The following is the final report associated with "Harness Testing Technical Proposal", submitted on March 3, 2008 to InterConnect Wiring, L.P. Attn. Mr. John Ashour.

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DRAFT

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July 29, 2008
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Executive Summary:

Lectromec tested 35 electrical wire harnesses from an F-16 aircraft supplied by InterConnect Wiring. These harnesses were analyzed using the Lectromec DelTest™ and the inherent viscosity tests to evaluate the condition of the wire insulation. The DelTest found 40 failures in the supplied harnesses corresponding to a failure rate of 4.5 breaches per 1000 feet of wire; more than 3 times the number found during similar tests on aged (< 20 year old) commercial aircraft. The number of breaches per thousand feet for this aircraft was lower than the results of similar testing performed for InterConnect Wiring in 2006 in which a failure rate of 5.4 breaches per thousand feet was found. Several of the failed harnesses were taken apart and numerous incidences of multiple wire failures in a single location were found. The inherent viscosity was measured for twenty-seven wire samples from different zones and the results indicated that a majority close to or were at the end of their useful life. In other locations the findings suggested that there is not an overall concern with the insulation. A comparison with the 2006 results gave good agreement in certain zones.

Introduction

This report is for the testing of 35 Electrical wire harnesses that were removed from an F-16 aircraft by InterConnect Wiring. There were two types of testing performed on the wire harnesses: a laboratory DelTest™ and an inherent viscosity test.

- The laboratory DelTest™ detects breaches in the wire insulation that reach the conductor. It is a snapshot of the harness condition on the day it was removed from the airplane. Lectromec performed a DelTest™ on all wires from each of the 35 harnesses taken from the F-16. The DelTest™ process tests wires to within 1-3 inch of the connector back shell, though it does not test inside the connectors. The DelTest™ was done without removing the Nomex™ braid. On a representative number of DelTest™ failure indications from the water bath test, Lectromec located and photographed a number of insulation breaches. More information on the DelTest™ is found in Appendix A.

- The inherent viscosity test measures the molecular weight of the polyimide film that is the primary insulation of the wire. This measurement is related to the elongation and other physical characteristics of the film. Inherent viscosity detects changes in the film due to environmental aging of the wire. Lectromec performed 27 inherent viscosity measurements. The inherent viscosity test requires a small sample of wire (~6 inches) and is a destructive on the polyimide (Kapton) tape. More information on the Inherent Viscosity is found in Appendix B.

DelTest Results

The results of the DelTest are broken down according to harness. Those wires that indicated failure were double-checked by matching the failures at both termination points. Wires in which a failure was indicated but that also were connected to a splice were removed because it was assumed that the failure occurred at the splice and differentiating between a splice and a wire failure is excessively time consuming.

Table 1. DelTest results for 35 Harnesses

ID	Zones	Mfr Date	Previously Tested	# Wires	# Feet	Wire Breaches	Failures /1000ft
651-27	CENTER FUSELAGE	6/1/1987	Yes	71	364.0	2	5.5
652-27	CENTER FUSELAGE	6/1/1987	Yes	69	396.4	1	2.5
653-27	CENTER FUSELAGE	6/1/1987	Yes	61	284.0	2	7.0
654-26	CENTER FUSELAGE	6/1/1987	Yes	72	304.5	1	3.3
656-01	CENTER FUSELAGE	6/1/1987	Yes	63	89.2	0	0.0
657-02	CENTER FUSELAGE	6/1/1987	Yes	17	27.9	0	0.0
661-22	MLG WHEEL WELL	6/1/1987	Yes	49	202.8	0	0.0
663-21	CENTER FUSELAGE	6/1/1987	Yes	48	233.0	0	0.0
668-44	CENTER FUSELAGE	6/1/1987	Yes	93	838.7	0	0.0
669-25	CENTER FUSELAGE	6/1/1987	Yes	41	311.5	6	19.3
677-26	MLG WHEEL WELL	6/1/1987	Yes	69	378.5	3	7.9
678-32	MLG WHEEL WELL	6/1/1987	Yes	59	411.7	0	0.0
681-26	CENTER FUSELAGE	6/1/1987	Yes	31	137.6	0	0.0
683-22	CENTER FUSELAGE	6/1/1987	Yes	3	20.3	0	0.0
684-22	CENTER FUSELAGE	6/1/1987	Yes	3	9.3	0	0.0
685-23	MLG WHEEL WELL	6/1/1987	Yes	4	23.2	1	43.2
692-20	NOSE LANDING GEAR	6/1/1987	Yes	7	9.5	0	0.0
693-21	NOSE LANDING GEAR	6/1/1987	Yes	12	33.0	0	0.0
696-21	MLG WHEEL WELL	6/1/1987	Yes	2	17.5	1	57.1
696-21	MLG WHEEL WELL	6/1/1987	Yes	2	17.5	2	114.3
698-23	AERIAL REFUELINNG CAVITY	6/1/1987	Yes	69	248.2	0	0.0
735-20	AFT FUSELAGE TANK	6/1/1987	Yes	6	13.5	0	0.0
736-24	AFT FUSELAGE TANK	6/1/1987	Yes	30	75.3	0	0.0
771-516	ENGINE BAY	6/1/1987	No	70	295.1	3	10.2
781-52	AFT FUSELAGE ENGINE AREA	6/1/1987	Yes	20	6.7	0	0.0
782-512	AFT FUSELAGE ENGINE AREA	6/1/1987	Yes	64	182.6	7	38.3
783-517	AFT FUSELAGE ENGINE AREA	6/1/1987	Yes	41	209.2	1	4.8
784-20	AFT FUSELAGE ENGINE AREA	6/1/1987	Yes	39	270.2	1	3.7
1523-01	COCKPIT	6/1/1987	Yes	35	77.5	0	0.0
2601-21	MLG WHEEL WELL	6/1/1987	Yes	134	1430.3	4	2.8
2603-08	CENTER FUSELAGE	6/1/1987	Yes	39	339.3	2	5.9
2604-06	MLG WHEEL WELL	6/1/1987	Yes	41	387.9	2	5.2
2606-08	CENTER FUSELAGE	6/1/1987	Yes	60	231.5	0	0.0
2609-37	MID FUSELAGE	6/1/1987	Yes	119	705.3	1	1.4
2610-08	CENTER FUSELAGE	6/1/1987	Yes	53	260.6	0	0.0
Total					8842.9	40.0	4.5

These failure rates are based upon the cut lengths for the wires supplied to Lectromec by InterConnect. In practice, the actual wire lengths have been found to be shorter than the cut lengths, as was confirmed on a number of wires. The lengths provided by InterConnect were used as they were the only available length determinations. As such, the reported failure rates are actually lower than the ‘exact’ results. Further, given that identification of multiple breaches for a given wire was not possible with the DelTest™ but was seen during the visual inspections of harnesses the 4.5 breaches per 1000 feet could be lower than the ‘exact’ results.

Figure 1. Harness H16DW685-9155. Breach of wire insulation down to the conductor.

Figure 1 and Figure 2 show examples of the types of failures found with the DelTest. In the case of the failure found in Figure 2, it shows that there was an additional breach in the same wire less than one centimeter from the wire failure seen in.

