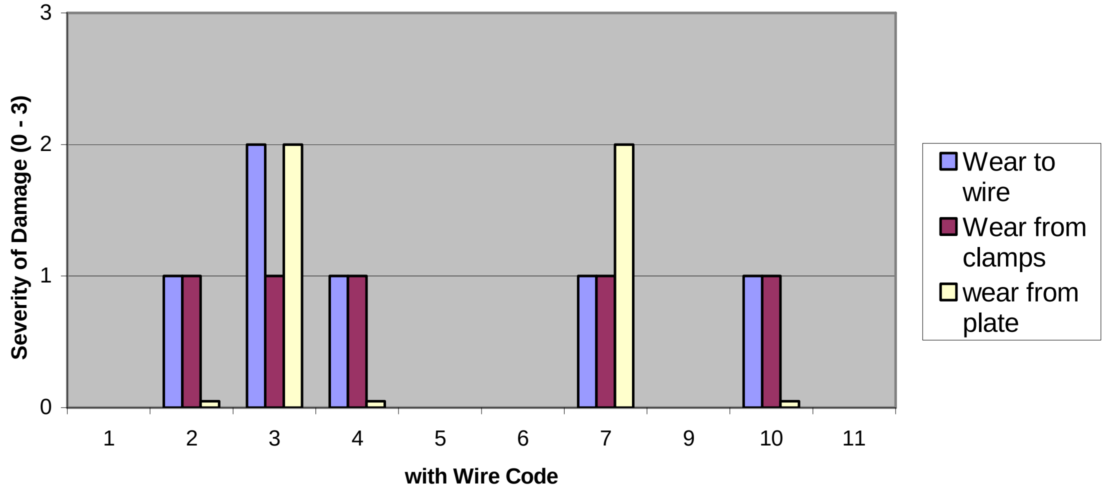

FIGURE 33. GROUP IIM TESTING: ALIPHATIC PI, ALLOY (WIRE CODE 3) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

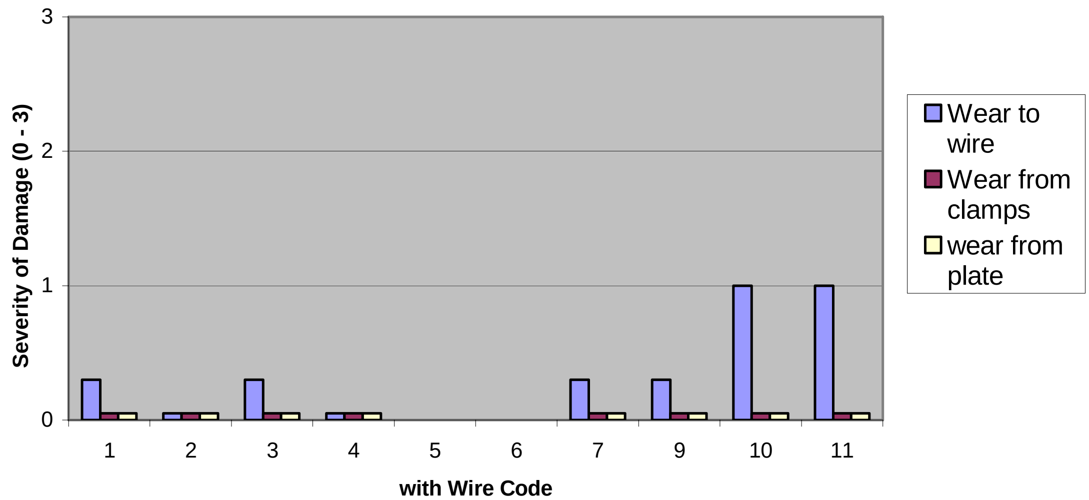

FIGURE 34. GROUP IIM TESTING: XLETFE (WIRE CODE 4) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

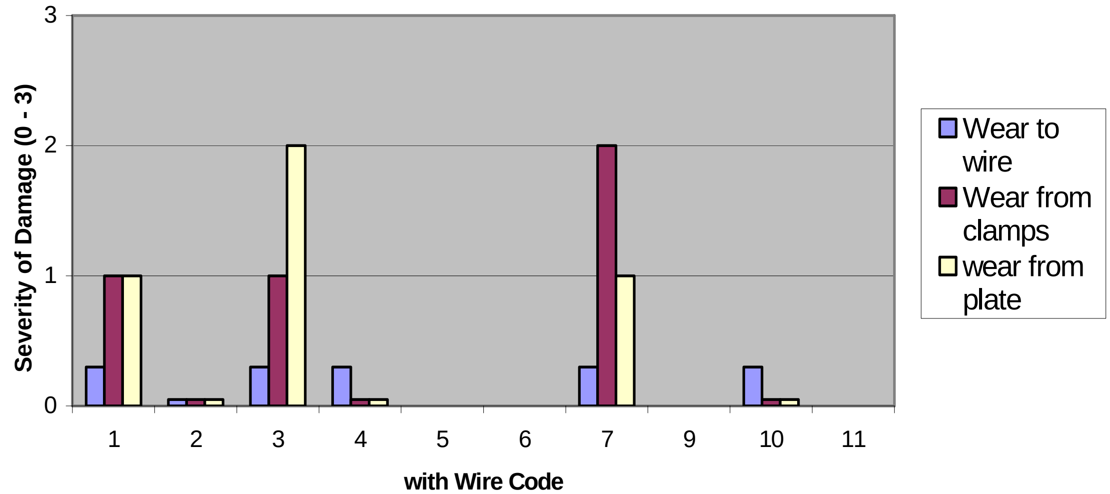

FIGURE 35. GROUP IIM TESTING: PTFE, MINERAL-FILLED (WIRE CODE 7) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

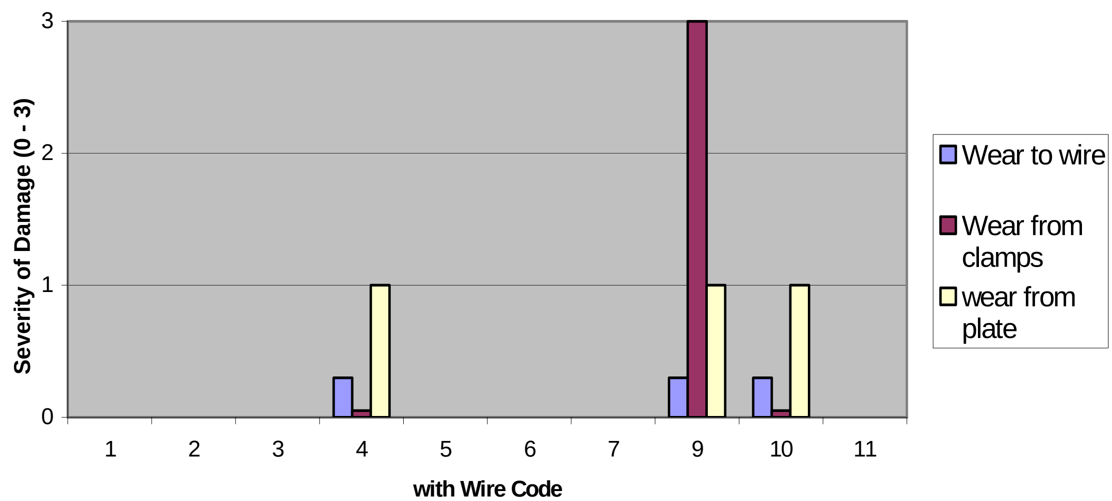

FIGURE 36. GROUP IIM TESTING: PTFE/GLASS BRAID (WIRE CODE 9) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

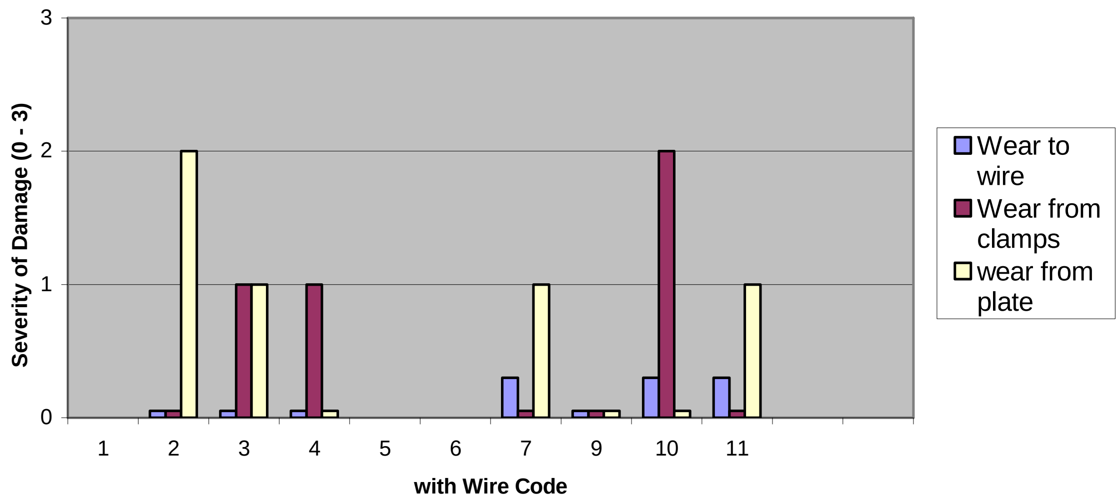

FIGURE 37. GROUP IIM TESTING: PI/PTFE (WIRE CODE 10) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

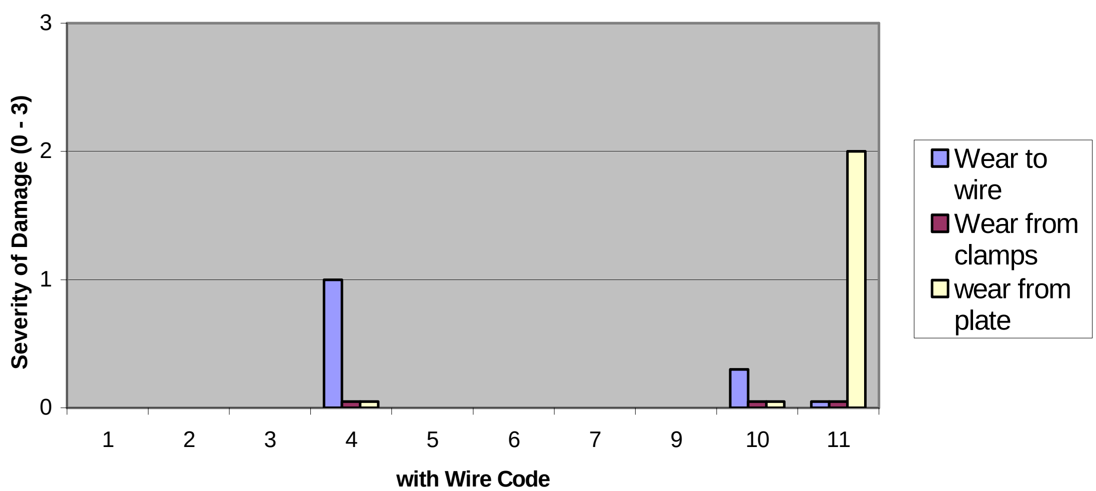

FIGURE 38. GROUP IIM TESTING: PI/PTFE, ALLOY (WIRE CODE 11) WIRE DAMAGE AFTER 250 HOURS OF VIBRATION CONDITIONING

Figure 31 indicates that PVC/glass/nylon exhibits very low wire-to-wire wear, whether in a nonmixed or mixed bundle.

Figure 32 indicates that PI wire exhibits low wire-to-wire wear in the nonmixed and mixed bundle conditions.

Figure 33 indicates that the XPI wire exhibits moderate wire-to-wire wear in the nonmixed condition, but less wear in combination with other wire types.

Figure 34 indicates that low wire-to-wire wear was observed on XLETFE wire when mixed with the PI/PTFE wire types (codes 10 and 11), but slight or negligible wear was noted in combination with other wire types and in the nonmixed bundle.

Figure 35 indicates that MF-PTFE wire exhibits low wear in both the mixed and nonmixed bundles.

Figure 36 indicates that PTFE/glass wire consistently exhibits low wear in both the mixed and nonmixed bundles.

Figure 37 indicates that the wire-to-wire wear of PI/PTFE wire is very low or negligible in all bundles.

Figure 38 indicates that the wear of PI/PTFE wire is low when mixed with XLETFE (code 4), but negligible or very low in other combinations tested.

Figure 39 provides a summary of six mixed wire bundle combinations from Group IIM in which one or both of the wire types exhibited more severe wire-to-wire wear than in the nonmixed bundle. Although the level of damage of one or both wire types in these combinations was worse in the mixed bundle than in the nonmixed bundle, the overall level was of damage was low. These combinations are discussed below.

- 1, 4 (PVC/glass/nylon, XLETFE): XLETFE was adversely affected by the harder PVC/glass/nylon wire, but the damage was only slightly worse than in the nonmixed bundle.
- 3, 4 (XPI, XLETFE): XLETFE exhibited only slightly more damage when mixed with XPI than in its baseline bundle. The XPI exhibited a lower level damage in this mixed bundle than in the baseline bundle.
- 7, 4 (MF-PTFE, XLETFE): XLETFE exhibited slightly more damage when mixed with MF-PTFE than in its baseline bundle. The MF-PTFE showed a similar level of damage in both the nonmixed bundle and this mixed combination.
- 9, 4 (PTFE/glass, XLETFE): The XLETFE reacted similarly with PTFE/glass as it did with MF-PTFE and PVC/glass/nylon.
- 10, 4 and 11, 4 (PI/PTFE, XLETFE and PI/PTFE alloy, XLETFE): The XLETFE had slightly more wear when mixed with either PI/PTFE wire type than in the baseline bundle. The PI/PTFE alloy was damaged slightly more than in the baseline bundle. The alloy wire was damaged slightly more by the XLETFE than was the annealed copper conductor wire.

- 10, 11 (PI/PTFE, PI/PTFE alloy): The alloy conductor wire was damage slightly more when mixed with annealed copper conductor wire than in the baseline, but the annealed copper conductor wire exhibited a similar level of damage.

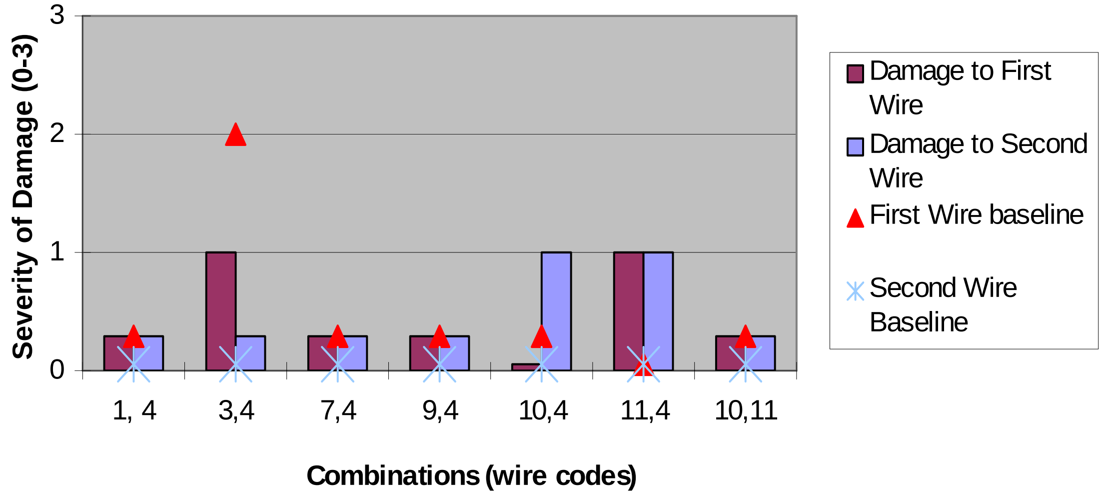

FIGURE 39. WIRE INTERACTIONS IN GROUP IIM MIXED BUNDLES

Overall, only the XLETFE (code 4) and PI/PTFE alloy (code 11) wire types exhibited more wear in mixed bundles contaminated with metal than in nonmixed bundles (see figures 34 and 38), but even then the amount of wear was slight. In addition, the XPI wire (code 3) was the only nonmixed bundle that exhibited moderate wire-to-wire wear in the metal contaminated bundles (see figures 33 and 40). The same wire type showed little wear in the mixed configurations.

