An Analysis of Arc Fault Ignition and Mitigation Techniques

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Abstract

The Federal Aviation Administration (FAA) has been intensely involved in investigating electrical ignition of materials and mitigation techniques. To assist in the investigation of this problem, the FAA William J. Hughes Technical Center has developed the Arc Fault Evaluation Laboratory (AFEL). This lab is dedicated to the understanding of electrical ignition and defining performance requirements of arc fault mitigation devices.

The FAA is currently conducting a test program to evaluate arc fault mitigation products, including arc fault circuit breakers, new insulation types, fault current reduction, and new thermal acoustical blanket material. Test results measured the effectiveness of the mitigating products in reducing electrical arcing damage. Electrical arcs were generated using realistic arcing test methods. The tests are were performed in a manner similar to those used in the acoustical insulation test program and created from documented incidents to simulate a chafed wire on a hydraulic line. The effectiveness of arc mitigation techniques, on the ignition of aircraft acoustical insulation blankets and wire bundle damage, will be assessed and reported.

In 1998, the FAA initiated an intense thermal acoustical insulation test program, including full-scale testing, intermediate testing, bench-scale testing, and electrical ignition testing. The results were published in FAA report DOT/FAA/AR-TN00/20 “Flammability of Aircraft Insulation Blankets Subjected to Electrical Arc Ignition Sources”. The test data and techniques from this study provided a unique opportunity to evaluate current arc fault mitigation techniques against previously recorded fault and ignition data.

“An Analysis of Arc Fault Ignition and Mitigation Techniques” study was only intended as an initial study in arcing mitigation techniques. Future tests will include ignition quantification of additional blanket material, conduit, control cables, AC/DC arcing damage quantification, and mitigation of mixed power in wire bundles, and the use of sleeving and conduit and additional wire insulation types.

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Executive Summary

The Federal Aviation Administration (FAA) has initiated a test program to evaluate arc fault mitigation products; including arc fault circuit breakers (AFCB), new wire insulation types, new thermal acoustical insulation blanket film cover material and fault current reduction. Test results measured the effectiveness of the mitigating products in reducing electrical arcing damage. Electrical arcs were generated using realistic arcing test methods. The tests were performed in a manner similar to those used in the acoustical insulation test program and created from documented incidents to simulate a chafed wire on a hydraulic line.

The thermal acoustical insulation blankets were tested at 115 V and were subjected to arcing until the blanket ignited (sustained flame). The sum of the results from the previous blanket testing from the DOT/FAA/AR-TN00/20 "Flammability of Aircraft Insulation Blankets Subjected to Electrical Arc Ignition Sources," was recreated using similar methods described within the report. In addition to monitoring the flame damage, voltage and current waveforms were taken to assess the amount of electrical energy necessary to initiate ignition. The amount of electrical energy to ignite the different types of blankets varied from 179 to 1107 Joules (J). The blankets were then retested, with a reduced fault current (the peak current available in an arcing fault; usually limited by the size of the generator and the amount of resistance between the generator and the fault). The final blanket test set-up replaced the thermal breaker with an AFCB. The amount of energy was compared to the amount needed to ignite the blanket. High-speed video was also used to examine the process of blanket ignition and to quantify the damage to the blanket.

In low-fault current testing sample blankets were tested, as many as ten times, without recurrence of ignition. The range of energy that blankets absorbed, on one particular test run, was approximately 5373 J. The energy increased (in comparison to the high fault current test); however, the arc peaks were reduced from 400 amps to approximately 93 amps. The reduction in fault current amplitude reduced the width of the plasma column. Due to the smaller plasma column, the wire would weld and short for brief periods of time to the frame. The damage obtained by the blanket was minimal; however, some carbonization of the metalized film was noted. At no time during testing did a sustained open flame occur after repeated testing. During examination of the video, occasional small open-flames were noted in the high-speed video.

During AFCB blanket testing, an AFCB device allowed 627 J of energy to occur before tripping, most of the AFCBs were tripped with less than half of the energy shown to ignite the blanket. When testing with low-fault current levels, the amount of energy required to trip the AFCB was an order-of-magnitude less than the recorded energy level required to ignite the blanket.

In the wire bundle test the amount of damage a particular test generated was dependent upon the amount of arcing and shorting occurring during the test. If the sample was

welded to the hydraulic line (shorting), very little damage occurred to the wire bundle, independent of the type of insulation and fault current used. When the experiment contained a great deal of arcing, wire insulation type, and fault current played a much greater role. Fault current also played a large role in the amount of damage a wire bundle would receive.