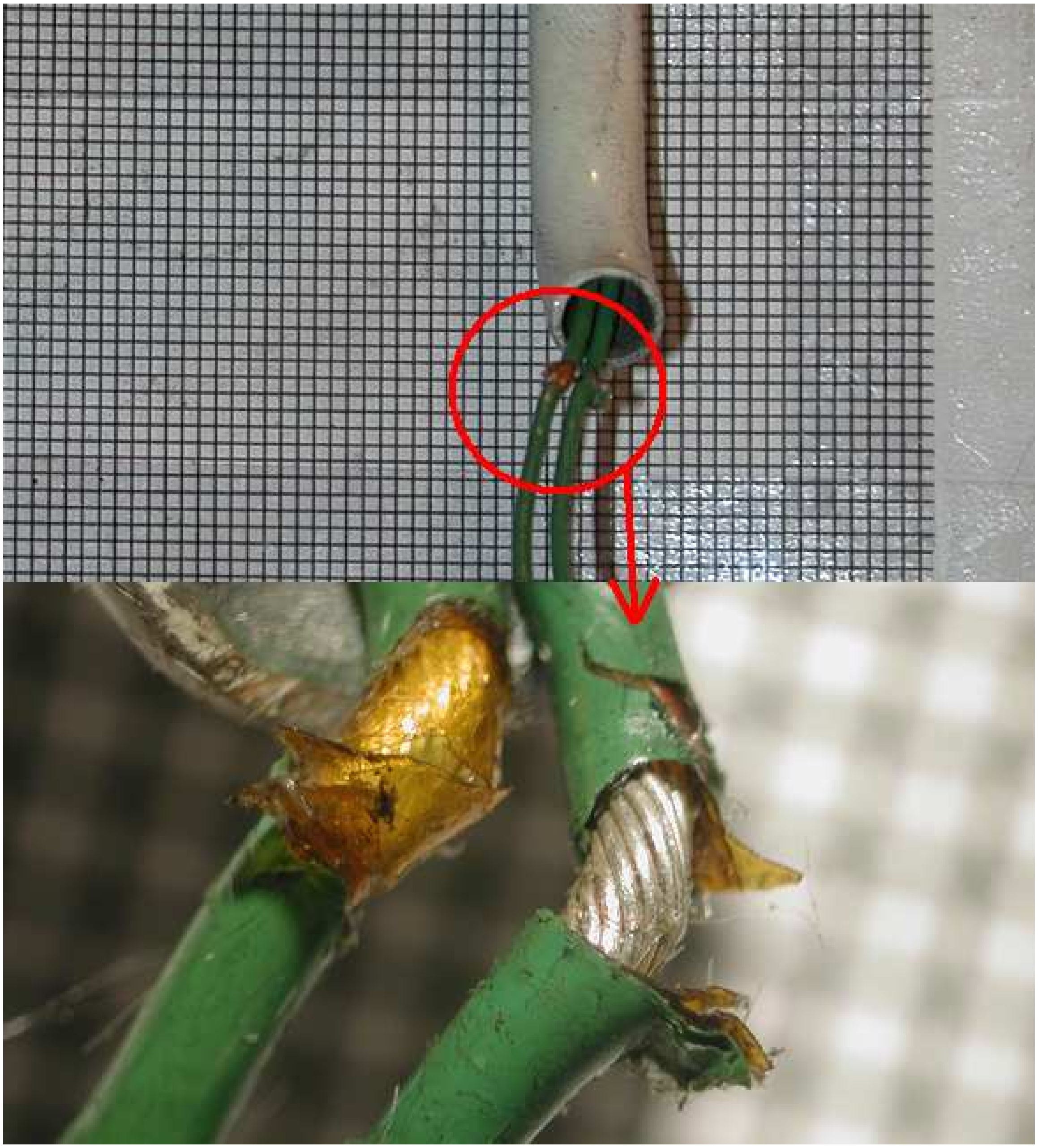


Figure 2. Harness H16DW696, two wires coming out of a conduit with breaks in the insulation at the same location. The grid size in the figures is 1mm x 1mm.

These visual inspections of the harnesses were performed on a select number of harnesses to verify the results gathered by the DelTest. Of the 32 failures over seven harnesses that were inspected visually to confirm recorded wire failures, all 32 were verified. Additional wire failure photos can be seen in Appendix C.

Failures by Zone

The following is the breakdown of the wire failures by the zones from which the harnesses were taken.

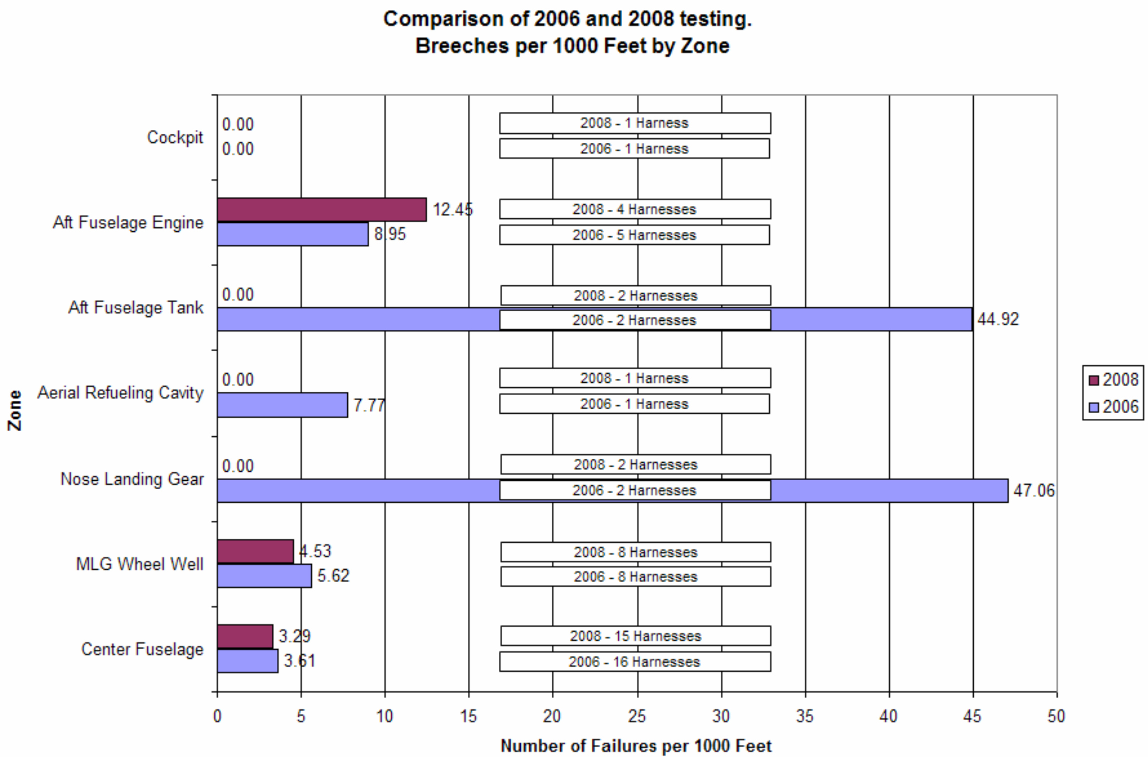


Figure 3. Comparison of DelTest 2006 and 2008. Breaches per 1000 Feet reported by zone.

Table 2. Breakdown of wire failures per zone for testing in 2006 and 2008.

	2006					2008				
Zone	Breeches	# Wires	Number of Harnesses	Total Wire Length	Breeches per 1000ft	Breeches	# Wires	Number of Harnesses	Total Wire Length	Breeches per 1000ft
Center Fuselage	20	745	16	5542.2	3.6	15	724	15	4,552.9	3.3
MLG Wheel Well	20	331	8	3557	5.6	13	360	8	2,869.4	4.5
Nose Landing Gear	2	18	2	42.5	**47.1**	0	19	2	42.5	**0.0**
Aerial Refueling Cavity	2	61	1	257.5	**7.8**	0	69	1	248.2	**0.0**
Aft Fuselage Tank	5	36	2	111.3	**44.9**	0	36	2	88.8	**0.0**
Aft Fuselage Engine	9	186	5	1005.4	9.0	12	164	4	963.7	12.5
Cockpit	0	29	1	151.2	0.0	0	35	1	77.5	0.0

The greatest variation seen between the 2006 and 2008 testing was in the Nose Landing Gear, Aerial Refueling Cavity and Aft Fuselage Tank. No wire breaches were found in any of these harnesses, whereas failures were found in previous testing (Table 2 and Figure 3). Given the limited number of wires in these harnesses, failure of any wire would show a significantly higher rate of failure (e.g. the Nose Landing Gear zone in the 2006 tests had only two failures, but, because of only 42feet of wire in the harnesses, exceptionally high rate was found). In comparing the results of the two zones from which most of the harnesses came (the center fuselage and main landing gear wheel well), the failure rates are comparable, though in both zones, the harnesses from 2008 testing showed a reduced failure rate. The only zone to show an increase in the number of failures was the Aft Fuselage Engine Area which showed an increase from 9.0 failures/1000ft in 2006 to 12.5 failures/1000ft.