FIGURE 40. MODERATE WIRE-TO-WIRE WEAR ON XPI IN NONMIXED GROUP IIM BUNDLE

5.2.4 Wire Wear From Clamps.

The visual examination results from the unassembled bundles were also summarized in appendix C, table C-12 so that the data regarding wire wear from the clamps could be analyzed. Each column in table C-12 provides a comparison of the nonmixed bundle to the mixed bundle combinations selected. The table also indicates whether the bundle was slipping within the cushion clamps after 100 hours of vibration, provides a damage rating for the wires rubbing against the fixture plate, and quantifies the electrical failures that were noted.

5.2.4.1 Group IIF Fluid-Soaked Bundles.

The only electrical failures detected in a fluid-contaminated bundle were on PI/PTFE wires (code 10) that were mixed with XPI wires (code 3). Although a little wire-to-wire and wire-to-fixture plate wear was noted, the failures were attributed to the severe wear from the clamps, as shown in figure 41.

FIGURE 41. SEVERE WEAR ON PI/PTFE FROM CLAMP WHEN MIXED WITH XPI IN GROUP IIF

The XPI, XLETFE, PI/PTFE, and PI/PTFE alloy wire types (codes 3, 4, 10, and 11, respectively) each exhibited more wear from clamps in mixed wire bundles than in the associated nonmixed wire bundle. The XPI wire type exhibited moderate wear from clamps when mixed with XLETFE, as opposed to a little wear in the nonmixed configuration.

Data was plotted to analyze whether the clamp diameter and bundle diameter difference or slippage in the clamps that was documented after 100 hours of vibration exposure had a direct correlation to the severity of wire-to-wire or wire-from-clamp damage.

Figure 42 indicates that a higher difference between the bundle and clamp diameters was not the only factor in determining the severity of the wire-to-wire wear in Group IIF, but it does correlate somewhat. The figure also indicates that slipping in the clamps did not necessarily cause the wire-to-wire damage to be more severe. The wire type was probably a factor as well.

Figure 43 indicates that a higher difference between the bundle and clamp diameters was not the only factor in determining the severity of the wire wear from the clamps in Group IIF. The figure also indicates that slipping in the clamps did not necessarily cause the wire wear from clamps to be more severe.

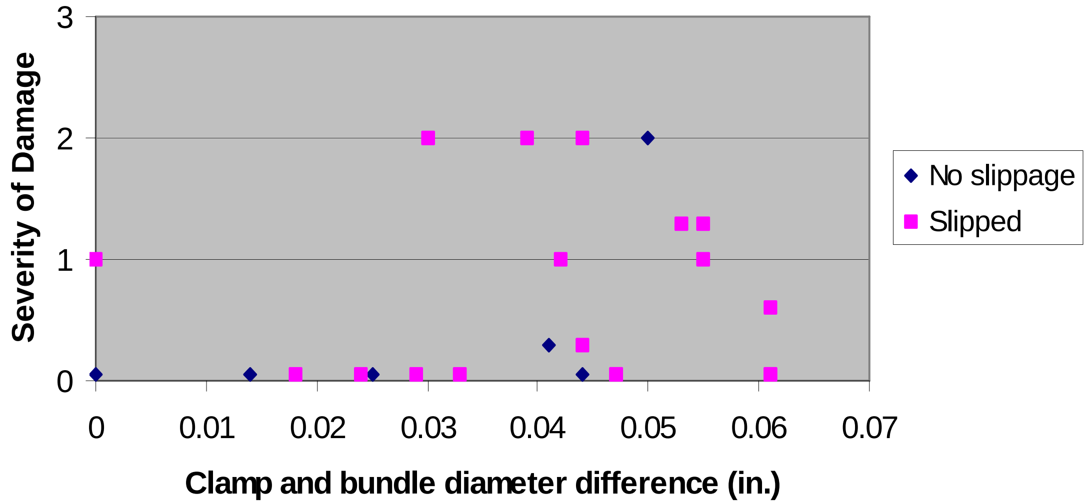

FIGURE 42. GROUP IIF: TIGHTNESS OF CLAMP VS WEAR FROM WIRE

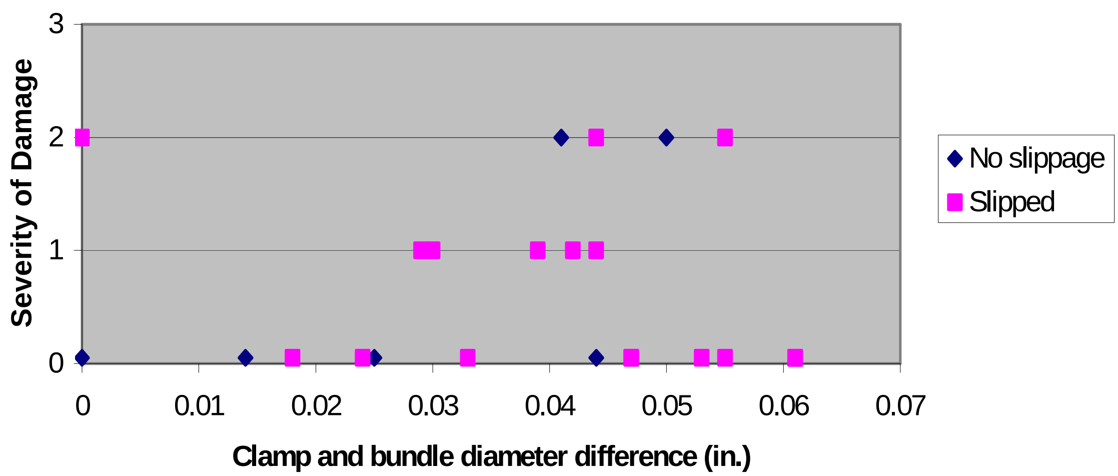

FIGURE 43. GROUP IIF: TIGHTNESS OF CLAMP VS WIRE WEAR FROM CLAMP

5.2.4.2 Group IIM Metal Shavings Bundles.

The only wet electrical failures on the bundles contaminated with the metal shavings were on a nonmixed bundle of PTFE/glass wires (code 9). This bundle exhibited severe wear from the clamps (see figure 44), and showed signs of a little wear from the vibration plate and wire-to-wire interaction.

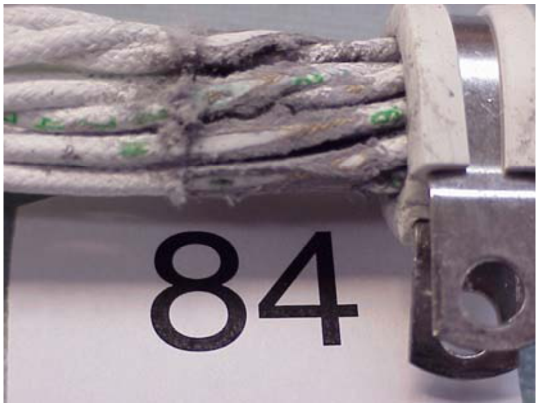

FIGURE 44. SEVERE WEAR OF PTFE/GLASS WIRE FROM CLAMP IN GROUP IIM NONMIXED BUNDLE

Data was plotted to analyze whether the clamp diameter and bundle diameter difference, or slippage in the clamps that was documented after 100 hours of vibration exposure, had a direct correlation to the severity of wire-to-wire or wire from clamp damage in group II.

Figures 45 and 46 indicate that for the wire bundles that did not slip within the clamps, the severity of the wire damage increased as the difference between the clamp and bundle diameters increased. However, the figures did not show the same direct correlation for the bundles that did slip in the clamps.

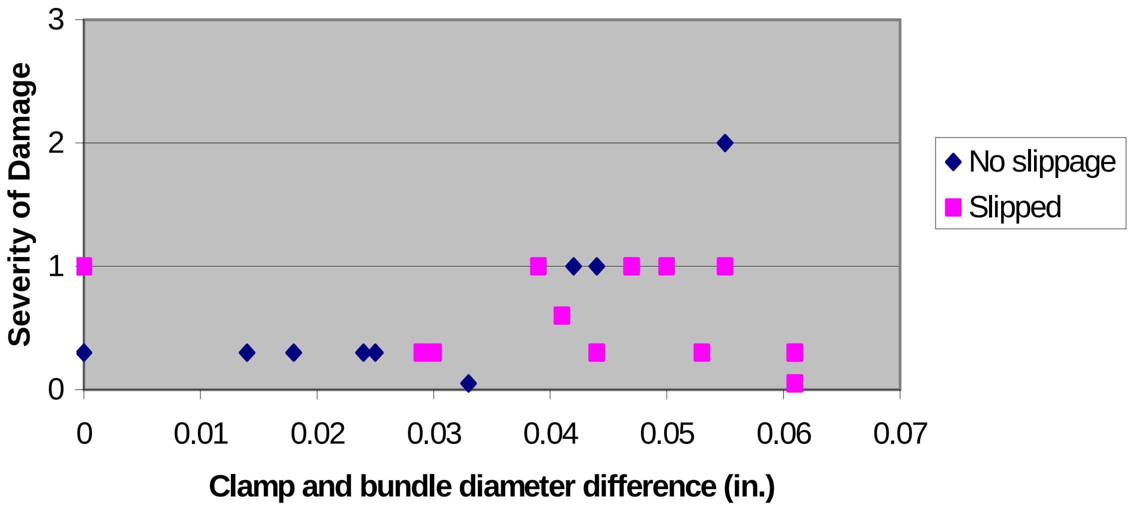

FIGURE 45. GROUP IIM: TIGHTNESS OF CLAMP VS WEAR FROM WIRE

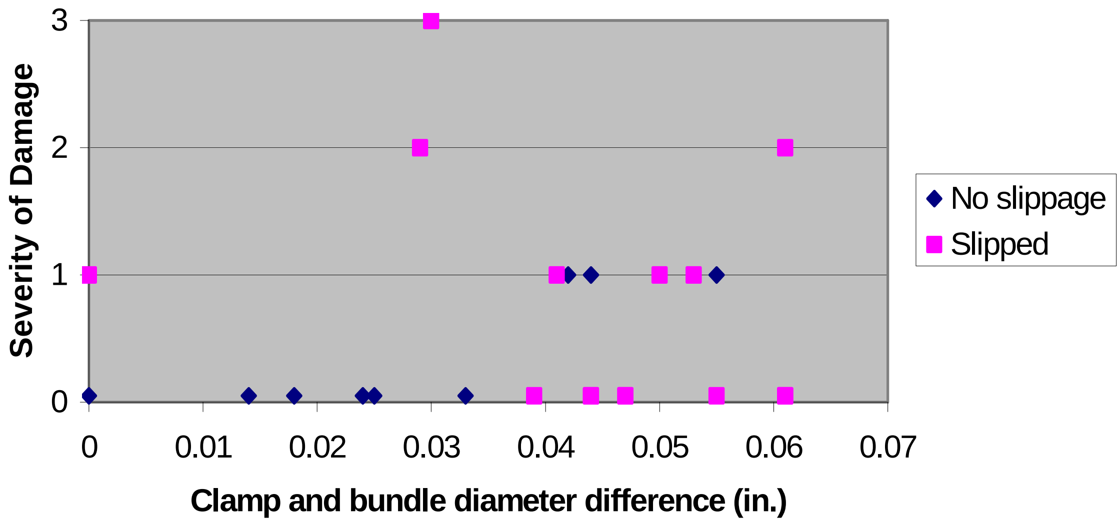

FIGURE 46. GROUP IIM: TIGHTNESS OF CLAMP VS WIRE WEAR FROM CLAMP

5.2.5 Wire Wear From Straps and Lacing String.

Posttest visual examination results were also reviewed to determine the amount of damage that the wires sustained from the straps and lacing string. A summary of the results is provided in appendix C, tables C-10 and C-11 and are discussed in the following sections.

5.2.5.1 Wear From Straps.

5.2.5.1.1 Group IIF.

Appendix C, table C-10 visual inspection results from the unassembled bundles indicate that the PI, XPI, and PI/PTFE wires (codes 2, 3, and 10, respectively) were the only types to display moderate wear from straps in mixed wire bundles that had been soaked in hydraulic fluid (see figures 47 and 48). The PI wire also exhibited moderate wear in the nonmixed bundle. All the other types displayed little or no wear at the straps in mixed and nonmixed bundles.

XPI wires (code 3) showed no wear from straps in the nonmixed bundle, but did show a little or moderate wear when mixed in bundles with PI, MF-PTFE, and PI/PTFE (see figure 47).

PI/PTFE wires (code 10) showed less wear in the nonmixed bundle than in bundles mixed with XPI and MF-PTFE (see figures 47 and 48).

FIGURE 47. MODERATE WEAR OF XPI AND PI/PTFE FROM STRAP IN GROUP IIF

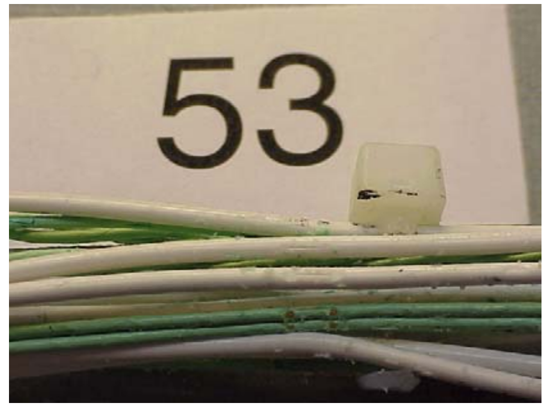

FIGURE 48. MODERATE WEAR OF PI/PTFE FROM STRAP WHEN MIXED WITH MF-PTFE IN GROUP IIF

5.2.5.1.2 Group IIM.

Table C-11 in appendix C shows that none of the bundles with metal shavings exhibited moderate or severe wear from the straps. Only the PI/PTFE wire (code 10) had slightly more wear when mixed with PI, XPI, XLETFE, MF-PTFE, and PTFE/glass (codes 2, 3, 4, 7, and 9, respectively) than in the nonmixed condition.

5.2.5.2 Wear From Lacing String.

5.2.5.2.1 Group IIF.

Of the fluid-soaked bundles, only the PI wires (code 2) exhibited wear from the lacing string (see figure 49 and appendix C, table C-12). A little wear was noted for the nonmixed bundle, whereas moderate wear was noted when mixed with MF-PTFE.

5.2.5.2.2 Group IIM.

Of the metal contaminated bundles, the MF-PTFE wires (code 7) were the only ones that showed slight wear from the lacing string. The metal shavings themselves may have induced this wear by lodging between the wire and string.

5.2.6 Wire Wear From Vibration Fixture.

One PI/PTFE wire (code 10), in a bundle mixed with PI/PTFE alloy wire (code 11) and contaminated with metal shavings, failed wet electrical testing. This bundle did exhibit some wear from the plate, and some wire-to-wire wear, but the cause of the failure could not be determined. A small mark, possibly a burn mark, was noted in an area that was inside a clamp, so it is possible that a metal shaving penetrated the insulation, weakening the insulation system.

FIGURE 49. MODERATE WEAR ON PI FROM LACING STRING WHEN MIXED WITH MF-PTFE IN GROUP IIF

5.2.7 Wear on Support Components.

The clamps were the only support components that exhibited wear with a moderate or severe rating, and in all but one case, one of the wire types was PVC/glass/nylon, MF-PTFE, or PTFE/glass. The one case that did not include one of those wire types was the nonmixed bundle of PI/PTFE alloy wires, which caused severe damage to the clamp.