In reduced fault current tests the arcing wire was more likely to weld to the hydraulic line; the normal thermal breaker seemed sufficient to protect the bundle from extreme wiring damage. The high-fault current test showed more damage and would arc for a longer period of time without mechanical prodding to continue arcing. Due to the arc tracking properties of the polyimide wire and the increased arcing found in the high fault current test, all arc insulation mitigation tests were conducted with a polyimide arcing wire and high-fault current.

The AFCB protected the bundle from damage very well on both low- and high-fault current bundle setups. The amount of damage on the wire bundle was minimal. In some cases the carbon from the event could only be seen under close visual examination of the wire.

Testing techniques evaluating arcing events (i.e. guillotine, wet arc, and shaker table) can play a large role in the results. Comparative evaluation of arcing events must include measurements of arc voltage and fault current. The wave shape of the arcing fault can play a definitive role in the arc detection based on the arc protection algorithm used in the device.

Arcing with mixed power sources needs further exploration to obtain a full picture of what occurs during arcing in a bundle. This study attempted to understand arcing damage from one power source; however, a wire bundle usually contains more than one power source.

The reduction in fault current available proved to be an effective technique to reduce arcing damage. This technique could be implemented with relatively inexpensive and simple components. Once implemented, the voltage drop created could lead to better load protection. An evaluation of how this technique could be used and its effect on aviation loads would prove valuable.

"An Analysis of Arc Fault Ignition and Mitigation Techniques" study was only intended as an initial study in arcing mitigation techniques. Future tests will include ignition quantification of additional blanket material, conduit, control cables, AC/DC arcing damage quantification, and mitigation of mixed power in wire bundles, and the use of sleeving and conduit and additional wire insulation types.

1.0 <u>Introduction</u>

1.1 Purpose

A test program is currently in place to evaluate arc fault mitigation techniques, including arc fault circuit breakers (AFCB), new insulation material, new thermal acoustical film cover materials, and fault current management. Test results from initial research measured the effectiveness of the mitigating products in reducing electrical arcing damage. Methods for generating electrical arcs were created to mimic realistic aviation arcing events. The thermal acoustical blanket testing methods were performed in a manner similar to that used in the DOT/FAA/AR-TN00/20 "Flammability of Aircraft Insulation Blankets Subjected to Electrical Arc Ignition Sources," test program. The effectiveness of the arc mitigation techniques on the ignition of aircraft thermal acoustical insulation blankets were measured and reported.

1.2 Background

On July 17, 1996, TWA Flight 800, a Boeing 747-131, broke apart mid-air and crashed into the Atlantic Ocean near East Moriches, New York. TWA Flight 800 was operating under Tittle 14 Code of Federal Regulations Part 121 as a scheduled international passenger flight from John F. Kennedy International Airport (JFK), to Charles DeGaulle International Airport, France. All 230 people on-board the aircraft perished and the airplane destroyed.

The ignition energy for the center wing tank explosion, most likely, entered the center wing tank through the Fuel Quantity Indication System (FQIS) wiring. Although it is possible that the release of ignition energy inside the center wing tank was facilitated by the existence of silver-sulfide deposits on an FQIS component, neither the energy release mechanism nor the location of ignition inside the center wing tank could be determined from the available remaining evidence.

The FAA is currently in the rulemaking process to address certification aspects of fuel tank design, with regard to minimizing the potential for fuel vapor ignition. As part of the rulemaking focus, wiring, as a source of direct and indirect arcing, is being addressed.

SwissAir Flight Number 111, crashed on September 2, 1998. The aircraft, en route from JFK, NY, to Geneva, Switzerland, crashed in the ocean approximately 40 miles southwest of Halifax, Nova Scotia, following a report of "smoke" in the cockpit. There were no survivors.

By September 1999, the Transportation Safety Board of Canada (TSB) recovered approximately 98 percent of the aircraft by weight. The TSB elected to reconstruct the forward 10 meters of the MD-11 fuselage. Most of the aircraft pieces were about 6 to 12 inches in diameter and the components had to be molded and sewn together. The assembled fuselage presented a distinct footprint of fire damage in the overhead cockpit and overhead the first-class seating area.

Further investigation into a number of in-flight and ground aircraft fires on MD-11 and MD-80 series airplanes revealed that insulation blankets covered with a particular film material, known as metalized Mylar™, possibly contributed to the spread of fire when ignition occurred from small ignition sources such as electrical arcing and sparking.

Twenty-three wires have been recovered with arcing damage. It cannot be determined, if the arcing initiated the fire or if the arcing was a direct result of the fire.