<u>Failures Comparison</u>

The following is the comparison of wire failures for similar harnesses tested by in 2006 and in 2008.

Table 3. Harness 2713-507 (2006), Harness 695-21 (2006), and Harness 771-516 (2008) are omitted from this table because these harnesses were not found during both periods of testing. The shipping list in 2008 listed 695-21 as an included harness to be tested, although upon inspection of the actual harness ID, it also read as 696-21 and was from then on referenced as Harness 696-21b

2006					**2008**				
Harness ID	Wire Breaches	# Wires	# Feet	Breaches per 1000'	Harness ID	Wire Breaches	# Wires	# Feet	Breaches per 1000'
651-23	0	71	548.5	0.0	**651-27**	2	71	364.0	**5.5**
652-23	1	69	600.9	1.7	**652-27**	1	69	396.4	**2.5**
653-23	1	61	443.5	2.3	**653-27**	2	61	284.0	**7.0**
654-21	0	61	405.5	0.0	**654-26**	1	72	304.5	**3.3**
656-01	1	39	106.2	9.4	**656-01**	0	63	89.2	**0.0**
657-02	0	11	27.9	0.0	**657-02**	0	17	27.9	**0.0**
661-22	0	39	465.8	0.0	**661-22**	0	49	202.8	**0.0**
663-21	1	48	233.0	4.3	**663-21**	0	48	233.0	**0.0**
668-529	3	85	998.8	3.0	**668-44**	0	93	838.7	**0.0**
669-23	4	38	329.7	12.1	**669-25**	6	41	311.5	**19.3**
677-26	2	51	466.7	4.3	**677-26**	3	69	378.5	**7.9**
678-30	1	58	617.5	1.6	**678-32**	0	59	411.7	**0.0**
681-26	0	13	107.4	0.0	**681-26**	0	31	137.6	**0.0**
683-22	0	3	60.8	0.0	**683-22**	0	3	20.3	**0.0**
684-22	0	3	27.8	0.0	**684-22**	0	3	9.3	**0.0**
685-21	1	4	34.8	28.7	**685-23**	1	4	23.2	**43.2**
692-20	0	6	9.5	0.0	**692-20**	0	7	9.5	**0.0**
693-21	2	12	33.0	60.6	**693-21**	0	12	33.0	**0.0**
696-21	2	2	17.5	114.3	**696-21**	1	2	17.5	**57.1**
					696-21	2	2	17.5	**114.3**
698-502	2	61	257.5	7.8	**698-23**	0	69	248.2	**0.0**
735-20	0	6	21.0	0.0	**735-20**	0	6	13.5	**0.0**
736-24	5	30	90.3	55.4	**736-24**	0	30	75.3	**0.0**
781-502	3	15	20.0	150.0	**781-52**	0	20	6.7	**0.0**
782-512	4	56	230.1	17.4	**782-512**	7	64	182.6	**38.3**
783-601	0	23	230.0	0.0	**783-517**	1	41	209.2	**4.8**
784-604	1	31	386.8	2.6	**784-20**	1	39	270.2	**3.7**
1523-01	0	29	151.2	0.0	**1523-01**	0	35	77.5	**0.0**
2601-16	8	134	1491.7	5.4	**2601-21**	4	134	1430.3	**2.8**
2603-04	6	39	339.3	17.7	**2603-08**	2	39	339.3	**5.9**
2604-502	4	41	447.2	8.9	**2604-06**	2	41	387.9	**5.2**
2606-07	2	34	227.9	8.8	**2606-08**	0	60	231.5	**0.0**
2609-521	0	119	705.3	0.0	**2609-37**	1	119	705.3	**1.4**
2610-502	1	51	379.8	2.6	**2610-08**	0	53	260.6	**0.0**

Inherent Viscosity Results

Table 4 is a summary of the inherent viscosity determinations in this study. The zones where the wires are located in the aircraft are included in the table. There is a range of inherent viscosity values from about 0.8 to 1.8 g/dl. Current values from recently produced wire are around 1.35 g/dl or larger. However, some older unstressed wires that have been kept in storage were observed to have values of approximately 1.2 g/dl. Some aging of these wires with storage cannot be ruled out. With several wires that have been artificially aged to failure by dielectric withstand voltage and similar tests, Lectromec has found inherent viscosity values in the 0.9 to 1.0 g/dl range. These observations have been with several different wires of varying starting ages for the determinations. It should be noted that duPont has used an inherent viscosity value of approximately 0.9 g/dl as a cut-off line for acceptance of PMDA-ODA. Any values below this number have been deemed unacceptable for insulation purposes. This has been based on tensile strength measurements plotted against inherent viscosity. Thus, from the findings of the inherent viscosity, there are some of the F-16 PMDA-ODA (Kapton®) insulated wires that have reached about their life's end.

Table 4. Results for the inherent viscosity determinations are given grouped by harness and wire.

Harness #	Wire #	Inherent Viscosity $(\eta)_{inh}$	Gauge	Zone
661	8	1.09	22	MLG Wheel Well
661	10	1.07	22	MLG Wheel Well
661	11	1.07	22	MLG Wheel Well
685	1	0.82	10	MLG Wheel Well
698	32	1.65	22	Aerial Refueling Cavity
698	42	1.64	22	Aerial Refueling Cavity
735	3	1.30	22	Aft Fuselage Tank
735	4	1.17	22	Aft Fuselage Tank
736	1	0.89	20	Aft Fuselage Tank
736	9	1.00	22	Aft Fuselage Tank
782	19	1.40	20	MLG Wheel Well
782	20	1.37	20	MLG Wheel Well
782	21	1.38	20	MLG Wheel Well
783	9	0.99	20	MLG Wheel Well
783	14	1.41	20	MLG Wheel Well
783	18	0.98	20	MLG Wheel Well
1523	206	1.78	22	Cockpit
1523	203 2791 P1 Pin 7	1.86	22	Cockpit
1523	203 2791 P1 Pin 8	1.82	22	Cockpit
2601	8	1.11	22	MLG Wheel Well
2601	34	1.08	22	MLG Wheel Well
2601	104	1.22	22	MLG Wheel Well
2603	10	1.09	22	Center Fuselage
2603	56	1.11	22	Center Fuselage
2609	48	1.07	20	Center Fuselage
2609	82	1.05	20	Center Fuselage
2609	164	1.05	20	Center Fuselage

The wires with higher values, i.e., about 1.1 or higher appear to still have some useful life. However, without adequate baseline values from the starting wires, it is almost impossible to make any sort of lifetime estimate. The reproducibility between analyses from the same wire is about 0.04 g/dl; this is based on previous results. There is another difficulty, i.e., we do not know if all of the wires examined are from the same lot of starting PMDA-ODA or even from the same manufacturer.

The wires from harness 661 show significant aging. The wire from harness 685 (the only power wire tested in this investigation) has very low value. This is consistent with the observation that this wire had failed. The values from the wires in harness 698 have values that are quite high. This suggests that they may be relatively new. Another possibility is that they had an even higher initial value and have degraded slightly. This point will be considered below also.

In harness 735 the wires appear to be relatively good condition. This cannot be said for those in harness 736, since they have reached their end-of-life when compared with earlier findings. The wires from harness 782 seem to be good condition and do not have any immediate life concerns. The results for the wires from harness 783 are inconsistent; two of the wires are in the range of failed wires. However, the third is in an acceptable range. There is not an easy explanation for these observations.