The straps exhibited only slight wear from several of the wire combinations, but the lacing string did not appear to cause wear on any of the wires in the bundles.

5.2.8 Wear of Single Wires Versus Twisted Pairs.

It was noted that the same number of wet electrical failures were detected on twisted pairs as on single wires in group II.

5.3 TEST GROUPS I AND II COMPARISON.

The results indicate that in the mixed wire bundles, moderate wire-to-wire wear occurred on more bundles contaminated with hydraulic fluid than with metal shavings. This condition was most pronounced on the PI and XPI wire types (codes 2 and 3, respectively). One explanation for this may be that many of the metal shavings in the unrestricted sections of the bundles fell out of the bundles during vibration conditioning. Another explanation may be that in the areas of the clamps, tie straps, and lacing string, the wires were restricted enough to prevent significant movement and interaction of the wires against the metal shavings. Still another could be that the hydraulic fluid, by swelling the insulation surface and softening the insulation, thereby reduced the resistance to abrasive forces during vibration.

Some wire combinations in groups II exhibited slipping in clamps after 100 hours of vibration, whereas no slipping was noted for the same combinations in group I after the same vibration conditioning.

The number of mixed wire bundles that showed more damage than the associated baseline bundles was greater in groups II than in group I; however, most of the combinations displaying this characteristic were different in groups I and II. There was more similarity between groups IIF and IIM.

Seventy-seven percent of the group I bundles did not slip in the clamps after 100 hours of vibration exposure, whereas the numbers for groups IIM and IIF were 38% and 25%, respectively.

In both groups I and II, the sections of the wire bundles that were mounted to stationary plates did not exhibit notable wire or clamp damage.

5.4 GROUP III CRUSH TEST RESULTS.

The crush test performed was a variation to the dynamic cut-through test that is define in SAE AS4373, method 703 [5]. In this crush test, a defined load was applied to compress two perpendicular wires, rather than compressing a blade against a single wire. The hardness of the second wire directly affects the amount of damage suffered by the first wire.

The testing was performed on the same 24 wire combinations as selected for group II. The complete results from the test are provided in appendix C, table C-13.

The results indicate that for the wire combinations tested, the MF-PTFE wire (code 7) always had the most damage in the pairs, and the PVC/glass/nylon, PI, and PTFE/glass wires (codes 1, 2, and 9, respectively) always had the least damage. It should be noted, however, that the PVC/glass/nylon and PTFE/glass were only tested in two mixed combinations each. The glass fiber braid has an extremely high modulus and provides protection against this type of force. The glass fiber braid even provides protection when a blade is used in the standard dynamic cut-through test method.

In certain pairings, the XPI, MF-PTFE, PI/PTFE, and PI/PTFE alloy wires (codes 3, 7, 10, and 11, respectively) each showed damage through the insulation, exposing the conductor, when using the 80-pound load (see figures 50 and 51 and figures D-12 and D-13 in appendix D). When the load was increased to 120 pounds, the XLETFE wire (code 4) also exhibited damage through the insulation to the conductor (see figure 52). The most severe damage was seen in the pairing of PI/PTFE alloy wire with itself (see figure 53). The alloy conductor is harder than the annealed copper conductor, and does not deform as easily, causing an increase in damage to the insulation.

The crush test was not performed at elevated temperature or after a heat aging test. Two scenarios where an elevated temperature may be a problem are (1) when a substitute wire has a lower or higher temperature rating and (2) blocking to a lower temperature-rated wire would decrease flexibility.

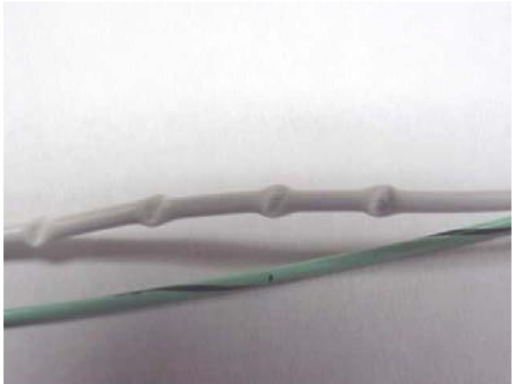

FIGURE 50. MF-PTFE WIRE DAMAGED FROM PI WIRE IN THE 80-POUND CRUSH TEST

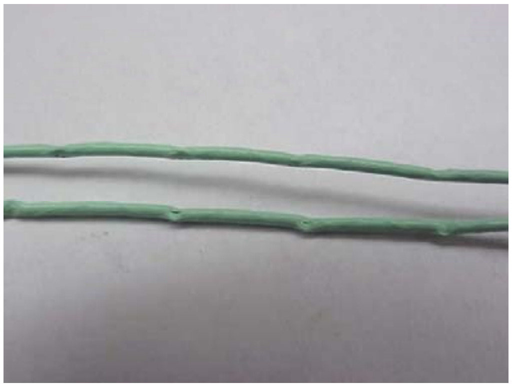

FIGURE 51. PI/PTFE ALLOY WIRE DAMAGED FROM PI/PTFE WIRE IN THE 80-POUND CRUSH TEST

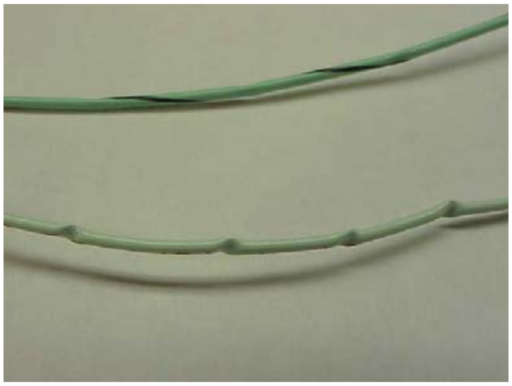

FIGURE 52. XLETFE WIRE DAMAGED BY PI WIRE IN THE 120-POUND CRUSH TEST

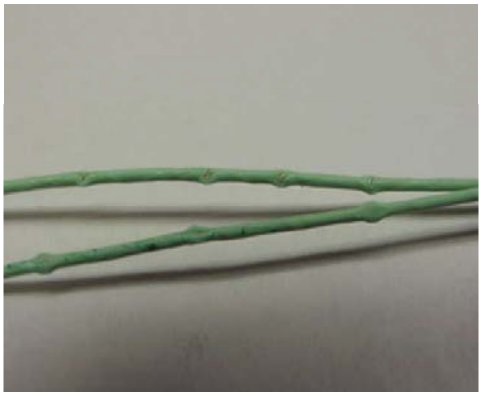

FIGURE 53. PI/PTFE ALLOY WIRE DAMAGED BY SAME WIRE TYPE IN THE 120-POUND CRUSH TEST

5.5 COMPARISON TO PREVIOUS DATA.

Whereas the NAC TR-2333 program used reduction in voltage capability as a parameter for evaluating the wires, this program selected a DWV pass/fail threshold, so electrical testing results could not be directly compared. This program also used visual examinations as the primary tool for determining the severity of wear to the wires or support components.

6. SUMMARY AND RECOMMENDATIONS.

6.1 SUMMARY.

None of the documents reviewed specifically addressed or restricted mixing of dissimilar wire types in bundles, but regulations stipulated that the wires selected must meet the environmental, application, interface, and design requirements. The results indicated that there is not significantly more insulation wear in mixed wire bundles than in nonmixed wire bundles. The results of this program did not corroborate the general finding of the Naval Avionics Center TR-2333. Since the two test programs did evaluate different insulation types, a direct comparison could not be made.

None of the electrical failures were attributed to the mixing of wire types in the bundles. All failures were due to damage caused by rubbing against the plate or movement in the clamps during vibration. The fluids and metal shavings appeared to have some impact on the wire-to-wire wear. For most wire types, hydraulic fluid and particulate contamination promoted wear of the wires. No significant difference was noted when comparing results from annealed copper conductor and copper alloy conductor wires with the same insulation type.

Softer insulation types suffered more damage in the crush test; however, wire with harder copper alloy conductors exhibited greater damage than wire with softer annealed copper conductor wires of the same insulation type. Cross-linked aliphatic polyimide wire exhibited significant levels of wire-to-wire wear in mixed and nonmixed bundles and in contaminated and uncontaminated bundles. Polyimide and polytetrafluoroethylene glass wires exhibited significant wire-to-wire wear in nonmixed, fluid-contaminated bundles. Polyimide wires were the only types that exhibited some wire-to-wire damage in all uncontaminated combinations.

More damage was caused by straps than by lacing string in the contaminated bundles. There was little damage from straps or clamps on uncontaminated bundles. No significant differences in wire-to-wire wear or from clamp wear was noted when comparing the curved end of the bundle to the straight end configuration. More damage to adjacent wires was caused by twisted pairs of wires than by single-end wires.

6.2 RECOMMENDATIONS.

Special precautions need to be considered when using many wire types (XPI, soft exterior types such as PTFE, MF-PTFE, and PI/PTFE, and glass braid covered types such as PTFE/glass) to prevent wear from clamps or from the structure. Frequent maintenance inspection schedules should be considered for aged aircraft if these precautions have not been taken.

Current clamping practices should be evaluated and alternative methods investigated to minimize damage to wire in aerospace applications.

Routine inspection schedules for aged aircraft should include wire-to-wire wear inspections for XPI wire. In addition, PI and PTFE/glass wire types should be routinely inspected for wire-to-wire wear in fluid-contaminated areas.

Routine inspection schedules for aged aircraft should include clamp to wire tightness inspections. Building up bundles to the clamp diameter should be considered as needed.

The following additional testing options should be considered to further understand the degradation characteristics of mixed wire in the EWIS:

- Subject test bundles to both fluid and metal shavings contamination
- Test bundles with and without twisted pairs
- Actively monitor during vibration testing
- Use tape wrap inside the cushion clamp if it does not fit snugly on the wire bundle
- Heat aging of wires prior to testing
- Crush test at elevated temperature
- Abrasion cut through testing
- Flex bending of bundles
- Alternative clamping practices

7. RELATED DOCUMENTATION.

a. Industry Standards

- AS50881, SAE Aerospace Standard, Wiring, Aerospace Vehicle
- AS22759, SAE Aerospace Standard, Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy
- AC 43.13-1B, Department of Transportation, Federal Aviation Administration, Advisory Circular: Acceptable Methods, Techniques, and Practices. Aircraft Inspection and Repair
- ANM-01-04, Department for Transportation, Federal Aviation Administration, Policy Statement, System Wiring Policy for Certification of 14 CFR Part 25 Airplanes
- Advancement Handbook for Aviation Electricians Mate of 15 October 2001
- SAE ARP4404A, Aerospace Recommended Practice, Aircraft Electrical Installation
- 14 CFR Part 25, Department of Transportation, Federal Aviation Administration
- SAE AS4373, Test Methods for Insulated Electric Wire

b. Military Standards

- MIL-W-81044, Military Specification, Wire, Electric, Crosslinked Polyalkene, Crosslinked Alkene-Imide Polymer, or Polyarylene Insulated, Copper or Copper Alloy

- MIL-W-5086, Military Specification, Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy

- ITSS (MATMEP) F/A-18 Duty Area (MOS 6337), Aircraft Electrical Technician

- MIL-HDBK-5400, Electronic Equipment, Aerospace, General Specification For

- MIL-HDBK-454, General Guidelines for Electronic Equipment

- MIL-W-5088L, Military Specification, Wiring, Aerospace Vehicle

- NAVAIR 01-1A-505, Technical Manual, Installation Practices, Aircraft Electric and Electronic Wiring

- Air Force T.O. 1-1A-14, Technical Manual, Installation Practices, Aircraft Electric and Electronic Wiring

- NAVWAG Guideline D5-GI-1188

c. Aircraft Manufacturer Specifications

- Airbus Industrie Manual 20-33-10, Electrical Standard Practices

- Boeing Standard D6-54446, 20-00-14, Wiring Practices Manual

- Boeing Specification Support Standard BSS 7324F, Procedure for Testing Electrical Wire and Cable

d. Miscellaneous Documentation

- Raytheon—Indianapolis and FAA report Aircraft Wire System, Recommendations for a TSO to Address Minimum Safety Performance of 30 June 2003

- Naval Avionics Center Report TR-2333, Testing of Selected Aircraft Electrical Wire Insulations

- McDonnell Douglas Corporation report MDC J1530: 09/73, Engineering Report, Vibration of DC-10 Wire Bundles

- McDonnell Douglas Corporation report MDC J1530/01: 08/74, Engineering Report, Vibration of DC-10 Wire Bundles

- McDonnell Douglas Corporation report MDC J6573: 04/76, Interim Engineering Methods Authorization Report

- McDonnell Douglas Corporation report MDC J6998: 09/76, Final Engineering Methods Authorization Report, Aircraft Wire Containment

- ASTRAC HWG ESWPM 10/31/02
- McDonnell Aircraft Company Report MDC B0482, Performance Comparison of M81381/9, M22759/19, M22759/33, and Non-MIL Spec Wire and Cable
- ASTRAC Task 6: Wire Systems Certification Requirements Harmonization Working Group Final Report
- ASTRAC Transport Aircraft Intrusive Inspection Project, An Analysis of the Wire Installations of Six Decommissioned Aircraft

8. REFERENCES.

1. ATSRAC Transport Aircraft Intrusive Inspection Project (An Analysis of the Wire Installations of Six Decommissioned Aircraft), section, Research Recommendations of the Intrusive Inspection Working Group, 29 December 2000.
2. NAC Report TR-2333, “Testing of Selected Aircraft Electrical Wire Insulations,” 8 June 1983.
3. ATSRAC Task 6 Report, “Wire Systems Certification Requirements Harmonization Working Group,” 29 October 2002.
4. Douglas Aircraft Company, Engineering Report MDC-J1530/01, “Vibration of DC-10 Wire Bundles,” 19 August 1974.
5. SAE AS4373, “Test Methods for Insulated Electric Wire, Method 703, Dynamic Cut-Through.”

APPENDIX A—REGULATIONS, STANDARD PRCTICES, AND PREVIOUS TEST DOCUMENTATION

Note: Titles of documents and page numbers are in boldface type. Information from documents is in regular type without quotations. Raytheon remarks and summaries of specific information are noted as a "comment."

I. REGULATIONS, PROPOSED REGULATIONS, AND DESIGN SPECIFICATIONS

1. ADVISORY CIRCULAR AC 43.13-1B: ACCEPTABLE METHODS, TECHNIQUES, AND PRACTICES. AIRCRAFT INSPECTION AND REPAIR SEPTEMBER 8, 1998, DEPARTMENT OF TRANSPORTATION, FEDERAL AVIATION ADMINISTRATION

Page 11-24

a. Mechanical Strength of Wires. If it is desirable to use wire sizes smaller than #20, particular attention should be given to the mechanical strength and installation handling of these wires, e.g., vibration, flexing, and termination. Wire containing less than 19 strands must not be used. Consideration should be given to the use of high-strength alloy conductors in small gauge wires to increase mechanical strength. As a general practice, wires smaller than size #20 should be provided with additional clamps and be grouped with at least three other wires. They should also have additional support at terminations, such as connector grommets, strain relief clamps, shrinkable sleeving, or telescoping bushings. They should not be used in applications where they will be subjected to excessive vibration, repeated bending, or frequent disconnection from screw termination.

Page 11-35

Installation Precautions for Small Wires. As a general practice, wires smaller than size #20 must be provided with additional clamps, grouped with at least three other wires, and have additional support at terminations, such as connector grommets, strain-relief clamps, shrinkable sleeving, or telescoping bushings. They should not be used in applications where they will be subjected to excessive vibration, repeated bending, or frequent disconnection from screw terminations.

Page 11-36

11-78. SUBSTITUTIONS. In the repair and modification of existing aircraft, when a replacement wire is required, the maintenance manual for that aircraft must first be reviewed to determine if the original aircraft manufacturer (OAM) has approved any substitution. If not, then the OAM must be contacted for an acceptable replacement.

a. MIL-W-5088L Wiring, Aerospace Vehicle, Appendix A lists wire types that have been approved for military aerospace applications in open and protected wiring applications. These wires could potentially be used for substitution when approved by the OAM.