The FAA (November 1998), mandated replacement of metalized Mylar™ insulation blankets to minimize the potential of ignition sources and flame propagation in the aircraft.

The FAA has sponsored arcing research and the development of AFCB for over the past 6 years. This research is in direct support of the findings and recommendations from the above documented incidents, ATSRAC recommendations, and current and future rulemaking.

2.0 Discussion

2.1 Test Set-up Background

FAA report DOT/FAA/AR-TN00/20 "Flammability of Aircraft Insulation Blankets Subjected to Electrical Arc Ignition Sources" describes different tests conducted in a cylindrical section of a DC-10 fuselage (Figure 1). Using a 400 Hz three-phase 115/208 volt generator, each phase (wire) was connected to a 15-amp aircraft thermal circuit breaker. One wire was connected to the load side of each breaker. Test insulation blankets were placed in a frame of the DC 10 test fixture so that contact was established with the ribs on both sides of the frame. The blanket was then subjected to the effects of electrical arcing at 115 volts. Furthermore, additional insulation blankets were installed in the test fixture, in the same manner, and were tested in a ten-wire bundle, then attached to the blanket using 208 volts phase-to-phase arcing.

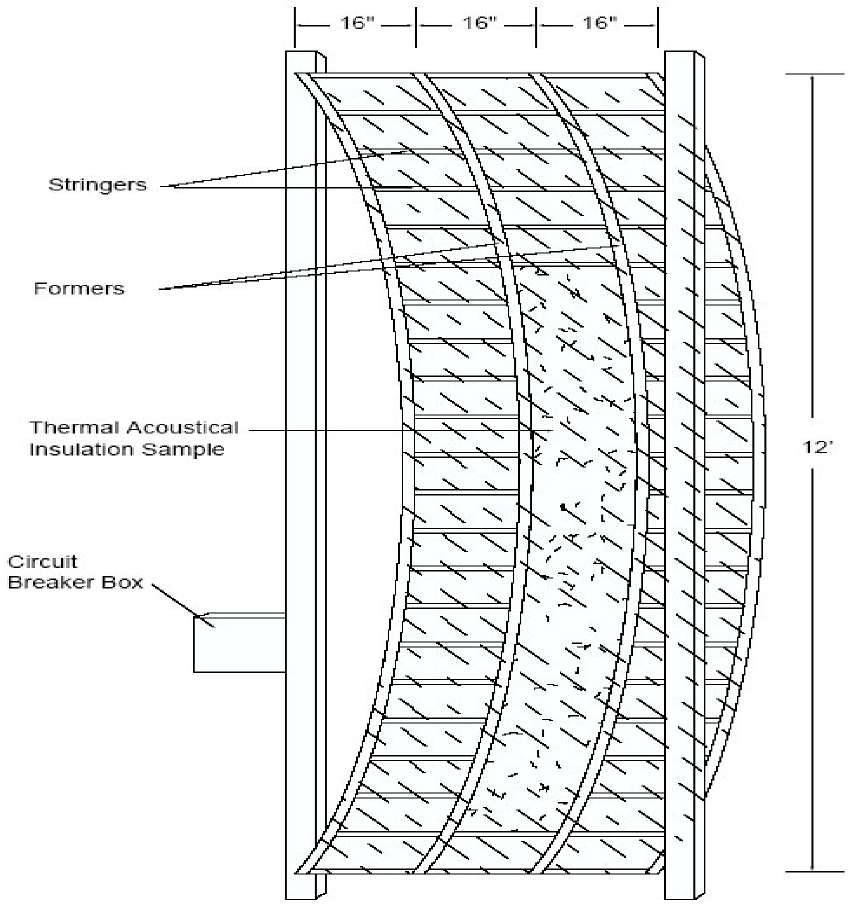


Figure 1. DC 10 Fuselage.

The results published from the FAA report showed that the polyimide and metalized poly (vinyl fluoride) (PVF) blankets did not ignite when subjected to multiple arcing events at either 115 or 208 volts. The polyimide film charred in those areas struck by the arcs, but no ignition of the blanket occurred. The PVF film shrank away from the intense heat of the arcing, leaving small circular voids in the film cover. The metalized polyester polyethylene terepthalate (PET) film ignited from arcing at both 115 and 208 volts, resulting in uncontrolled flame propagation. When subjected to an electrical arc, the metalized PET film cover, sprayed with a corrosion-inhibiting compound (Dinitrol AV 8TM), ignited with flame propagation. At 115 volts, approximately 50 percent of the blanket was consumed, and at 208 volts, approximately 75 percent of the blanket was consumed. The amount of blanket consumed is more likely due to the existence of test variables such as flatness of the film cover, melting and dripping, and air currents as opposed to merely spraying the surface with corrosion inhibiting compound. The plain PET blanket ignited at the seam, when tested at 115 volts, and self-extinguished with minimal flame spread. When tested at 208 volts, no ignition occurred.