The inherent viscosity values measured for the wires in harness 1523 are the highest that have been found at Lectromec, even for new wire. These wires may have been produced quite a while ago when the manufacturing processes were not as good as those with more currently produced material. It would not be unexpected that better processes and more pure starting materials are currently in use that yield more consistent PMDA-ODA than previously produced. Some of the early inherent viscosity results from duPont for experimental PMDA-ODA had even higher inherent viscosity values than these wires tested. This may account also for the determinations with the wires in harness 698 discussed above.

The determinations for the inherent viscosity with the wires in harnesses 2601, 2603, and 2609 are near the values that suggest significant aging.

A comparison with the earlier investigation for some of the wires is given in Table 5. It was not possible to perform the comparison with all of the wires analyzed in this investigation with those studied previously. Initially, these comparisons would be expected to yield very similar results; however, different sources, maintenance, etc. could account for the observations where large variations were found.

The values for the wires in harnesses 661 and 685 are in reasonable agreement. This is especially true for the power wire in harness 685. The values for the wires in harnesses 698 and 782 in the current study are much larger than the previous determinations. The reason for this variation may be due to reasons given above. The observations for the wires in harness 783 do not have a pattern. The results from this study show that two of the wires have a significant decrease compared to those from the 2006 study.

Table 5. A comparison of inherent viscosity values from 2006 and 2008 determinations.

Harness #	Wire #	Inherent Viscosity $(\eta)_{inh}$ 2006	Inherent Viscosity $(\eta)_{inh}$ 2008	Zone
661	8	0.90	1.09	MLG Wheel Well
661	10	1.05	1.07	MLG Wheel Well
661	11	0.97	1.07	MLG Wheel Well
685	1	0.84	0.82	MLG Wheel Well
698	32	1.04	1.65	Aerial Refueling Cavity
698	42	1.19	1.64	Aerial Refueling Cavity
782	19	0.94	1.40	MLG Wheel Well
782	20	1.20	1.37	MLG Wheel Well
782	21	1.08	1.38	MLG Wheel Well
783	9	1.18	0.99	MLG Wheel Well
783	14	1.27	1.41	MLG Wheel Well
783	18	1.17	0.98	MLG Wheel Well
1523	203-1	1.08	1.82	Cockpit
1523	203-2	1.09	1.86	Cockpit
1523	206-1	1.10	1.78	Cockpit
2609	48	1.21	1.07	Center Fuselage
2609	164	1.26	1.05	Center Fuselage

However, one of the current values is larger than any of the results from the earlier determinations.

The results for the wires in harness 1523 give the greatest contrast with the values from each year internally being very consistent. The reasons for the differences were suggested above.

The determinations for the wires in the 2006 investigation for harness 2609 wires were somewhat higher than those found this year. However, the difference was not extremely large.

In Table 6 the data are sorted by the inherent viscosity values. There do not appear to be any major trends. A majority of the wires have inherent viscosity values of 1.1 g/dl or less. Many of the determinations suggest that these wires have aged significantly. Generally, the wheel well does appear to have lower inherent viscosity values.

Table 6. Finding sorted by inherent viscosity values.

Harness #	Wire #	Inherent Viscosity $(\eta)_{inh}$	Zone
685	1	0.82	MLG Wheel Well
736	1	0.89	Aft Fuselage Tank
783	18	0.98	MLG Wheel Well
783	9	0.99	MLG Wheel Well
736	9	1.00	Aft Fuselage Tank
2609	164	1.05	Center Fuselage
2609	82	1.05	Center Fuselage
2609	48	1.07	Center Fuselage
661	11	1.07	MLG Wheel Well
661	10	1.07	MLG Wheel Well
2601	34	1.08	MLG Wheel Well
2603	10	1.09	Center Fuselage
661	8	1.09	MLG Wheel Well
2603	56	1.11	Center Fuselage
2601	8	1.11	MLG Wheel Well
735	4	1.17	Aft Fuselage Tank
2601	104	1.22	MLG Wheel Well
735	3	1.30	Aft Fuselage Tank
782	20	1.37	MLG Wheel Well
782	21	1.38	MLG Wheel Well
782	19	1.40	MLG Wheel Well
783	14	1.41	MLG Wheel Well
698	42	1.64	Aerial Refueling Cavity
698	32	1.65	Aerial Refueling Cavity
1523	206	1.78	Cockpit
1523	203 2791 P1 Pin 8	1.82	Cockpit
1523	203 2791 P1 Pin 7	1.86	Cockpit

This is not unexpected, since the wheel well zone of an aircraft experiences a greater environmental exposure than other locations. The exception to this general observation is with harness 782 and one wire in harness 783.

The findings for the Central Fuselage also imply that these wires are close to the end of their lifetime.

The wires in harnesses 698 and 1523, the Aerial refueling cavity and cockpit, respectively, have values that indicate that there is not any immediate concern for these wires. The values for the cockpit are not surprising, since this zone probably experiences the least environmental challenge in the aircraft. However, this does not explain why there were relatively low values for the wires tested in 2006 from this location. There does not appear to be any trend for the wires located in the aft fuselage tank.

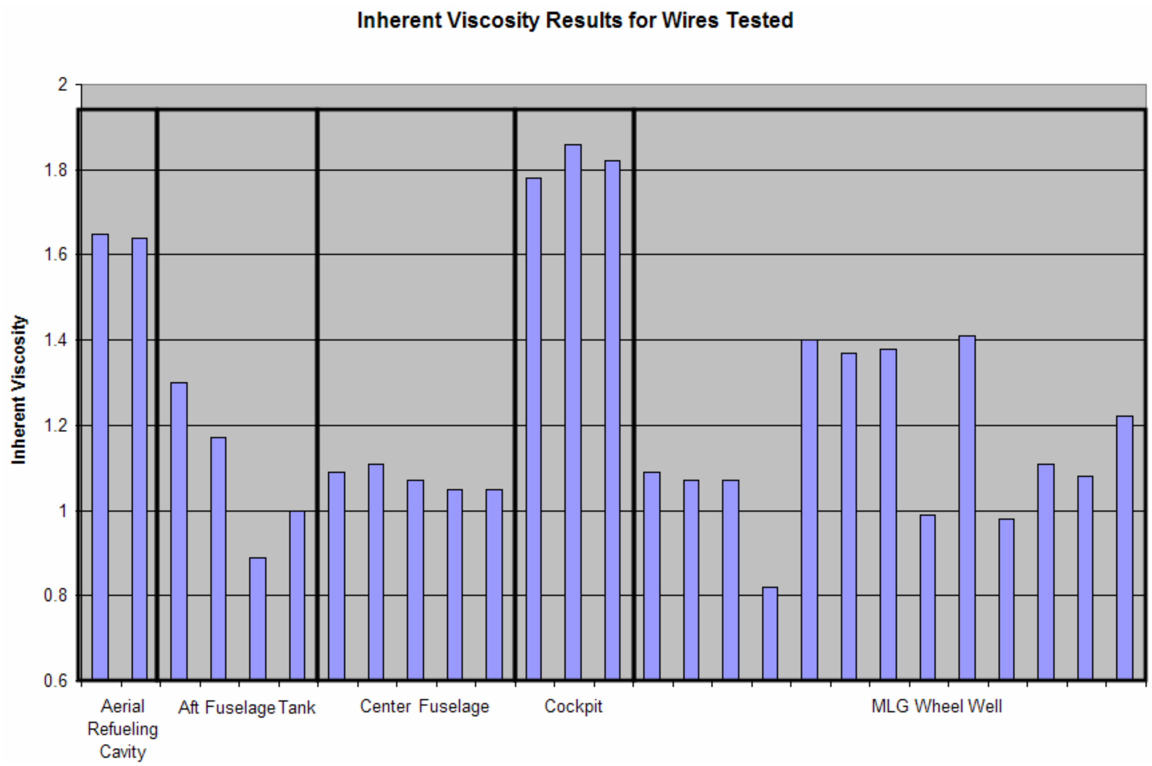


Figure 4. Inherent Viscosity results broken down by zone.