Pages 11-45 through 11-46

11-97. WIRING REPLACEMENTS. Wiring must be replaced with equivalent wire (see paragraph 11-78) when found to have any of the following defects:

a. Wiring that has been subjected to chafing or fraying, that has been severely damaged, or that primary insulation is suspected of being penetrated.

b. Wiring on which the outer insulation is brittle to the point that slight flexing causes it to crack.

c. Wiring having weather-cracked outer insulation.

d. Wiring that is known to have been exposed to electrolyte or on which the insulation appears to be, or is suspected of being, in an initial stage of deterioration due to the effects of electrolyte.

e. Check wiring that shows evidence of overheating (even if only to a minor degree) for the cause of the overheating.

f. Wiring on which the insulation has become saturated with engine oil, hydraulic fluid, or another lubricant.

g. Wiring that bears evidence of having been crushed or severely kinked.

h. Shielded wiring on which the metallic shield is frayed and/or corroded. Cleaning agents or preservatives should not be used to minimize the effects of corrosion or deterioration of wire shields.

i. Wiring showing evidence of breaks, cracks, dirt, or moisture in the plastic sleeves placed over wire splices or terminal lugs.

j. Sections of wire in which splices occur at less than 10-foot intervals, unless specifically authorized, due to parallel connections, locations, or inaccessibility.

k. When replacing wiring or coaxial cables, identify them properly at both equipment power source ends.

l. Testing of the electrical and chemical integrity of the insulation of sample wires taken from areas of the aircraft that have experienced wiring problems in the past, can be used to supplement visual examination of the wire. The test for chemical integrity should be specific for the degradation mode of the insulation. If the samples fail either the electrical or chemical integrity tests, then the wiring in the area surrounding the sampling area is a candidate for replacement.

2. ADVANCEMENT HANDBOOK FOR AVIATION ELECTRICIANS MATE (AE), 10/15/2001

Comment: There is no information pertaining to mixing of dissimilar wire types in bundles.

3. DEPARTMENT OF TRANSPORTATION, FEDERAL AVIATION ADMINISTRATION, POLICY STATEMENT NUMBER ANM-01-04; SYSTEM WIRING POLICY FOR CERTIFICATION OF PART 25 AIRPLANES: 01/28/02

Bullet in paragraph 4 of section titled "Disposition of Comments"

Comment: Issues relating to the mixing of wire types are not addressed. Mixing of wire types is not addressed in this policy statement. Wires in a bundle must be securely clamped and bound and be compatible with their environment (i.e., vibration, temperature, etc.). These details are addressed in the design and installation requirements of the wire. These requirements are called out in the installation drawings.

4. ITSS (MATMEP) F/A-18 DUTY AREA, AIRCRAFT ELECTRICAL TECHNICIAN (MOS 6337): 08/2002

Comment: There is no information pertaining to mixing of dissimilar wire types in bundles.

5. MIL-E-5400T, ELECTRONIC EQUIPMENT, AEROSPACE, GENERAL SPECIFICATION FOR: 11/16/79

Comment: There is no information pertaining to mixing of dissimilar wire types in bundles.

6. MIL-HDBK-5400, ELECTRONIC EQUIPMENT, AIRBORNE, GENERAL GUIDELINES FOR: 11/30/95

Comment: There is no information pertaining to mixing of dissimilar wire types in bundles.

7. MIL-HDBK-454, GENERAL GUIDELINES FOR ELECTRONIC EQUIPMENT, (GUIDELINE 71): 11/03/2000

Comment: There is no information pertaining to mixing of dissimilar wire types in bundles.

8. MIL-W-5088L, WIRING, AEROSPACE VEHICLE: 05/10/91
(Same as SAE AS50881A: 04/01/2000)

3.3.4 Commonality. An objective in the selection of parts shall be to maximize commonality and minimize the variety of wiring components and related servicing tools required in the construction, installation, and maintenance of the electrical wiring system.

9. SAE ARP4404 REV A, AIRCRAFT ELECTRICAL INSTALLATIONS: 07/01/2002

PAGES 52-53

9.1 General

The selection of proper type and size of wire for any aircraft circuit is as important as selecting the proper protector for the wire. Improper wire selection, either as to type, size, or poor wire routing can make an otherwise good electrical system unsafe.

AS50881 covers aspects of wire selection for military aerospace vehicles and is normally used as a guide for many commercial programs. This document is maintained on a current basis through coordinated industry and military activities and should be used as a reference. Detail data is included for current ratings, altitude derating, corona considerations, and list of approved wire types.

9.2 Wire Type Selection

SAE AS4372 and SAE AS4373 are recommended for the evaluation and proposed selection of wire constructions not listed in AS50881

In the repair and modification of existing aircraft, when replacement wire is required, the maintenance manual for that aircraft should first be reviewed to determine if the original aircraft manufacturer (OAM) has approved any substitution. If not, then OAM must be contacted for an acceptable replacement.

10. ATSRAC STATEMENT OF CONCERN REGARDING WIRE SEPARATION DESIGN CRITERIA, KENT V. HOLLINGER 08/21/2002

Comment: There is no information pertaining to mixing of dissimilar wire types in bundles.

11. ATSRAC TASK 6: WIRE SYSTEMS, CERTIFICATION REQUIREMENTS, HARMONIZATION WORKING GROUP: FINAL REPORT TO ASTRAC: 10/29/2002

Page B-7 (iv)

Wire installed in the same bundle shall be able to withstand the wire-to-wire abrasion. The Routing of wires with dissimilar insulation, within the same bundle, is not generally recommended, particularly when relative motion and abrasion between wires having dissimilar insulation could occur.

12. AIRCRAFT CIRCULAR, DEVELOPMENT OF ELECTRICAL STANDARD WIRING DOCUMENTATION: 10/28/02

Appendix A and Appendix B.

Comment: Tables in each Appendix include the following Major Topic:

WIRE AND CABLE TYPES
The principle material component of airplane wiring; includes type identification and basic description; alternative wire types (replacements, substitutions).

13. FINAL REPORT, ATSRAC HWG TASK 7, ELECTRICAL STANDARD WIRE PRACTICES MANUAL (ESWPM): 10/31/02

Appendix IV

Comment: Table in this Appendix includes the following Major Topic:

WIRE AND CABLE TYPES
The principle material component of airplane wiring; includes type identification and basic description; alternative wire types (replacements, substitutions).

14. DEPARTMENT OF TRANSPORTATION, FEDERAL AVIATION ADMINISTRATION 14 CFR PART 25:

25.1353 Electrical equipment and installations.

(a) Electrical equipment, controls and wiring must be installed so that operation of any one unit or system of units will not adversely affect the simultaneous operation of any other electrical unit or system essential to the safe operation

(b) Cables must be grouped, routed, and spaced so that damage to essential circuits will be minimized if there are faults in heavy current-carrying cables

15. BOEING SPECIFICATION SUPPORT STANDARD BSS 7324F OF 02-DEC-1998, PARA 7.57 WIRE-TO-WIRE ABRASION

Comment: Some aircraft wire types are required to withstand a minimum number of wire-to-wire rubbing cycles without insulation failure. The number of cycles to failure vary with wire type and compression weight. Cycles to failure range from 6,150,000 to 18,500,000 cycles, and compression weight varies from 1 to 5 pounds depending on the wire type and insulation thickness. Wire-to-wire abrasion between two different types of wires is not required.

16. MCDONNELL AIRCRAFT COMPANY REPORT MDC B0482 OF 16 DECEMBER 1987 PARA 3.5.12

Comment: An abrasion comparison between various wire types was performed. The abrasion test consisted of a rubbing action using a small diameter rod compressed on the insulation with three different weight values. There was no wire-to-wire abrasion between two different types of wires.

II. AIRCRAFT WIRING PRACTICES DOCUMENTS

1. NAVAIR 01-1A-505.2, TECHNICAL MANUAL: INSTALLATION PRACTICES FOR AIRCRAFT ELECTRIC AND ELECTRONIC WIRING: 09/01/1996

Work Package 004, Wire Selection, Page 3

6. COMMONALITY. An objective in the selection of parts shall be to maximize commonality and minimize the variety of wiring components and related servicing tools required in the construction, installation, and maintenance of the electrical wiring system.

Work Package 006, Single Conductor Wire Repair, Page 3

WARNING: If M81381 type wire is damaged along its length, the damaged area must be removed and replaced with appropriate M22759, refer to table 1.

Work Package 006, Single Conductor Wire Repair, Page 5

Comment: Table 1 (not repeated here) provides specific MIL-W-81381 to MIL-W-22759 Replacement wires.

2. T.O. 1-1A-14 TECHNICAL MANUAL: INSTALLATION PRACTICES FOR AIRCRAFT ELECTRIC AND ELECTRONIC WIRING, PAGE 14-3

14-7. Wire Separation.

Military Specification MIL-W-5088 restricts the grouping or bundling of certain wires, such as electrically unprotected power wiring, and wiring to duplicate vital equipment. Do not add such wires to existing bundles unless specifically authorized.

3. BOEING STANDARD WIRING PRACTICES MANUAL (DOCUMENT D6-54446, 20-00-14) PAGES 1-9 [Proprietary]

Comment: Tables 1-7 (not repeated here because of proprietary reasons) provide standard wire type replacements permitted for wires. No specific information pertaining to mixing of dissimilar wire types was discovered. The Boeing document contained a plethora of substitution tables, which allow the substitution of various wire types and show interchangeability for general-purpose BMS 13-48 and BMS 13-60 wire types. The tables also showed other general-purpose wire types that can be replaced by BMS 13-48 and BMS 13-60 wire types. As with military wiring practice documents, the promotion of wire mixing in bundles is evident through repair and maintenance guidelines and actions.

4. AIRBUS INDUSTRIE, ELECTRICAL STANDARD PRACTICES MANUAL (20-33-10): 10/01/02

Comment: There is no information pertaining to mixing of dissimilar wire types in bundles.

III. TEST DOCUMENTATION (FORMAL AND INFORMAL)

1. ENG. REPORT, VIBRATION OF DC-10 WIRE BUNDLES, MDC J1530: 09/73
ENG. REPORT, VIBRATION OF DC-10 WIRE BUNDLES, MDC J1530/01: 08/74
EMA REPORT, WIRE CONTAINMENT, MDC J6573: 04/76
FINAL EMA REPORT, AIRCRAFT WIRE, MDC J6998: 09/76

Comment: The MDC test reports were written in response to wire bundle containment problems observed on DC-10 aircraft due to high vibration environments. Reports discuss wire damage by containment devices as well as drifting of plastic straps and tying tape. Most (if not all) wire bundles designed for the test programs use a single wire type. Mixing of wire types into a single bundle is not addressed.

2. INTERVIEW WITH PRINCIPLE TECHNOLOGIST MR. GEORGE SELENSKI AT AIR FORCE RELIABILITY LABORATORY WPAFB, OHIO.

Comment: The U.S. Air Force has allowed composite and aromatic polyimide insulated wire to be used together in particular instances, and they do not have specific data at this time to indicate that this combination is detrimental to the performance of those applications. Decisions to make wire substitutions, which may result in combinations of wire types, are made by the system program director on a case-by-case basis.

3. NAVAL VEHICLE AIRCRAFT WIRING ACTION GROUP (NAVWAG) WIRE SUBSTITUTION CHART

Comment: The Naval Vehicle Aircraft Wiring Action Group (NAVWAG) published a wire substitution chart for all wire being used in the fleets in order to permit standardization of wire types in cable repair shops. This action has permitted mixed wires to be used in U.S. Navy aircraft. No field failures have been reported.

4. NAVAL AVIONIC CENTER (NAC) AND RAYTHEON RECOMMENDATIONS TO NAVAIR FOR WIRE SUBSTITUTION OF CANCELED WIRE SPECIFICATIONS

Comment: In December 2000 Raytheon recommended MIL-W-22759/32 wire be used as a replacement for the cancelled MIL-W-81044/18 wire. Prior to this time similar NAC recommendations were made for cancelled MIL-W-5086 wire and wires with known application problems such as MIL-W-81381 wire.

5. INTERVIEWS WITH LOCKHEED MARIETTA SENIOR WIRE ENGINEER

Comment: Lockheed Marietta has conducted numerous vibration tests (sometime with temperature) for various aircraft (C-130, C-141, C-5, F-22, P3 and L-1011) as new wires were developed in order to substantiate the use of the new wires in combination with the original wire types. No formal reports were written. Over 2 million rubs were performed to get one failure. Lockheed Marietta concluded that mixed wires was not an issue.

6. FIELD DATA ANALYSIS FROM RAYTHEON REPORT "AIRCRAFT WIRE SYSTEM RECOMMENDATIONS FOR A TSO TO ADDRESS MINIMUM SAFETY PERFORMANCE" JUNE 30, 2003

The field data from the following databases were reviewed for possible mixed wire incidents. There were reported cases of abraded wires, but no indication the abrasions may have been caused by mixing of various wire types.

TABLE A-1. FIELD DATA SOURCES

Field Data Description [1]	Time Frame Data was Collected	Source of Information [2, 3]
NTSB Aviation Accident Incident Data System	1983 – July 2002	https://nasdac.faa.gov/pls/nasdac/ [1, 2]
NTSB Aviation Safety Reporting System	1988 – July 2002	https://nasdac.faa.gov/pls/nasdac/ [1,2]
Service Difficulty Reports (SDRs)	October 2000 – July 2002	http://av-info.faa.gov/ [3]
Airworthiness Directives (ADs)	1979 – July 2002	http://av-info.faa.gov/
Navy Safety Info	1/10/97 to 5/2/01	Information obtained from Cmdr. Bowers
Miscellaneous and ATSRAC Info	October 1978 – August 2000	Information obtained from the intrusive inspection final report and other various sources
NALDA Cable and Connector Shop	January 1996 - July 2002	NALDA 3M Data
NALDA Electrical Shop	January 1996 - July 2002	NALDA 3M Data

Notes:

1. During the investigation several web sites were under construction and may no longer be directly accessible since the time that the data was gathered.

2. www.ntsb.gov/ntsb/query.asp was used as an alternate source for backup information.

3. Several incident reports, which were not on the NTSB website contained information deemed useable and were included in this database.

7. NAC PUBLICATION TR-2333 "TESTING OF SELECTED AIRCRAFT WIRES INSULATIONS" 8 JUNE 1983

Page 2

A particular wire type could be selected for use in a given part of an aircraft depending upon the combination of environmental and mechanical stresses encountered in that particular part of the airframe. None of the wires tested demonstrated acceptable qualities for optimum use in all areas of Navy aircraft.

Page 4

It is recommended that until a universal insulation is developed, a wire should be chosen based on its application.

Comment: In vibration, three bundles of two wire types (15 wires of each type) were tested for 100, 250, and 512 hours at the AV-8B aircraft cruising test level. One bundle contained M22759/16 and M22759/34 wire types, one contained M81381/11 and M22759/16 wire types, and one bundle contained M22759/32 and M81381/11 wire types. The wires were tested to failure to their maximum dielectric voltage withstand capability.

Comment: Statistically, the results indicated, in general, that harder insulation dielectric characteristics are reduced significantly more than the softer insulation. In some cases, the reduced voltage capability is nearly 50% from the initial values, but it should be recognized even at these reduced levels the wire voltage is still 15 time greater than its rated value. The most significant result is that, as the vibration time is continued, the withstand voltage begins to level off after 250 hours. It is unknown whether the voltage would continue to stay the same after 512 hours. Visual observations indicate the reduction in voltage capability is probably due to wire-to-wire wear.

8. RAYTHEON INDIANAPOLIS DESIGN AND AIRCRAFT INSPECTION EXPERIENCES

Comment: Based on Raytheon Indianapolis and NAC wiring designs as well as previous military aircraft inspections, it is not uncommon to find two different wire types in the same bundles or adjacent bundles. The wire types are necessary as indicated in the NAC TR-2333 report to meet all the extreme environmental zones in the aircraft. The designer has the option of using one wire type by protecting it more in the most extreme environmental zones, but this is seldom done for labor cost and weight reasons.

APPENDIX B—TEST PROGRAM

B.1. BACKGROUND.

Questions have been raised related to the degradation effects of the insulations of different wire types in contact with each other. Chemicals, debris, and other environmental contamination are also expected to accelerate degradation on certain insulation surfaces, as well as increase the coefficient of friction and cause surface wear. Since many of these wires are constructed with very stable polymer insulations, such as polytetrafluoroethylene, the actual chemical interaction between them is expected to be negligible. There are potential issues related to the mixing of wires with different conductor types as well. A stiffer wire and a harder subsurface to the insulations may accelerate the physical interaction of the different wire types. Raytheon has experience testing wire with all of these possible interactions. Previously generated test data has validated the possibility that these factors could affect the wire-to-wire interaction.

B.2. TEST DESIGN.

Physically conditioning wire bundles with vibration accelerates the interactions between the wires, such as abrasion and chaffing, and evaluates their characteristic behavior in mixed bundles. The magnitude depends on environmental factors such as temperature and humidity; chemical stresses with the presence of aircraft fluids; and physical stresses such as the presence of foreign matter, vibration, and shock. Three primary mechanisms by which the wire is damaged in a mixed state include:

a. Abrasion and Chaffing. Abrasion is a primary action that will degrade the wire when a “sawing” motion is involved. Factors that have been speculated as having influence on this degradation mechanism include the hardness of one insulation compared to another, tape edges which bite into the another wire, and pigment and mineral fillers that will abrade another insulation.

b. Cut Through. Cut through of the insulation, to expose the underlying conductor, is a mechanism that affects the wire integrity. This is the mechanism of one wire pushing aside or cutting into another wire by pressure or by the rigidity of the surrounding wires that forces the wire into a structural member or other sharp object. Cold flow is a mechanism closely related to cut through whereby the insulation will flow, leaving the wire less protected with insulation.

c. Chemical Degradation. The presence of chemicals or debris could be the mechanism that is degrading the wire insulation, and the abrasion against another wire may continually expose fresh wire surfaces to the damaging effects.

In addition to those listed, combinations of the above stresses may occur.

Several specific conditioning stresses may affect the wire samples based on the above degradation mechanisms. These stresses include:

a. Vibration. Vibration is a major issue in that it increases the overall exposure of the wire to cycles of wear. This stress will increase the abrading or sawing mechanisms that may be occurring between wires. Operation of aircraft engines and equipment subjects all electrical wiring interconnect systems (EWIS) components to some level of vibration. Damage to the support system (clamps and straps) or improper replacement of supports following maintenance actions can prevent vibration levels from being dampened properly and permit increased chafing due to undesirable contact between wire types. The introduction of chemicals, dirt, and debris can cause further damage to the EWIS when vibration is not restricted properly.

b. Wire Flexure. Flexure of the wires, especially when twisted, such as in twisted conductors, may occur during maintenance and operation. The flexing will cause a force between the wires in the bundle to abrade or rub against each other. This may contribute to the degradation mechanism occurring between mixed or similar wire types. The introduction of chemicals, dirt, and debris can cause further damage to the EWIS when this flexure occurs. A flexure test will not be used in this test since it accelerates the same degradation mechanism as vibration. Flexure on its own may cause differences in the failure rates due to potential differences in the blocking that may occur within the conductors. Previous test data has shown that blocked conductor strands, which are bonded together, dramatically decrease the flex life of the wire. Having an insulated wire with a tin-coated conductor, which more easily blocks with exposure to high heat, mixed with an insulated nickel-coated conductor could result in premature failure of the wire. This is seen as a design flaw and is not specifically related to the interaction of the two wires. Therefore, testing for this interaction was not included in this test program.

c. Wire-to-Wire Cut Through. Crushing two insulated wires together could cause the failure of one of the wires preferentially over another. Although this may not be a common failure mechanism, it does demonstrate differences in the physical characteristics of the materials.

d. Wire Flexibility. Flexibility of the wires can affect the amount of stress that is imparted on specific wires within the bundle. Rigid wires have the potential of creating more force against other components or the structure since it cannot bend out of the way as easily. Wire with softer type insulations may be more likely to suffer physically when mixed with more rigid wires. The presence of mixed conductor types may cause the additional stress to occur between the wires if there is additional stress placed on the bundles, and if there is to be an alloy conductor wire mixed with annealed copper conductor wire. Since the alloy does not have the same elongation properties, a disproportionate amount of stress may be put on the alloy wire, increasing the chance of breakage. Furthermore, the additional hardness underneath the insulation may cause increased wear on the wire surface.

B.3. DESIGN OF TEST PROGRAM.

The performance baseline used the same type wires in the same configuration and under the same stresses. Simulation testing was performed on the wire properties that are affected by the mixing of different wire types. The wire types that were focused upon in group I were the following:

- PVC/glass/nylon
- Wrapped aromatic polyimide (PI)
- Cross-linked polyalkane-imide (XPI)
- Extruded cross-linked ethylene tetrafluoroethylene (XLETFE)
- Mineral-filled and extruded polytetrafluoroethylene (MF-PTFE and PTFE)
- PTFE/glass outer braid
- Wrapped aromatic polyimide/wrapped PTFE composite (PI/PTFE)
- Annealed and alloy conductor

Group II of the test plan incorporated some specific examples of interaction with common aircraft contamination: hydraulic fluid and metal shavings. Due to the limitations of this effort, this portion was not extensively tested, but previous data and selected testing was performed to generate conclusions and recommendations regarding the need for future testing.

The wire bundle samples consisted of a variety of mixed wire combinations using the aforementioned wire types. The testing concentrated on the properties of the insulation of the wires, with the failure criteria being the loss of the integrity of the wire insulation, leading to the potential for direct electrical shorts. The wire-to-wire and bundle tests in tables B-1 and B-2, respectively, were decided upon for the program, with the concentration being on the wire bundles since that condition more closely simulates the actual environment of the aircraft.

TABLE B-1. WIRE-TO-WIRE TESTS

Test	Purpose
Crush	To determine which wire insulation types are most susceptible to damage. One wire placed over another perpendicularly.

TABLE B-2. BUNDLE TESTS

Test	Purpose
Vibration	Periodically perform visual and electrical evaluations to monitor failures.
Vibration with foreign matter	Periodically perform visual and electrical evaluations to monitor failures.
Vibration with chemical contamination	Periodically perform visual and electrical evaluations to monitor failures.

Vibration testing was performed with the wire bundles clamped onto fixtures that allowed the testing of 48 bundles concurrently. A vibration profile similar to the one documented in Naval Avionics Center (NAC) report TR-2333, "Testing of Selected Aircraft Electrical Wire Insulations," dated 8 June 1983, was used for this program. Previous testing has shown that significant wire abrasion can be achieved within 500 hours using this method.

Selection of the wire types took into consideration the differences that fillers can have in the PTFE construction by taking types that vary in filler content, and in the construction differences of extrusions versus tape-wrapped products. The PTFE insulated wire may behave differently than the PI/PTFE due to the rigidity of the polyimide underneath the PTFE wrap. Also, to test the theory that conductor differences could play a part in the interaction of wire types, two alloy constructions were tested. Three-way combinations were not expected to have more degradation than a two-wire interaction.

The specific wire types tested are shown in table B-3.

TABLE B-3. WIRE TYPES, SPECIFICATION OR COMMERCIAL EQUIVALENT

Wire Code	Wire Type	Part Number
1	PVC/glass/nylon	MIL-W-5086/2-22-9
2	PI	BMS13-51T08C01G22-50
3	XPI, alloy	Spec 88A
4	XLETFE	BMS13-48T08C01G22
5	XLETFE, alloy	MIL-W-22759/42-24-9
6	PTFE, extruded	MIL-W-22759/9-22-9
7	PTFE, extruded mineral-filled	MIL-W-22759/8-22-9
8	PTFE, tape wrap	Not included in program
9	PTFE/glass	MIL-W-22759/1-22-9
10	PI/PTFE	BMS13-60T19C01G22
11	PI/PTFE, alloy	BMS13-60T04C1G22

B.4. TEST PROCEDURES AND DATA COLLECTION.

4.1 Group I.

A total of 48 wire combinations were tested in group I, which consisted of bundles that were uncontaminated, and were subjected to 500 hours of vibration conditioning. The unshaded boxes shown in table B-4 were the combinations selected for group I of the program.

TABLE B-4. GROUP I TEST WIRE COMBINATIONS

Wire Type	1	2	3	4	5	6	7	8	9	10	11
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											

The shaded areas are duplicate or very implausible wire combinations that were not tested. Non-mineral-filled PTFE insulated wire is not normally approved for use in open wire harnesses; however, it was included in this study to baseline the PTFE with the mineral filler. Nylon can crack off the insulation, leaving behind glass braided PVC insulated wire. (Other wire types incorporate the use of glass braid in the outer layer of larger gauge sizes for mechanical protection.) It is anticipated that wire in this condition will be replaced at the same time that the new wire is added, eliminating the need to have a glass braid vibration test. Nylon, which cracks off the wire, can cause foreign object damage in the wire bundles that may accelerate the degradation. Fluids, metal shavings, and other debris may also accelerate the degradation of the wire. Coaxial cables generally have FEP, PTFE, or XLETFE insulations that would behave similarly to the wires listed in this test program; however, rubber types are not incorporated in this test program. Therefore, twisted pairs were tested in a limited fashion, since it is possible that these constructions would increase the stress placed on adjacent wire. The ultimate degradation mechanism for the two wire types, however, would be identical.

B.4.1.1 Assembly of Bundles.

Similar to the NAC TR-2333 testing, wire bundles consisted of 20 wires of the same or two different types of insulation. Each bundle consisted of 12 single wires and 4 twisted pairs that were cut to approximately 36 inches in length. For bundles containing two wire types, half of the singles and twisted pairs were of each wire type. The wires were installed so that each wire type would have single wires and twisted pairs located in the outer and inner portions of the bundles. Annealed copper type constructions were 22 gauge, whereas alloy type conductors were 24 or 22 gauge, indicative of the actual sizes used in the aircraft. One end of each wire was terminated with an electrical contact and installed in a connector. The unterminated end of each wire was dipped in RTV to prevent dielectric withstand voltage or insulation resistance failures from adjacent exposed conductors rather than wear from the vibration testing. Tiedown straps and lacing string were alternately used on the bundles to contain the wires, and MS21919 cushion clamps were used to secure the bundles to the vibration fixtures. The clamps mounted on the vibrated center plates were 11 inches apart. The lacing string and the tiedown strap installed on the bundle between those clamps were approximately 3 inches from the clamps. The lacing string and tiedown strap installed between the clamps on the stationary plates and the vibrating center plate were spaced at approximately 3-inch intervals. A bend was put into the nonterminated end of each bundle, and it was secured with cushion clamps to a stationary plate that was perpendicular to the vibrating center plate (see figures D-14 and D-15 in appendix D). In the NAC TR-2333 test program, a bend was placed in both ends of the bundle, but for this program, only one end contained a bend so that the impact of this configuration could be compared to that of a straight bundle.

B.4.1.2 Environmental Conditioning and Electrical Testing.

The bundles were subjected to the vibration profile shown in figure B-1. This profile is similar to the one that produced the insulation wear documented in NAC TR-2333. The vibration testing was stopped after 100, 250, and 500 cumulative hours for visual inspection and dry insulation resistance and dielectric withstand voltage testing. The bundles remained on the fixtures for the visual examination and dry electrical testing. After this testing had been completed, the bundles were removed from vibration fixtures and subjected to wet insulation resistance and dielectric withstand voltage testing. The clamps, tiedown straps, and lacing string were then removed to permit a more thorough visual inspection of the wires and surfaces of the support components that were in contact with the wires.

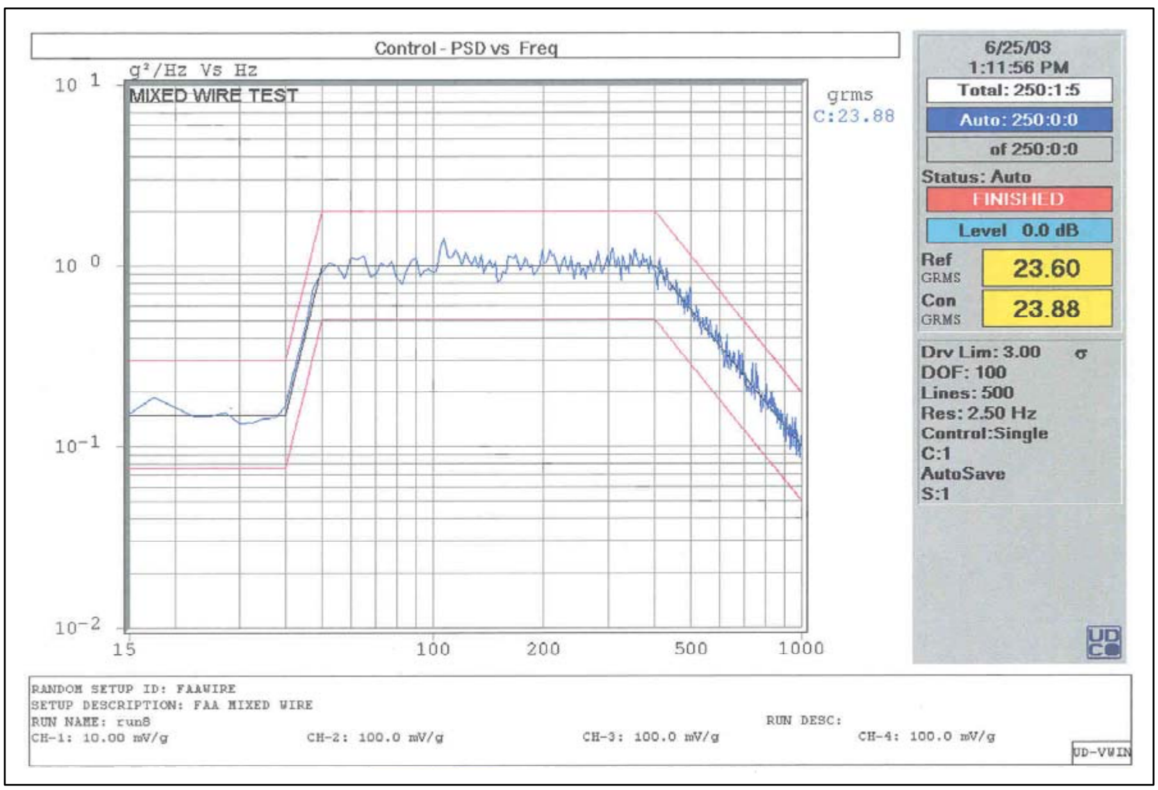

FIGURE B-1. RANDOM VIBRATION PROFILE

B.4.1.3 Specific Tests.

Detailed descriptions of the tests performed during the execution of the group I test program follow.

a. Visual Inspection. After 100, 250, and 500 hours of vibration, the wire bundles were inspected while still mounted on the test fixtures. The inspections were designed to document things such as damage to the wires and support components; rotation of the heads of the tie wraps; twisted pairs separating from the bundles; wear marks on the fixtures from wires, straps, and lacing string; and slippage of bundles in the cushion clamps.

b. Dry Electrical Testing. After 100, 250, and 500 hours of vibration conditioning, the fixtures and wire bundles were removed from the vibration table and subjected to dry electrical tests using a DITMCO test station. The parameters of the testing were as follows:

   - Insulation resistance:

     500 Vdc, 1000 megohms pass/fail threshold, 1 second dwell

   - Dielectric withstand voltage:

     1000 Vac (500 Vac/second ramp), 1 mA leakage current, 1 second dwell

   The unterminated end of each wire was dipped in RTV to prevent dielectric withstand voltage or insulation resistance failures from adjacent exposed conductors.

c. Wet Electrical Testing. After being subjected to the 500 hours of vibration conditioning, visual examination, and dry electrical testing, the bundles were removed from the test fixtures and soaked for a minimum of 1 hour in a 5% sodium chloride water bath, then subjected to wet electrical testing using the following parameters:

   - Insulation resistance:

     500 Vdc, 1000 megohms pass/fail threshold, 1 minute dwell time

   - Dielectric withstand voltage:

     1000 Vac (500 Vac/second ramp), 1 mA leakage current, 1 minute dwell time

d. Visual Inspection of Disassembled Bundles. Following the wet electrical testing, the clamps, tiedown straps, and lacing string were removed, and the wires were separated to allow for a more thorough inspection of the complete insulation surface. The inspections were designed to document outer wire wear from the clamps, plate, straps, and lacing string; inner bundle wire-to-wire wear; and wear on the clamps, straps; and lacing string.