It has to be remembered that the inherent viscosity measurements are for a small part (about 12 inches or 30 cm or less) of a wire. If a wire goes between areas where there is a large environmental change, e.g., temperature, then where the sample is taken may have an effect of the results. If a wire has been mishandled during aircraft manufacture or subsequent maintenance in a small, specific location, the overall material properties of the material will not be changed. With such a case, a material test such inherent viscosity will not reveal the wire's problem. This type of test gives an overall picture of the insulation material.

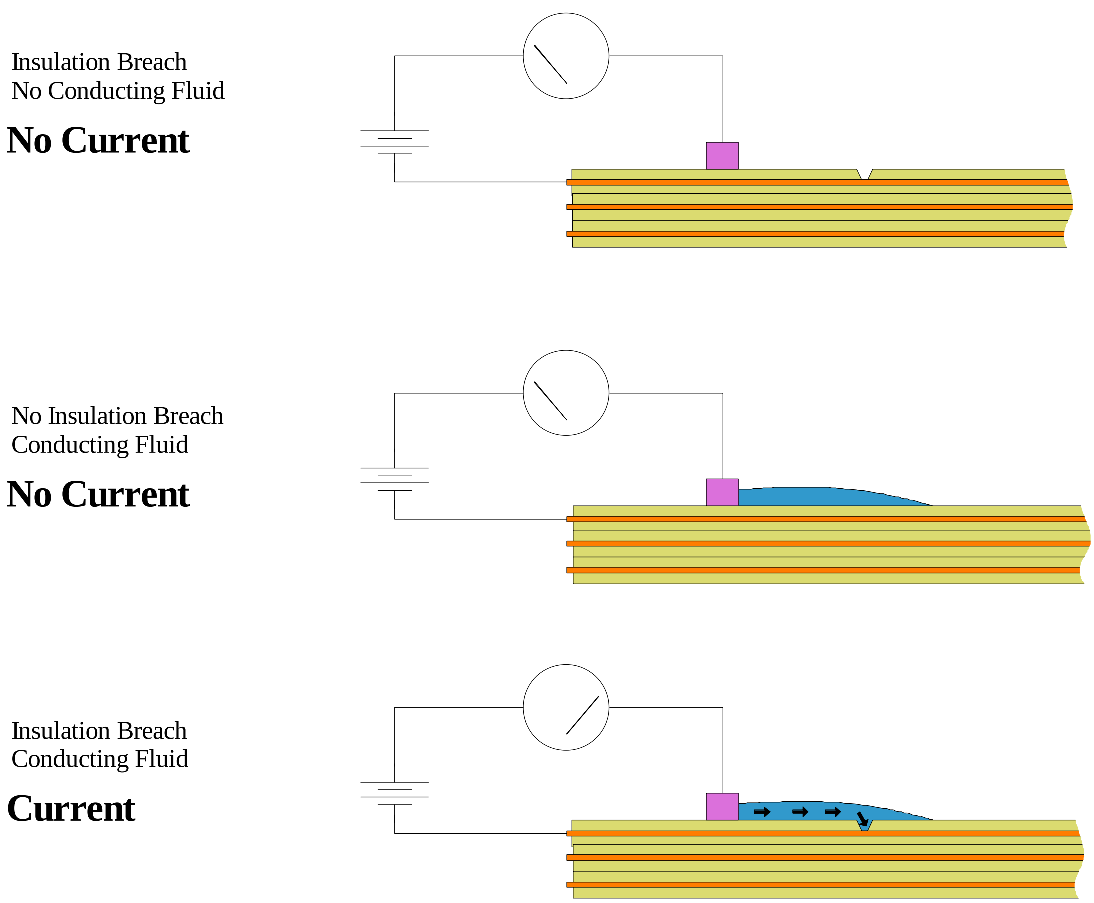
Summary

The results of the DelTest showed the that while the number of wire insulation breaches was 4.5failures/1000ft, this result is lower than the results of the testing performed in 2006 (5.4failures/1000ft. A number of common mode wire insulation failures (where 2 or more breaches were found in the same location) were found during the visual examination of the harnesses. These common mode failures pose a threat to the continued airworthiness of the aircraft by creating situations in which electrical arcing may occur.

The inherent viscosity for twenty-seven wires from different zones of an F-16 was measured and indicated that a majority were at or close to the end of their useful life; a majority showed aging and several (15%) showed close to end of life. Although the sample size is small, the samples that showed aging occurred in the areas with the highest failure rates. In other locations, the findings suggested that there is not an overall concern with the PMDA-ODA insulation. A comparison with the 2006 results gave good agreement in certain zones, but not in others.

APPENDIX A. DelTest™

The DelTest™ is a procedure to find breaches in the insulation of a wire that reaches to the conductor. In this procedure, a conducting fluid is injected into the harnesses under test. A small test voltage is placed on the inner conductor of the wires in the harness. A return electrode is placed on the outside of the harness in contact with the conducting fluid. A current measured in the test circuit indicates a breach in the insulation. This is illustrated in the figure below.



1. In the first harness, there is a breach but there is no current measured because the surface resistance of the wire is too high.
2. In the second case, the conducting fluid is present but there is no breach in the insulation so again no current is measured.
3. In the third case, there is both a breach and conducting fluid present and a current is measured.

This process has been performed “in situ” on aircraft and in the laboratory on harnesses that have been removed from the aircraft. When doing the DelTest™ in the lab, the harness is placed in a water bath with the connectors secured above the water.

APPENDIX B. Inherent Viscosity

Introduction

The definition of a polymer is “a long molecule which contains a chain of atoms”. This definition is very broad and encompasses life itself to highly sophisticated synthetic materials. While man has used polymers from prehistoric times, e.g., hides and fibers, polymer science dates to the early 20^{th} century. It was from this time that truly man-made polymers were discovered and developed. These synthetic polymers have numerous uses in the modern technology and society in general. Organic polymers, due to their structure and composition, almost always are insulators, i.e., they have a band gap of approximately three or more electron-Volts. While there are naturally occurring polymers that are employed for insulation purposes, e.g., isoprene, most insulating materials used for wiring today are synthetic.

A widely utilized polymer for wire insulation in aircraft is the material derived from the reaction between pyromellitic dianhydride (PMDA) and 4,4’-diamino-diphenyl ether (ODA) and is an aromatic polyimide. The structural formula of the monomeric unit from this polymerization is shown Figure B-1 and will be abbreviated as PMDA-ODA.

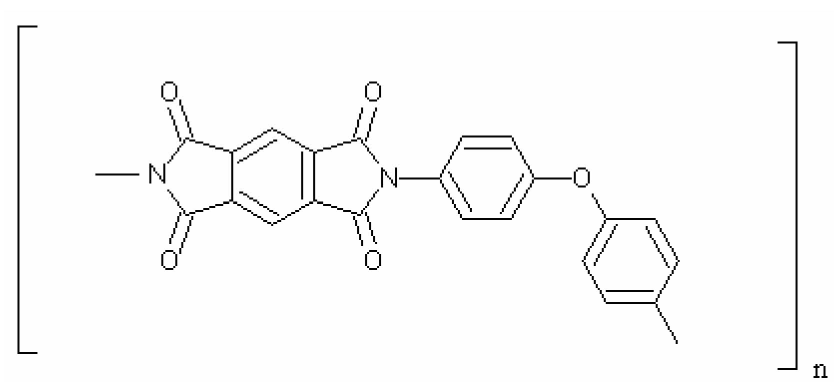


Figure B-1. Structural formula for the monomeric PMDA-ODA.

The hydrogen and carbon atoms are not shown in the figure. Carbon atoms are at the vertices of two or more straight lines; hydrogen atoms are attached at vertices where three lines including the detached straight lines are located. The exception is at either end of the structure; these are where one complete PDMA-ODA unit is attached to another. The empirical formula for this monomer is $C_{22}H_{10}O_5N_2$. This polymer was synthesized by duPont in the 1960’s and has the trade name Kapton®. There are now added sources for this material. The United States Department of Defense specification designation for wires using this material is MIL-W-81381. Note: there were a few “slash numbers” of MIL-W-81381 that employed a different monomeric unit; however, these were removed from use a short time after their introduction.

The “n” shown with the structural diagram above is the degree of polymerization. Each individual polymer molecule will have its own “n”. With an aggregate of polymer molecules having the same monomeric unit, there will be a range of “n’s”. Depending on the polymer, “n” can start at less than 10. At the other extreme are polymers where “n” can be well above 10,000. For PMDA-ODA almost all of the “n’s” will be 200 or less. As would be expected, the molecular weight of a polymer is a very important property of a polymer. Thinking simply, if “n” is known, the molecular weight of a given polymer molecule can be calculated. However, the problem is much more difficult.

First, there is the definition of molecular weight for an aggregate of polymer molecules due to the distribution of “n’s”. The two most common definitions for polymer molecular weights are the number average molecular weight (NAMW) and the weight average molecular weight (WAMW). With polymers NAMW usually is less than WAMW with typical distributions; the exception is when there is a very narrow range of “n’s”. Then the NAMW and WAMW values will be close. Details about polymer molecular weights are available elsewhere. The second issue is how to measure NAMW or WAMW, since most techniques will measure only one of these quantities. With some polymers the number of procedures that can be employed will be very limited as well.

Organic materials, which include almost all polymers, will change over time. The usual change is for a break to occur somewhere in the chain. This would reduce the “n” for that polymer molecule. For example, if a break occurs with a polymer molecule with an “n” of 100 in the middle of the chain, then there would be two new polymer molecules each with an “n” of 50. Some of these breaks can be caused by simple environmental exposure, e.g., oxygen , water, or light. If there are a sufficient number of breaks, then the molecular weight (both NAMW and WAMW) will decline measurably. In addition, it would be expected that some physical properties of the material, e.g, flexibility or the formation of voids, will happen. Extensive degradation could result is loss of material in some instances. Such changes when a polymer is used for wiring insulation might be very serious.

For PMDA-ODA the only currently available method to determine molecular weight is viscosity. Viscosity is typically thought of as an end property of a material, e.g., how easily syrup pours or the oil in an engine. However, in polymer science viscosity can be employed to measure the molecular weight of a polymer. Viscosity measurements with a dissolved polymer give a value that is close to the WAMW. The difference between the true WAMW and the viscosity value typically is a few percent. The relationship between viscosity and molecular weight is given by the semi-empirical Mark-Houwink equation

$$MW = K\eta_{inh}^{(1/a)} \qquad (1)$$

where MW is the viscosity average molecular weight, K and a are constants, and η_{inh} is the inherent viscosity[•]. Values for a range from 0.5 to 1.0, K is directly proportional to

[•] The International Union of Pure and Applied Chemistry term for this quantity is the logarithmic viscosity number.

MW, and each polymer-solvent combination has its own values of K and a. Inherent viscosity is defined in equation (2).

$$\eta_{inh} = \left(\frac{1}{c}\right) \ln \left(\frac{t}{t_o}\right) \quad (2)$$

where 't' and 't_o' are the respective times for the solution with and without polymer dissolved to go between two lines in a viscometer, and 'c' is the concentration of dissolved polymer. Typical units for η_{inh} are g/dl (dl is 0.1 liter). If η_{inh} decreases there is a decline in MW, and hence, a degradation of the polymer has occurred.

The physical properties of PMDA-ODA have many features that make it attractive for use as insulation. For example, the thermal stability at 275^o C (based on the retention of film flexibility) is over a year. The material is insoluble in organic solvents and appears to resist damage due to ionizing radiation. When used as insulation, the thickness required is less than that of many other polymers, and this material is very flexible over a wide temperature range. These properties make PMDA-ODA especially attractive for use on aircraft.

Experimental Procedure

Two continuous strips of PMDA-ODA (often about 25 micrometers thick) are helically overlapped over the conducting material. The polyimide is coated with a thin fluoro polymer for adhesive purposes. On the outside of the outer PMDA-ODA film a "top-coat" is placed. Different materials have been used for the "top-coat. Before analysis, the top-coat is removed from the wire. Then, the PMDA-ODA tapes are separated from each other and the conductor. The tapes then are weighed, dissolved in concentrated H_2SO_4 following the previously developed method of Wallach.

A little less than 0.1 gram per specimen of PMDA-ODA is needed for analysis purposes. For the analyses in this project, only the inner tape was analyzed. This was done because there are possible difficulties with the top-coat are avoided. All of the films were 0.001 inches (0.025 mm) thick with the exception for wire number 1 in harness 685. This film was 0.002 inches (0.051 mm) thick. After dissolution of the film, the fluoro-polymer (not soluble in H_2SO_4) is separated from the solution. Then, η_{inh} of the dissolved PMDA-ODA is determined. A schematic diagram of the experimental equipment is shown in Figure B-2.

The individual wires to be analyzed were chosen from harnesses that had been examined with the DelTest (results elsewhere in this report). Many of the wire had the same number in the same harness as those investigated in 2006 by Lectromec. All of the wires were either 20 or 22 gauge with one exception.

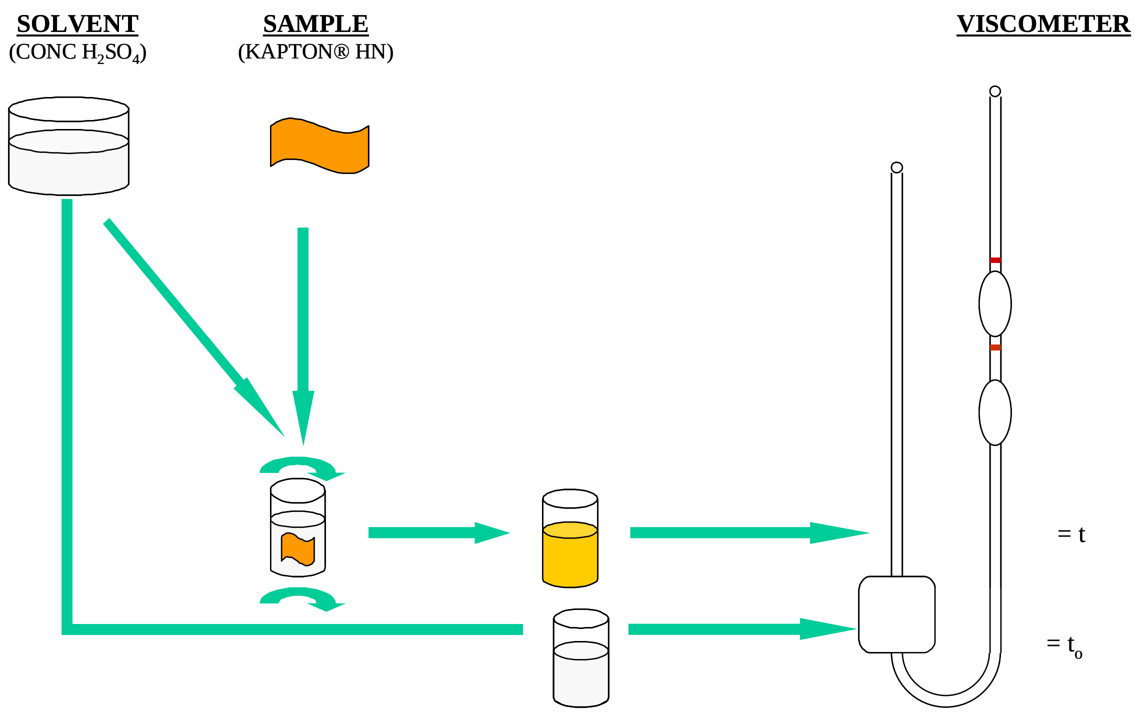


Figure B-2. A schematic representation of the experimental equipment for viscosity measurements.