B.4.2 Group II.

Twenty-four of the original forty-eight wire bundle types were selected to be contaminated with fluid, and a similar set of twenty-four to be contaminated with metal shavings. The selected combinations are shown by the unshaded cells in table B-5.

TABLE B-5. GROUP II TEST COMBINATIONS

Wire Type	1	2	3	4	7	9	10	11
1								
2								
3								
4								
7								
9								
10								
11								

B.4.2.1 Assembly of Bundles.

The bundles were supported and clamped the same as in group I.

B.4.2.2 Environmental Conditioning.

The center sections of one set of the 24 wire combinations in table B-5 were soaked for 4 hours in Skydrol 500B4 hydraulic fluid, which meets Standard SAE AS1241, "Fire Resistant Phosphate Ester Hydraulic Fluid For Aircraft," at a temperature of approximately 50°C, then allowed to drip dry.

An equivalent set of wire bundles was contaminated with aluminum drill shavings by bird-caging the center section of the bundles before installing the clamps, tiedown straps, and lacing string to allow the shavings to become entrapped within the bundle.

The bundles were subjected to the same vibration profile as in group I. The vibration testing was stopped after 100 and 250 cumulative hours for visual inspection and dry insulation resistance and dielectric withstand voltage testing. The bundles remained on the fixtures for the visual examination and dry electrical testing. After this testing was completed, the bundles were removed from the vibration fixtures and subjected to wet insulation resistance and dielectric withstand voltage testing. The clamps, tiedown straps, and lacing string were then removed to permit a more thorough visual inspection of the wires and surfaces of the support components that were in contact with the wires.

B.4.2.3 Specific Tests.

Prior to the vibration conditioning, the bundles were subjected to dry insulation resistance and dielectric withstand voltage testing. No failures were noted. Following the environmental conditioning, the same tests were performed as in group I.

a. Visual Inspection. After 100 and 250 hours of vibration, the wire bundles were inspected while still mounted on the test fixtures. The inspections were designed to document things such as damage to the wires and support components; rotation of the heads of the tie wraps; twisted pairs separating from the bundles; wear marks on the fixtures from wires, straps, and lacing string; and slippage of bundles in the cushion clamps.

b. Dry Electrical Testing. After 100 and 250 hours of vibration conditioning, the fixtures and wire bundles were removed from the vibration table and subjected to dry electrical tests using a DITMCO test station. The parameters of the testing were as follows:

- Insulation resistance:

  500 Vdc, 1000 megohms pass/fail threshold, 1-second dwell

- Dielectric withstand voltage:

  1000 Vac (500 Vac/second ramp), 1 mA leakage current, 1-second dwell

The unterminated end of each wire was dipped in RTV to prevent dielectric withstand voltage or insulation resistance failures from adjacent exposed conductors.

c. Wet Electrical Testing. After being subjected to the 250 hours of vibration conditioning, visual examination, and dry electrical testing, the bundles were removed from the test fixtures and soaked for a minimum of 1 hour in a 5% sodium chloride water bath, then subjected to wet electrical testing using the following parameters:

- Insulation resistance:

  500 Vdc, 1000 megohms pass/fail threshold, 1-minute dwell time

- Dielectric withstand voltage:

  1000 Vac (500 Vac/second ramp), 1 mA leakage current, 1-minute dwell time

d. Visual Inspection of Disassembled Bundles. Following the wet electrical testing, the clamps, tiedown straps, and lacing string were removed, and the wires were separated to allow for a more thorough inspection of the complete insulation surface. The inspections were designed to document outer wire wear from the clamps, plate, straps, and lacing string; inner bundle wire-to-wire wear; and wear on the clamps, straps, and lacing string.

B.4.3 Group III—Crush Test.

Fourteen-inch lengths of untested wires were subjected to a crush test at room temperature to determine which wire insulations were more susceptible to damage. The test method was a variation to the standard dynamic cut through test, with the difference being that two perpendicular wires are compressed against each other instead of a blade being pressed on a wire. The same 24 wire combinations that were evaluated in group II were subjected to the crush test. For each combination of wires tested, eight crushes were performed at approximately 1/2-inch intervals. Half of the crushes were performed with an 80-pound load applied and half with a 120-pound load. The wires were then evaluated for damage.

APPENDIX C—TEST DATA

TABLE C-1. GROUP I VISUAL OBSERVATIONS ON MOUNTED BUNDLES

Condition Observed	On Bundle Number* After 100 hrs Vibration	After 250 hrs Vibration	After 500 hrs Vibration
Twisted pairs separating from bundle			
Strap rubbing on center plate	2-12, 14, 18, 22, 23, 28, 31, 37-39, 41, 45-47	2-12, 14, 16, 18, 20, 22, 23, 26, 28, 30, 31, 35, 37-39, 41, 45-47	1, 2, 8-10, 14, 18, 22, 28, 30, 31, 35, 37-40, 45, 47
Wire rubbing on plate	1, 2, 4-6, 8, 10, 12, 14, 16-18, 20, 22, 25, 27-33, 35-40, 42-47	1, 2, 4-6, 8, 10, 12-15, 17-22, 24, 25, 27-33, 35-47	1, 2, 4-6, 8, 10-12, 14, 17-20, 22, 24, 25, 27-33, 35-37, 39-48
White residue from clamp or wire insulation		1, 13, 25, 36, 37, 48	1, 5, 8, 12, 13, 15, 18, 20, 22, 24, 25, 27, 29, 32, 36, 37, 39, 48
Bundle slipping in clamp	11-13, 23-25, 29, 35, 36, 47, 48	1, 2, 4, 5, 11-13, 17, 20, 23-25, 29, 30, 33, 35, 36, 47, 48	All
Lacing string cutting into wire		5, 18, 22, 30, 41	1, 5, 18, 22, 30, 32, 36, 41, 44, 48
Wire stripe wearing off		16, 43, 45, 47	16, 43, 45, 47
Clamp cutting insulation		1, 2, 12, 14, 25, 27, 36, 39, 47, 48	1, 2, 5, 12, 13, 17, 28, 36, 37, 48
Strap rubbing on flat side plate		6, 9, 37, 43, 47	

*See table C-5 for wire types found in each bundle number.

TABLE C-2. GROUP I DRY ELECTRICAL FAILURES FOLLOWING 250 HOURS OF VIBRATION TESTING*

Bundle No.	Wire Codes	Failed Cavity	Wire Code	Single or Pair	IR (Ohms)	DWV
18	6, 5	J2-5	5	P	9.484 km pass	Fail
20	6, 6	J2-15	6	P	1.147	Fail

*No failures were noted after 100 hours of vibration.

TABLE C-3. GROUP I DRY ELECTRICAL FAILURES FOLLOWING 500 HOURS OF VIBRATION TESTING**

Bundle No.	Wire Codes	Failed Cavity	Wire Code	Single or Pair	IR (Ohms)	DWV
13	7, 7	J2-10	7	P	6.520 km pass	Fail
15	10, 9	J2-8	10	S	13.82 km pass	Fail
16	3, 2	J2-8	3	S	7.405 km pass	Fail
17	10, 7	J2-8	10	S	5.192 km pass	Fail
19	11, 4	J2-8	11	S	5.739 km pass	Fail
20	6, 6	J2-8	6	S	8.234 km pass	Fail

**Dry electrical results are considered suspect.

TABLE C-4. GROUP I WET ELECTRICAL FAILURES FOLLOWING 500 HOURS OF VIBRATION TESTING

Bundle No.	Wire Codes	Failed Cavity	Wire Code	Single or Pair	IR (Ohms)	DWV (Pass/Fail)
11	5, 5	J2-19	5	P	11.44 k	Fail
11	5, 5	J2-5	5	P	22.66 km pass	Fail
12	9, 9	J2-11	9	S	5.533 k	Fail
12	9, 9	J2-13	9	S	3.776 k	Fail
12	9, 9	J2-15	9	P	1.987 k	Fail
12	9, 9	J2-3	9	S	5.197 k	Fail
12	9, 9	J2-6	9	S	6.297 k	Fail
12	9, 9	J2-8	9	P	2.042 k	Fail
17	10, 7	J2-9	10	P	low	Fail
20	6, 6	J2-10	6	P	4.210 k	Fail
20	6, 6	J2-14	6	P	5.301 k	Fail
20	6, 6	J2-15	6	P	4.946 k	Fail
20	6, 6	J2-17	6	S	6.705 k	Fail
20	6, 6	J2-20	6	P	3.049 k	Fail
20	6, 6	J2-4	6	P	12.18 k	Fail
20	6, 6	J2-5	6	P	4.874 k	Fail
20	6, 6	J2-7	6	S	9.451 k	Fail
20	6, 6	J2-9	6	P	7.489 k	Fail
21	3, 3	J2-7	3	S	11.14 km pass	Fail
24	9, 1	J2-19	9	P	7.167 k	Fail
24	9, 1	J2-9	9	P	3.247 km pass	Fail
25	9, 6	J1-19	6	P	1.611 k	Fail
25	9, 6	J1-20	6	P	2.052 k	Fail
25	9, 6	J1-21	9	S	4.210 k	Fail
25	9, 6	J1-25	9	P	1.025 k	Fail
25	9, 6	J1-27	6	S	5.881 k	Fail
25	9, 6	J1-29	6	P	6.681 k	Fail
25	9, 6	J1-30	6	P	6.483 k	Fail
25	9, 6	J1-32	9	S	5.346 k	Fail
29	7, 5	J1-20	5	P	814.6 km pass	Fail
36	9, 7	J1-24	9	P	1.711 k	Fail
36	9, 7	J1-26	7	S	3.816 k	Fail
36	9, 7	J1-28	7	S	4.379 k	Fail
36	9, 7	J1-34	9	P	533.7	Fail

*All DWV failures were determined to be due to installation rather than wire-to-wire wear.

TABLE C-5. GROUP I POSTTEST VISUAL INSPECTION

Bundle No.	1	2	3	4	5	6	7	8	9	10	11	12
Wire Types	7/1	11/10	11/9	11/2	11/7	4/4	10/4	7/2	11/3	9/4	5/5	9/9
Outer Bundle Wear From:												
Plate	L/N	N/N	N/L	L/N	L/L	L/L	N/L	L/N	N/L	L/N	S/S	L/L
Clamps	M/N	M/M	N/N	M/L	M/M	N/N	M/N	L/N	M/M	L/N	N/N	S/S
Straps	L/N	N/N	N/L	L/N	L/L	L/L	L/L	L/N	L/N	L/N	N/N	L/L
String	N/N	N/N	N/N	N/L	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N
Photos	Yes	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes
Wire Wear:												
Single/Single	N/N	N/N	N/N	N/L	N/N	N/N	N/N	N/L	N/L	N/N	L/L	N/N
Pair/Pair	N/N	N/N	N/N	N/L	N/N	N/N	N/N	N/L	N/L	N/N	N/N	N/N
Pair/Single	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/L	N/L	N/N	L/L	N/N
Photos	No	No	No	No	No	No	No	No	No	No	No	No
Wear on Support:												
Clamps	M	N	L	L	N	N	L	L	L	L	L	M
Straps	N	N	L	L	N	N	L	L	L	N	N	L
String	N	N	N	N	N	N	N	N	N	N	N	N
Photos	Yes	No	No	No	No	No	No	No	No	No	No	Yes

L =
M =

TABLE C-5. GROUP I POSTTEST VISUAL INSPECTION (Continued)

Bundle No.	13	14	15	16	17	18	19	20	21	22	23	24
Wire Types	7/7	11/11	10/9	3/2	10/7	6/5	11/4	6/6	3/3	7/6	10/5	9/1
Outer Bundle Wear From:												
Plate	M/M	N/N	N/L	M/N	L/N	N/M	M/N	S/S	N/N	S/N	N/N	M/L
Clamps	S/S	M/M	L/N	M/L	M/M	N/N	M/N	S/S	M/M	M/L	M/N	S/L
Straps	L/L	L/L	N/L	N/N	L/L	L/L	L/L	L/L	N/N	L/L	L/L	N/N
String	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N
Photos	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Wire Wear:												
Single/Single	N/N	N/N	N/N	M/L	N/N	N/N	N/N	N/N	M/M	N/N	N/N	N/N
Pair/Pair	N/N	N/N	N/N	M/L	N/N	N/N	N/N	N/N	M/M	N/N	N/N	N/N
Pair/Single	N/N	N/N	N/N	M/L	N/N	N/N	N/N	N/N	M/M	N/N	N/N	N/N
Photos	No	No	No	No	No	No	No	No	Yes	No	No	No
Wear on Support:												
Clamps	L	N	L	L	L	L	L	L	L	L	L	M
Straps	N	L	N	N	L	L	N	L	N	L	L	N
String	N	N	N	N	N	N	N	N	N	N	N	N
Photos	No	No	No	No	No	No	No	No	Yes	No	No	No

TABLE C-5. GROUP I POSTTEST VISUAL INSPECTION (Continued)

Bundle No.	25	26	27	28	29	30	31	32	33	34	35	36
Wire Types	9/6	5/3	9/5	2/2	7/5	11/6	4/3	5/1	5/2	9/2	10/10	9/7
Outer Bundle Wear From:												
Plate	N/N	N/N	L/N	N/N	L/L	L/M	L/L	L/L	L/M	N/M	M/M	N/N
Clamps	S/S	N/M	L/N	L/L	M/L	N/N	N/L	L/N	N/N	N/N	M/M	S/S
Straps	L/L	L/N	N/N	N/N	L/N	N/N	L/N	N/N	N/N	L/L	N/N	N/L
String	N/N	N/N	N/N	N/N	L/N	L/N	N/N	N/N	N/N	N/N	N/N	N/N
Photos	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	Yes
Wire Wear:												
Single/Single	N/N	N/L	N/N	L/L	N/N	N/N	N/M	N/N	L/L	N/L	N/N	N/N
Pair/Pair	N/N	N/M	N/N	L/L	L/N	N/N	N/M	L/N	L/L	N/L	N/N	N/N
Pair/Single	N/N	N/M	N/N	L/L	L/N	N/N	N/M	N/N	L/L	N/L	N/N	N/N
Photos	No	No	No	No	No	No	Yes	No	No	No	No	No
Wear on Support:												
Clamps	M	L	L	L	L	N	L	L	L	L	L	M
Straps	N	N	N	N	N	N	N	N	N	N	N	N
String	N	N	N	N	N	N	N	N	N	N	N	N
Photos	No	No	No	No	No	No	No	No	No	No	No	No

TABLE C-5. GROUP I POSTTEST VISUAL INSPECTION (Continued)