Understanding the Results

The graph below shows the comparison between elongation to break as a function of the inherent viscosity of the polymer with greater than 90% elongation to break corresponding to new polymer.

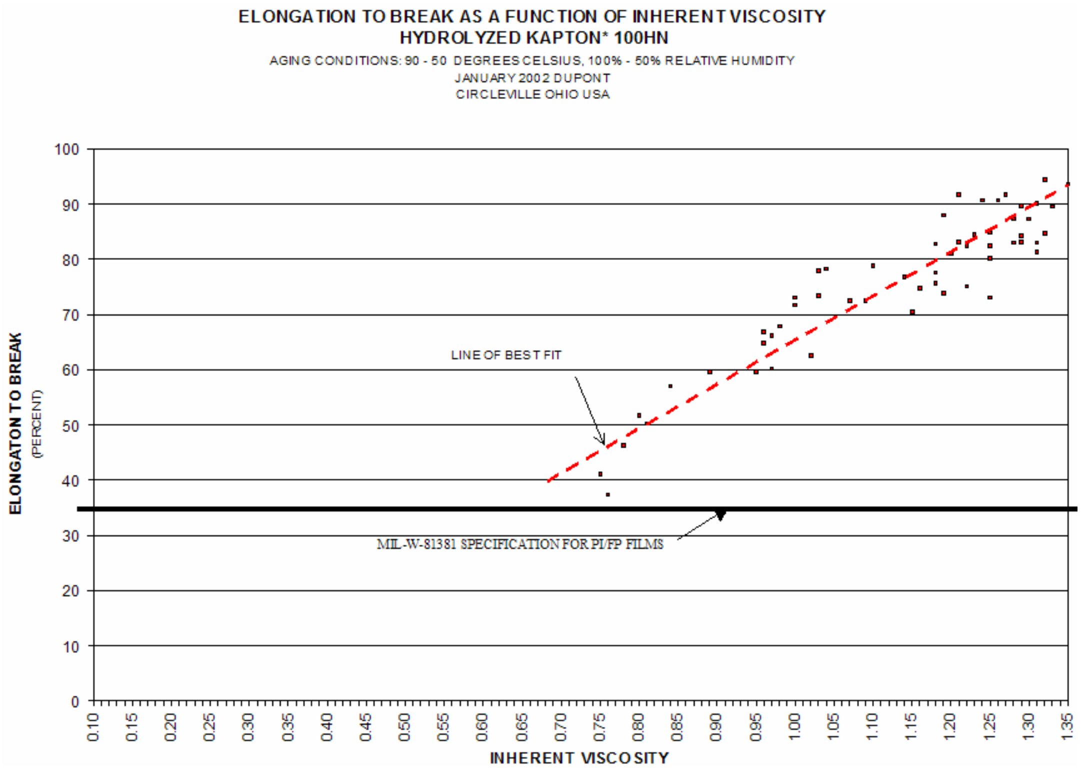


Figure B-3: DuPont tests correlating inherent viscosity measurements with elongation to break.

These tests from the above figure were done on accelerated aged wire for various durations by DuPont. While this is greater than the value required meeting the specification requirements, this does correspond to a wire that is more likely to fail as the results of mechanical stress.

APPENDIX C. Failure Photos

Figure C-1: Photo: Harness: H16DW685-23. Conductor exposed

Figure C-2: Photo: Harness: H16DW685-23: Photo taken under higher magnification. Conductor exposed.

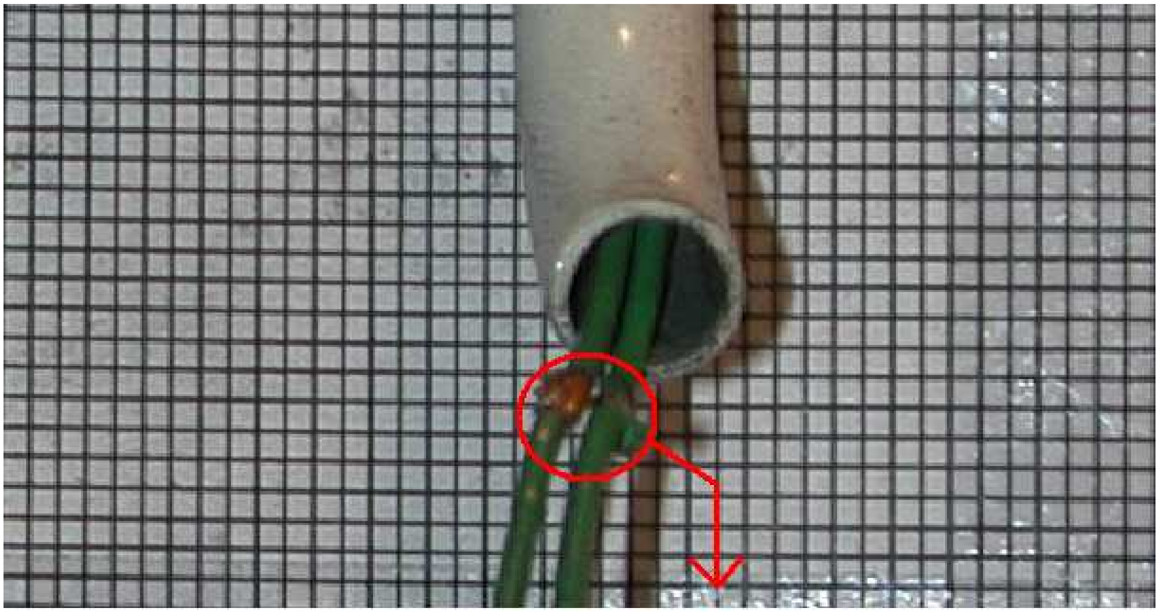


Figure C-3: Harness H16DW696-21 (a). Background grid is 1mm by 1mm. Wire 2 as seen with minimal magnification.

Figure C-4: Harness H16DW606-21 (a). Wire 2 has exposed conductor. Damage to the insulation of wire 1.