Bundle No.	37	38	39	40	41	42	43	44	45	46	47	48
Wire Types	7/4	10/3	4/1	5/4	6/2	6/3	4/2	7/3	10/2	9/3	11/5	1/1
Outer Bundle Wear From:												
Plate	N/N	N/N	L/N	N/L	S/N	M/M	L/N	L/M	L/L	L/L	L/N	L/L
Clamps	L/N	M/M	L/N	N/N	N/N	N/L	N/N	M/M	M/L	N/N	L/N	N/N
Straps	N/N	L/N	N/N	N/N	L/N	L/N	N/N	L/N	N/N	L/N	L/N	N/N
String	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N
Photos	No	Yes	No	No	Yes	No	No	Yes	No	No	No	No
Wire Wear:												
Single/Single	N/N	N/L	N/N	N/N	N/L	N/M	N/L	L/M	L/L	N/L	N/N	N/N
Pair/Pair	N/N	N/L	N/N	N/N	N/L	N/M	N/L	N/M	L/L	N/L	N/N	N/N
Pair/Single	N/N	N/L	L/N	N/N	N/L	L/M	N/L	L/M	L/L	N/L	N/N	N/N
Photos	No	No	No	No	No	Yes	No	No	No	No	No	No
Wear on Support:												
Clamps	L	L	L	N	N	L	L	L	L	L	N	M
Straps	L	N	N	N	N	N	N	L	L	N	N	N
String	N	N	N	N	N	N	N	N	N	N	N	N
Photos	No	No	No	No	No	No	No	No	No	No	No	No

TABLE C-6. GROUP I SUMMARY OF RESULTS BY WIRE TYPE

Wire Code 1 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1	48	0.438	0.42	0.018	N		Y	N	L
2									
3									
4	39	0.375	0.35	0.025	N		N	N	N
5	32	0.375	0.336	0.039	N		N	N	L
6									
7	1	0.438	0.414	0.024	N		N	N	N
9	24	0.5	0.445	0.055	N		Y	L	L
10									
11									

Wire Code 2 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1									
2	28	0.313	0.263	0.05	L		N	L	N
3	16	0.313	0.26	0.053	L		N	L	N
4	43	0.313	0.272	0.041	L		N	N	N
5	33	0.313	0.258	0.055	L		N	N	M
6	41	0.313	0.3	0.013	L		N	N	N
7	8	0.375	0.336	0.039	L		N	N	N
9	34	0.375	0.367	0.008	L		N	N	M
10	45	0.313	0.258	0.055	L		N	L	L
11	4	0.313	0.258	0.055	L,N		N	L	N

Key:
N = No
Y = Yes
N = None
L = Low
M = Moderate
S = Severe

TABLE C-6. GROUP I SUMMARY OF RESULTS BY WIRE TYPE (Continued)

Wire Code 3 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1									
2	16				M		N	M	M
3	21	0.313	0.258	0.055	M	1	N	M	N
4	31	0.313	0.269	0.044	M		N	L	L
5	26	0.313	0.255	0.058	M,L		N	M	N
6	42	0.313	0.297	0.016	M		N	L	M
7	44	0.375	0.333	0.042	M		N	M	M
9	46	0.375	0.364	0.011	L		N	N	L
10	38	0.375	0.375	0	L		N	M	N
11	9	0.313	0.255	0.058	L		N	M	L

Wire Code 4 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1	39				L		N	L	L
2	43				N		N	N	L
3	31				N		N	N	L
4	6	0.313	0.28	0.033	N		N	N	L
5	40	0.313	0.266	0.047	N		N	N	L
6									
7	37	0.438	0.394	0.044	N		N	N	N
9	10	0.375	0.375	0	N		N	N	N
10	7	0.313	0.266	0.047	N		N	N	L
11	19	0.313	0.266	0.047	N		N	N	N

Key:
N = No
Y = Yes
N = None
L = Low
M = Moderate
S = Severe

TABLE C-6. GROUP I SUMMARY OF RESULTS BY WIRE TYPE (Continued)

Wire Code 5 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1	32				L,N		N	L	L
2	33				L,N		N	N	L
3	26				N		N	N	N
4	40				N		N	N	N
5	11	0.313	0.252	0.061	L,N	2	Y	N	S
6	18	0.313	0.294	0.019	N		N	N	M
7	29	0.375	0.33	0.045	N	1	Y	L	L
9	27	0.375	0.361	0.014	N		N	N	N
10	23	0.313	0.252	0.061	N		Y	N	N
11	47	0.313	0.252	0.061	N		Y	N	N

Wire Code 6 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1									
2	41				N		N	N	S
3	42				L		N	N	M
4									
5	18				N		N	N	N
6	20	0.375	0.336	0.039	N	9	N	S	S
7	22	0.375	0.375	0	N		N	L	N
9	25	0.438	0.403	0.035	N	5	Y	S	N
10									
11	30	0.313	0.294	0.019	N		N	N	M

Key: N = No
Y = Yes
N = None
L = Low
M = Moderate
S = Severe

TABLE C-6. GROUP I SUMMARY OF RESULTS BY WIRE TYPE (Continued)

Wire Code 7 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1	1				N		N	M	L
2	8				N		N	L	L
3	44				L,N		N	M	L
4	37				N		N	L	N
5	29				L,N		Y	M	L
6	22				N		N	M	S
7	13	0.438	0.409	0.029	N		Y	S	M
9	36	0.5	0.44	0.06	N	2	Y	S	N
10	17	0.375	0.331	0.044	N		N	M	N
11	5	0.375	0.331	0.044	N		N	M	L

Wire Code 9 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1	24				N	2	Y	S	M
2	34				N		N	N	N
3	46				N		N	N	L
4	10				N		N	L	L
5	27				N		N	L	L
6	25				N	3	Y	S	N
7	36				N	2	Y	S	N
9	12	0.5	0.47	0.03	N	6	Y	S	L
10	15	0.375	0.361	0.014	N		N	N	L
11	3	0.375	0.361	0.014	N		N	N	L

Key: N = No
Y = Yes
N = None
L = Low
M = Moderate
S = Severe

TABLE C-6. GROUP I SUMMARY OF RESULTS BY WIRE TYPE (Continued)

Wire Code 10 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1									
2	45				L		N	M	L
3	38				N		N	M	N
4	7				N		N	M	N
5	23				N		Y	M	N
6									
7	17				N	1	N	M	L
9	15				N		N	L	N
10	35	0.313	0.252	0.061	N		Y	M	M
11	2	0.313	0.252	0.061	N		N	M	N

Wire Code 11 Group I

With Code	Bundle	Clamp Diameter	Bundle Diameter	Diameter Difference	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1									
2	4				N		N	M	L
3	9				N		N	M	N
4	19				N		N	M	M
5	47				N		Y	L	L
6	30				N		N	N	L
7	5				N		N	M	L
9	3				N		N	N	N
10	2				N		N	M	N
11	14	0.313	0.252	0.061	N		N	M	N

Key:
N = No
Y = Yes
N = None
L = Low
M = Moderate
S = Severe

TABLE C-7. GROUP II VISUAL OBSERVATIONS ON MOUNTED BUNDLES

Condition Observed	On Bundle Number*	
	After 100 hrs	After 250 hrs
Twisted pairs separating from bundle	All	All
Strap rubbing on plate	50, 54, 56-58, 62-64, 68-71, 75-79, 81, 83, 85, 90, 91, 96	
Wire rubbing on plate	49, 50, 54-56, 59-66, 68-70, 72, 75-85, 88-90, 96	49, 50, 54-56, 59-64, 66, 69, 73, 77, 80, 81, 83-86, 92, 96
White, gray, or green residue from clamp or wire insulation	49-54, 60, 61, 63-67, 72, 73, 84, 85, 87, 96	49, 51-55, 59, 60, 63, 66, 70, 72, 73, 77, 84, 85, 87, 92, 94
Bundle slipping in clamp	49, 50, 53, 55-57, 59-62, 64-69, 71, 72, 74, 76-86, 88, 91, 95	49-53, 55, 57, 59, 60-69, 71-74, 76-84, 86, 88, 91, 92
Lacing string cutting into wire	56	52, 56, 60
Torn cushion clamp	59, 72	59, 72,
Black splatter	58, 61, 62, 66, 67	49, 58, 61, 62, 66, 67, 84

*See tables C-10 and C-11 for wire types found in each bundle number.

TABLE C-8. GROUP II DRY ELECTRICAL FAILURES FOLLOWING 250 HOURS OF VIBRATION TESTING*

Bundle No.	Wire Codes	Failed Cavity	Wire Code	Single or Pair	IR (Ohms)	DWV (Pass/Fail)
60	9, 9	J1-14	9	p	678.8 m	Pass
60	9, 9	J1-15	9	p	590.4 m	Pass
60	9, 9	J1-17	9	s	819.1 m	Pass
60	9, 9	J1-18	9	s	728.3 m	Pass
60	9, 9	J1-9	9	p	6.321 m	Pass

No failures were noted after 100 hours of vibration.
*Dry electrical results are considered suspect.

TABLE C-9. GROUP II WET ELECTRICAL FAILURES FOLLOWING 250 HOURS OF VIBRATION TESTING

Bundle No.	Wire Codes	Failed Cavity	Wire Code	Single or Pair	IR (Ohms)	DWV (Pass/Fail)
49	7, 1	J1-12	1	S	976.4 m	Pass
49	7, 1	J1-14	1	P	379.5 m	Pass
49	7, 1	J1-15	1	P	189.3 m	Pass
50	10, 3	J1-18	10	S	8.6 k	Fail
50	10, 3	J1-19	10	P	6.917 k	Fail
50	10, 3	J1-20	10	P	7.289 k	Fail
60	9, 9	J1-15	9	P	738.2 m	Pass
60	9, 9	J1-9	9	P	830.6 m	Pass
63	4, 1	J1-12	1	S	398.5 m	Pass
63	4, 1	J1-14	1	P	354.4 m	Pass
63	4, 1	J1-15	1	P	428.3 m	Pass
63	4, 1	J1-5	1	P	735 m	Pass
72	1, 1	J1-17	1	S	519.7 m	Pass
72	1, 1	J1-18	1	S	998.3 m	Pass
84	9, 9	J2-12	9	S	6.372 k	Fail
84	9, 9	J2-19	9	P	5.381 k	Fail
84	9, 9	J2-5	9	P	44.48 m	Pass
95	11, 10	J2-13	10	S	814.2 km pass	Fail

For this program analysis, highlighted items are not considered failures since passed DWV.

TABLE C-10. GROUP IIF POSTTESTING VISUAL INSPECTION

Bundle No.	49	50	51	52	53	54	55	56	57	58	59	60
Wire Types	7/1	10/3	10/9	2/2	10/7	4/2	11/4	7/2	10/2	7/4	11/11	9/9
Outer Bundle Wear From:												
Plate	N/L	L/N	L/M	L/L	L/L	N/N	L/L	L/N	N/N	N/N	M/M	L/L
Clamps	N/N	S/M	N/N	M/M	N/L	L/M	L/N	L/L	L/M	N/N	L/L	L/L
Straps	L/N	M/M	L/L	M/M	M/L	N/L	L/N	L/L	L/M	L/N	L/L	L/L
String	N/N	N/N	N/N	L/L	N/N	N/N	N/N	N/M	N/N	N/N	N/N	N/N
Photos	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No
Wire Wear:												
Single/Single	N/N	L/L	N/N	M/M	N/L	N/L	N/N	L/M	N/L	N/N	N/N	M/M
Pair/Pair	L/N	L/L	N/N	M/M	N/N	N/N	N/N	L/M	N/L	N/N	N/N	M/M
Pair/Single	N/N	L/L	N/N	M/M	N/N	N/N	L/N	L/M	N/L	N/N	N/N	M/M
Photos	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
Wear on Support:												
Clamps	M	L	L	L	L	L	N	L	N	L	S	M
Straps	N	L	N	N	N	N	N	L	N	L	N	N
String	N	N	N	N	N	N	N	N	N	N	N	N
Photos	Yes	No	No	No	No	No	No	No	No	No	Yes	No

TABLE C-10. GROUP IIF POSTTESTING VISUAL INSPECTION (Continued)

Bundle No.	61	62	63	64	65	66	67	68	69	70	71	72
Wire Types	7/7	10/10	4/1	3/2	4/4	4/3	10/4	7/3	3/3	9/4	11/10	1/1
Outer Bundle Wear From:												
Plate	M/M	S/S	M/L	M/N	N/N	L/L	N/N	N/N	L/L	L/N	N/L	N/N
Clamps	L/L	N/N	N/N	N/N	N/N	N/M	L/N	N/L	N/N	N/N	N/N	N/N
Straps	L/L	L/L	N/N	L/L	N/N	N/N	L/N	L/L	N/N	N/N	N/N	N/N
String	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N
Photos	No	Yes	No	Yes	No	No	No	No	No	No	No	No
Wire Wear:												
Single/Single	N/N	N/N	N/N	L/L	N/N	N/M	N/N	N/L	L/L	N/N	N/N	N/N
Pair/Pair	N/N	N/N	N/N	M/M	N/N	N/M	N/N	N/L	L/L	L/N	L/L	N/N
Pair/Single	N/N	N/N	N/N	L/L	N/N	N/M	N/N	N/L	L/L	L/N	L/L	N/N
Photos	No	No	No	No	No	No	No	No	No	No	No	No
Wear on Support:												
Clamps	L	N	M	L	L	L	L	N	N	L	N	M
Straps	N	L	L	L	N	N	N	L	N	N	N	N
String	N	N	N	N	N	N	N	N	N	N	N	N
Photos	No	No	No	No	No	No	No	No	No	No	No	No

TABLE C-11. GROUP IIM POSTTESTING VISUAL INSPECTION

Bundle No.	73	74	75	76	77	78	79	80	81	82	83	84
Wire Types	7/1	10/3	10/9	2/2	10/7	4/2	11/4	7/2	10/2	7/4	11/11	9/9
Outer Bundle Wear From:												
Plate	L/N	L/N	N/L	N/N	L/N	N/N	N/N	N/N	M/N	N/N	M/M	L/L
Clamps	L/N	L/L	N/N	L/L	N/N	N/L	N/N	N/N	N/N	N/N	N/N	S/S
Straps	L/N	L/N	L/N	N/N	L/L	N/N	L/N	L/N	L/N	L/N	L/L	L/L
String	L/N	N/N	N/N	N/N	N/N	N/N	N/N	L/N	N/N	N/N	N/N	N/N
Metal Shavings	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N
Photos	No	No	No	No	No	No	No	No	Yes	No	Yes	Yes
Wire Wear:												
Single/Single	N/N	N/L	N/N	L/L	N/N	N/L	N/N	N/L	N/L	N/N	N/N	N/N
Pair/Pair	N/N	N/L	N/N	L/L	N/N	N/L	N/N	N/L	N/L	N/N	N/N	N/N
Pair/Single	N/N	N/L	N/N	L/L	N/N	N/L	N/N	N/L	N/L	N/N	N/N	N/N
From Shavings	L/L	N/N	N/L	L/L	L/L	N/N	L/L	N/L	N/L	L/L	N/N	L/L
Photos	No	No	No	No	No	No	No	No	No	Yes	No	No
Wear on Support:												
Clamps	M	L	L	L	L	L	L	S	L	L	N	M
Straps	L	N	N	N	L	N	L	N	N	N	L	N
String	N	N	N	N	N	N	N	N	N	N	N	N
From Shavings	N	N	N	N	N	N	N	N	N	N	N	N
Photos	No	No	No	No	No	No	No	Yes	No	No	No	No

TABLE C-11. GROUP IIM POSTTESTING VISUAL INSPECTION (Continued)

Bundle No.	85	86	87	88	89	90	91	92	93	94	95	96
Wire Types	7/7	10/10	4/1	3/2	4/4	4/3	10/4	7/3	3/3	9/4	11/10	1/1
Outer Bundle Wear From:												
Plate	L/L	N/N	N/N	N/N	N/N	N/N	N/N	M/M	M/M	L/N	N/L	N/N
Clamps	M/M	M/M	N/N	L/L	N/N	N/L	L/N	L/L	L/L	N/N	N/N	N/N
Straps	L/L	N/N	N/N	N/N	N/N	N/N	L/N	N/N	N/N	N/N	N/N	N/N
String	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N	N/N
Metal Shavings	N/N	N/N	N/L	N/N	L/L	L/L	N/N	N/N	N/N	L/N	N/N	N/N
Photos	Yes	Yes	No	No	Yes	No	No	Yes	Yes	No	No	No
Wire Wear:												
Single/Single	N/N	N/N	N/N	L/N	N/N	N/L	N/N	N/L	M/M	N/N	N/N	N/N
Pair/Pair	N/N	N/N	N/N	L/N	N/N	N/L	N/N	N/L	M/M	N/N	N/N	N/N
Pair/Single	N/N	N/N	N/N	L/N	N/N	N/L	N/N	N/L	M/M	N/N	N/N	N/N
From Shavings	L/L	L/L	L/L	L/L	N/N	L/L	N/L	L/L	N/N	L/L	L/L	L/L
Photos	No	No	No	No	No	No	No	Yes	Yes	No	No	No
Wear on Support:												
Clamps	L	L	L	L	L	L	L	L	L	L	N	N
Straps	L	N	N	N	N	L	N	N	N	N	N	N
String	N	N	N	N	N	N	N	N	N	N	N	N
From Shavings	N	N	N	N	N	N	N	N	N	L	N	N
Photos	No	No	No	No	No	No	No	No	No	No	No	No

TABLE C-12. GROUP II SUMMARY OF RESULTS BY WIRE TYPE

Wire Code 1				Group IIF Fluid						Group IIM Metal					
With Code	Clamp Diameter	Bundle Diameter	Diameter Difference	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1	0.438	0.42	0.018	72	N		Y	N	N	96	N,L		N	N	N
2															
3															
4	0.375	0.35	0.025	63	N		N	N	L	87	N,L		N	N	N
5	0.375	0.336	0.039												
6															
7	0.438	0.414	0.024	49	N		Y	N	L	73	N,L		N	N	N
9	0.5	0.445	0.055												
10															
11															

Wire Code 2				Group IIF Fluid						Group IIM Metal					
With Code	Clamp Diameter	Bundle Diameter	Diameter Difference	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1															
2	0.313	0.263	0.05	52	M		N	M	L	76	L		Y	L	N
3	0.313	0.26	0.053	64	L,M		Y	N	N	88	N,L		Y	L	N
4	0.313	0.272	0.041	54	N,L		N	M	N	78	L,N		Y	L	N
5	0.313	0.258	0.055												
6	0.313	0.3	0.013												
7	0.375	0.336	0.039	56	M		Y	L	N	80	L		Y	N	N
9	0.375	0.367	0.008												
10	0.313	0.258	0.055	57	L		Y	M	N	81	L		Y	N	N
11	0.313	0.258	0.055												

Key:

N = No   N = None   M = Moderate

Y = Yes   L = Low   S = Severe

TABLE C-12. GROUP II SUMMARY OF RESULTS BY WIRE TYPE (Continued)

Wire Code 3

				Group IIF Fluid						Group IIM Metal					
With Code	Clamp Diameter	Bundle Diameter	Diameter Difference	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1															
2				64	L,M		Y	N	M	88	L		Y	L	N
3	0.313	0.258	0.055	69	L,M		Y	N	L	93	M		N	L	M
4	0.313	0.269	0.044	66	M		Y	M	L	90	L		N	L	N
5	0.313	0.255	0.058												
6	0.313	0.297	0.016												
7	0.375	0.333	0.042	68	L		Y	L	N	92	L		N	L	M
9	0.375	0.364	0.011												
10	0.375	0.375	0	50	L		Y	M	N	74	L		Y	L	N
11	0.313	0.255	0.058												

Wire Code 4

				Group IIF Fluid						Group IIM Metal					
With Code	Clamp Diameter	Bundle Diameter	Diameter Difference	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1				63	N		N	N	M	87	N,L		N	N	N
2				54	N		N	L	N	78	N		Y	N	N
3				66	N		Y	N	L	90	N,L		N	N	N
4	0.313	0.28	0.033	65	N		Y	N	N	89	N		N	N	N
5	0.313	0.266	0.047												
6															
7	0.438	0.394	0.044	58	N		N	N	N	82	N,L		Y	N	N
9	0.375	0.375	0	70	N		N	N	N	94	N,L		N	N	N
10	0.313	0.266	0.047	67	N		Y	N	N	91	L		Y	N	N
11	0.313	0.266	0.047	55	N		Y	N	L	79	L		Y	N	N

Key:
N = No　　N = None　　M = Moderate
Y = Yes　　L = Low　　S = Severe

TABLE C-12. GROUP II SUMMARY OF RESULTS BY WIRE TYPE (Continued)

Wire Code 7

				Group IIF Fluid						Group IIM Metal					
With Code	Clamp Diameter	Bundle Diameter	Diameter Difference	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1				49	N,L		Y	N	N	73	N,L		N	L	L
2				56	L		Y	L	L	80	N		Y	N	N
3				68	N		Y	N	N	92	N,L		N	L	M
4				58	N		N	N	N	82	N,L		Y	N	N
5															
6															
7	0.438	0.409	0.029	61	N		Y	L	M	85	N,L		Y	M	L
9	0.5	0.44	0.06												
10	0.375	0.331	0.044	53	N,L		Y	L	L	77	N,L		Y	N	N
11	0.375	0.331	0.044												

Wire Code 9

				Group IIF Fluid						Group IIM Metal					
With Code	Clamp Diameter	Bundle Diameter	Diameter Difference	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1															
2															
3															
4				70	L,N		N	N	L	94	N,L		N	N	L
5															
6															
7															
9	0.5	0.47	0.03	60	M		Y	L	L	84	N,L	2	Y	S	L
10	0.375	0.361	0.014	51	N		N	N	M	75	N,L		N	N	L
11	0.375	0.361	0.014												

Key:
N = No   N = None   M = Moderate
Y = Yes   L = Low   S = Severe

TABLE C-12. GROUP II SUMMARY OF RESULTS BY WIRE TYPE (Continued)

Wire Code 10

				Group IIF Fluid						Group IIM Metal					
With Code	Clamp Diameter	Bundle Diameter	Diameter Difference	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1															
2				57	N		Y	L	N	81	N		Y	N	M
3				50	L	3	Y	S	L	74	N		Y	L	L
4				67	N		Y	L	N	91	N		Y	L	N
5															
6															
7				53	N		Y	N	L	77	N,L		Y	N	L
9				51	N		N	N	L	75	N		N	N	N
10	0.313	0.252	0.061	62	N		Y	N	S	86	N,L		Y	M	N
11	0.313	0.252	0.061	71	L,N		Y	N	L	95	N,L	1	Y	N	L

Wire Code 11

				Group IIF Fluid						Group IIM Metal					
With Code	Clamp Diameter	Bundle Diameter	Diameter Difference	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate	Bundle	Wear From Wire	DWV, No. Failed	Slip at 100 Hrs?	Wear From Clamps	Wear From Plate
1															
2															
3															
4				55	N,L		Y	L	L	79	L		Y	N	N
5															
6															
7															
9															
10				71	L,N		Y	N	N	95	N,L		Y	N	N
11	0.313	0.252	0.061	59	N		Y	N	M	83	N		Y	N	M

Key:

N = No N = None M = Moderate
Y = Yes L = Low S = Severe

TABLE C-13. WIRE CRUSH TEST RESULTS

Load Applied (lb)	Top Wire Code	Bottom Wire Code	Wire Code Most Damaged	Wire Damage Rating	
				Top	Bottom
80	7	4	7	1	1
120			7	2	1
80	1	7	7	0	1
120			7	0	2
80	3	10	3	1	1
120			3	2	1
80	9	10	10	0	1
120			10	0	1
80	2	2	B2	1	1
120			B2	1	1
80	10	7	7	0	2
120			7	1	2
80	4	2	4	1	0
120			4	2	1
80	11	4	4	1	1
120			4	1	2
80	7	2	7	2	0
120			7	2	0
80	10	2	10	1	1
120			10	2	1
80	11	11		2	2
120				2	2
80	9	9		0	1
120			T9	0	1
80	7	7		1	1
120				1	1
80	10	10		1	1
120				2	2
80	4	1	4	1	0
120			4	1	1
80	3	2	3	2	0
120			3	2	1
80	4	4		1	1
120				1	1
80	4	3	3	1	1
120			3	1	2
80	10	4	4	1	1
120			4	1	1

TABLE C-13. WIRE CRUSH TEST RESULTS (Continued)

Load Applied (lb)	Top Wire Code	Bottom Wire Code	Wire Code Most Damaged	Wire Damage Rating	
				Top	Bottom
80	7	3	7	1	1
120			7	2	1
80	3	3		1	1
120				2	2
80	9	4	4	0	1
120			4	1	2
80	11	10	11	2	2
120			11	2	2
80	1	1		1	1
120				1	1

* Wire Damage Ratings

0 – No damage
1 – Partially through insulation
2 – Completely through insulation to conductor
3 – Through conductor

APPENDIX D—ADDITIONAL PHOTOGRAPHIC DOCUMENTATION

FIGURE D-1. SEVERE WIRE WEAR FROM CLAMP IN GROUP I PTFE WIRE NONMIXED BUNDLE

FIGURE D-2. SEVERE WEAR OF PTFE AND PTFE/GLASS WIRES FROM CLAMP IN GROUP I

FIGURE D-3. SEVERE WEAR OF PTFE/GLASS WIRE FROM CLAMP IN NONMIXED GROUP I BUNDLE

FIGURE D-4. SEVERE WEAR OF MF-PTFE WIRE FROM CLAMP IN GROUP I NONMIXED BUNDLE

FIGURE D-5. SEVERE WEAR OF PTFE/GLASS AND MF-PTFE WIRES FROM CLAMP IN GROUP I

FIGURE D-6. MODERATE WEAR OF PI/PTFE ALLOY FROM CLAMP IN GROUP I NONMIXED BUNDLE

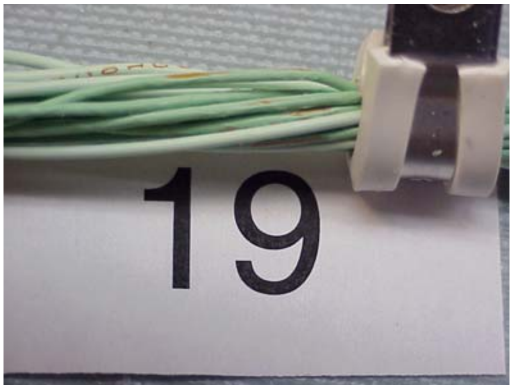

FIGURE D-7. MODERATE WEAR OF PI/PTFE ALLOY FROM CLAMP WHEN MIXED WITH XLETFE IN GROUP I

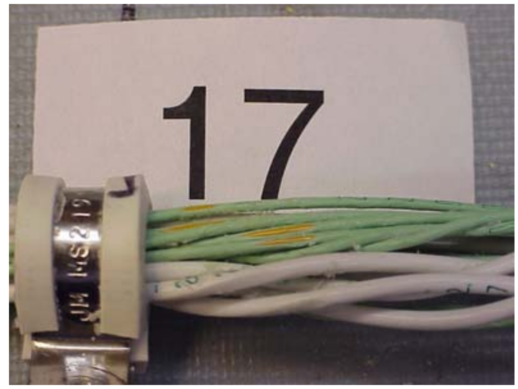

FIGURE D-8. MODERATE WEAR OF PI/PTFE FROM CLAMP IN GROUP I BUNDLE MIXED WITH MF-PTFE

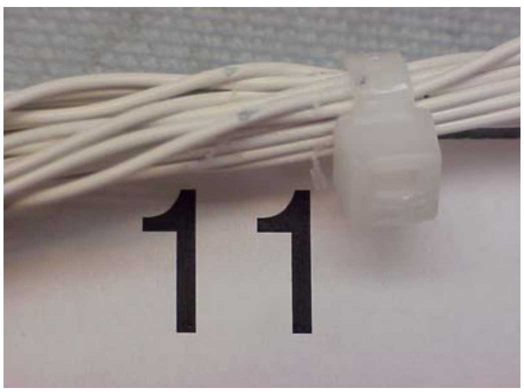

FIGURE D-9. SEVERE WEAR OF XLETFE ALLOY WIRE FROM PLATE IN GROUP I NONMIXED BUNDLE

FIGURE D-10. MODERATE WIRE-TO-WIRE WEAR ON XPI WIRE WHEN MIXED WITH XLETFE GROUP IIF BUNDLE

FIGURE D-11. MODERATE WIRE-TO-WIRE WEAR ON PTFE/GLASS IN NONMIXED GROUP IIF BUNDLE

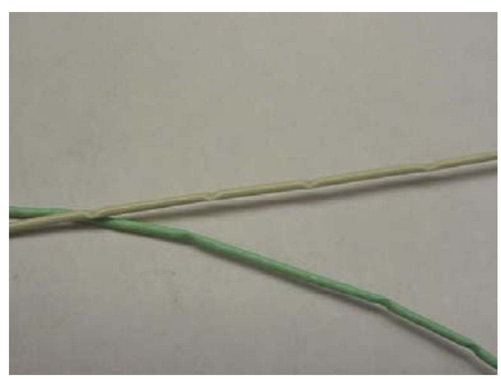

FIGURE D-12. XPI WIRE DAMAGED FROM PI/PTFE WIRE IN THE 80-POUND CRUSH TEST

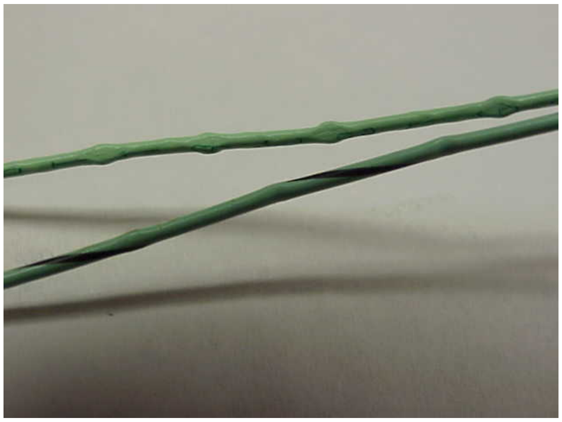

FIGURE D-13. PI/PTFE WIRE DAMAGED FROM PI WIRE IN THE 80-POUND CRUSH TEST

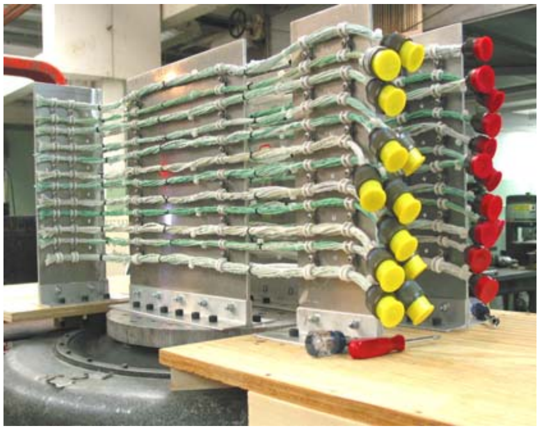

FIGURE D-14. TEST BUNDLES MOUNTED ON VIBRATION FIXTURES

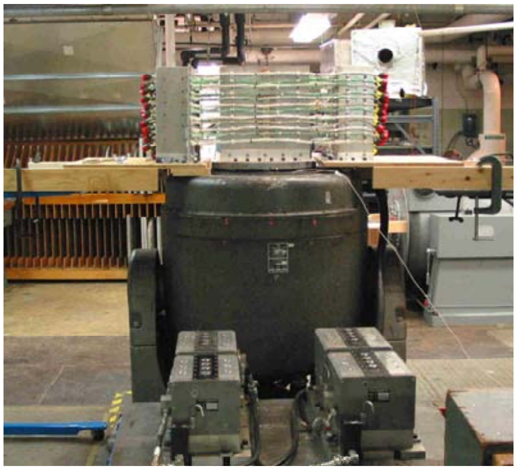

FIGURE D-15. FIXTURES MOUNTED ON VIBRATION TABLE