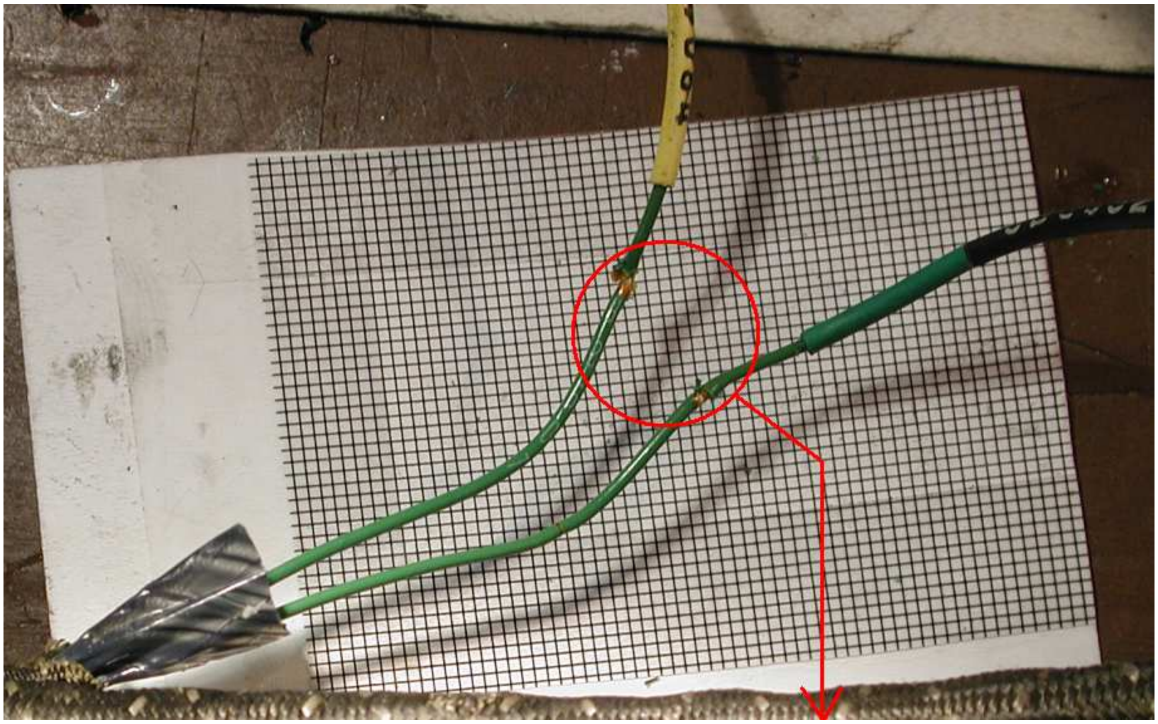


Figure C-5: H16DW651- wires 54 and 55. Background grid is 1mm long by 1mm wide. Wires 54 and 55 as seen with minimal magnification. Insulation breached to the conductor towards the GD6552 end.

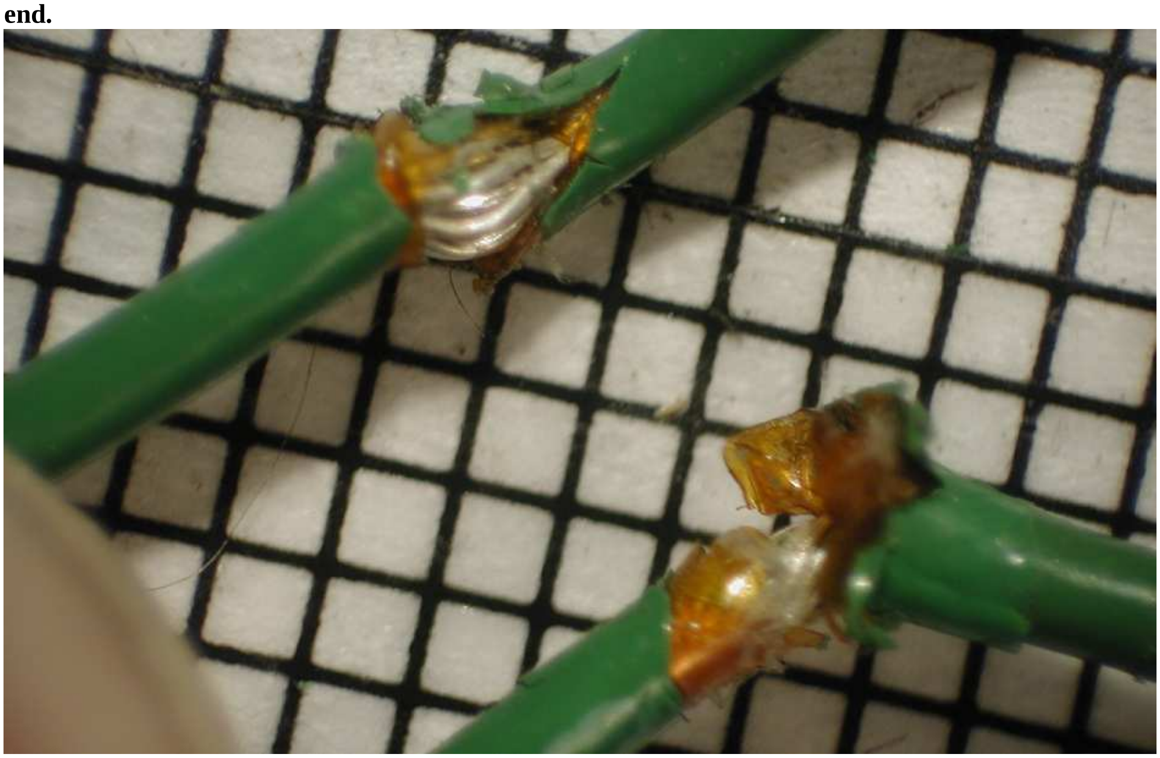


Figure C-6: Photo: H16DW651-wires 54 and 55. Background grid is 1mm long by 1mm wide. Wires 54(top) and 55(bottom) as seen under a microscope. Conductor Exposed.

Figure C-7: Harness: H16DW653, wire224-1. Break in 24 gauge wire. Background grid scale 1mm x 1mm.

Figure C-8: Harness: H16DW653, wire224-1. Close-up photo of Figure C-7. Background grid scale 1mm x 1mm.

Figure C-9: Harness: H16DW693-21. Wires coming out of a conduit with multiple breaches to conductor.

Figure C-10: Harness: H16DW693-21. Same as Figure C-9.

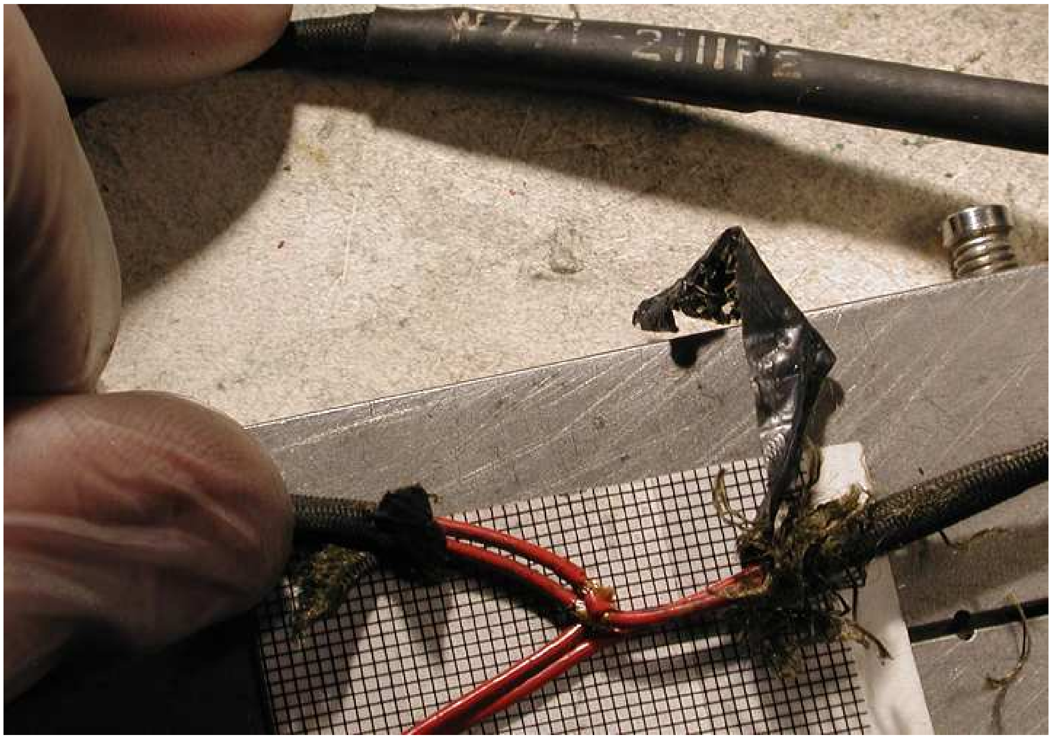


Figure C-11. Harness H16DW771, wire numbers 15 and 16. Insulation breach found at break intersection with wire bundle. Background grid scale 1mm x 1mm.

Figure C-12. Harness H16DW771, wire numbers 15 and 16. Close-up photo of Figure C-11. Background grid scale 1mm x 1mm.