The Arc Fault Evaluation Laboratory (AFEL) was used to conduct a test program to evaluate the electrical energy produced in the earlier FAA study and evaluate arc fault mitigation techniques, including arc fault circuit breakers, new wire insulation types, and reduced fault currents. Test results found from this research will measure the effectiveness of mitigating techniques in reducing electrical arcing damage.

2.2 Blanket Ignition

2.2.1 AFEL Test Method

The test method from the FAA Report DOT/FAA/AR-TN00/20 "Flammability of Aircraft Insulation Blankets Subjected to Electrical Arc Ignition Sources" was repeated with the addition of recording current and voltage waveforms with a Nicolet Vision Data Acquisition Monitoring System. The schematic, shown in Figure 2 describes the test set-up. High-speed video was also used to assess arcing energy and damage on the different types of blankets and wire bundles. Video was taken at 500 and 1000 frames per second, respectively.

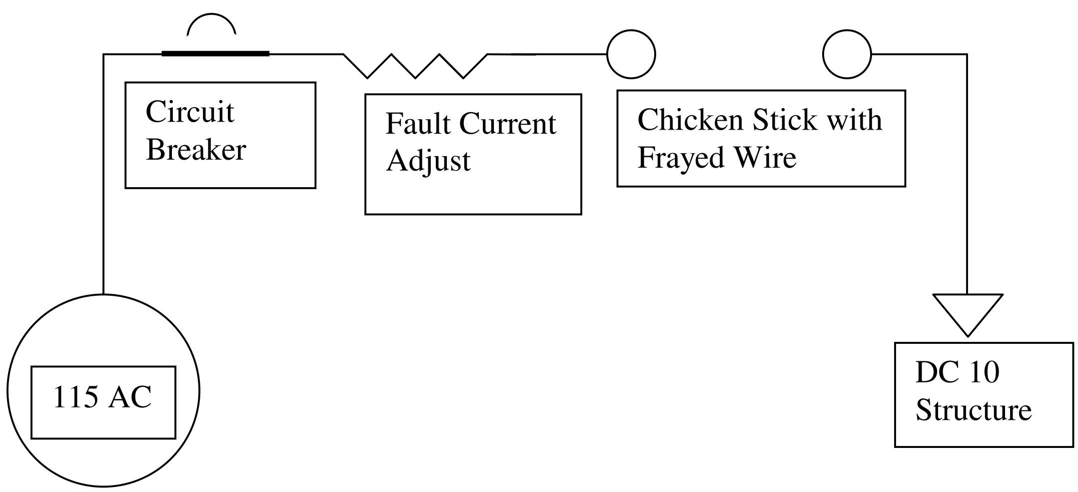


Figure 2. Schematic of Test Set-Up.

The blankets were tested at 115 V and were subjected to arcing until the blanket ignited (sustained flame). The energy, required for ignition, was recorded. Then the blankets were retested, with a reduced fault current (the peak current available in an arcing fault usually limited by the size of the generator and the amount of resistance between the generator and the fault). The next test set-up replaced the thermal breaker with an AFCB. The amount of energy was compared to the amount needed to ignite the blanket. High-speed video was also used to examine the process of blanket ignition and to quantify the damage to the blanket.

2.2.2 Procedure

Experiments were conducted in a cylindrical section of a DC 10 Fuselage (see Figure 1). Using a 400 Hz, three-phase 115-volts 60-KVA generator, where one phase (wire) was connected to a 7.5-amp aircraft thermal circuit breaker or a 7.5-amp AFCB. One wire was connected to the load side of the breaker. The end of the wire was stripped and used for arc initiation. Test insulation blankets were placed in a frame of the DC 10 test fixture so that it was in contact with the ribs on both sides of the frame. The blanket was then subjected to the effects of electrical arcing at 115 volts (see Figure 3). The current was monitored by a shunt resistor at the line side of the breaker and recorded. The line side voltages of the breaker and the arcing voltage were also monitored with respect to airframe ground. The arcing voltage was monitored as closely to the arcing end of the chicken stick as possible; this dose introduces a small error in the measurement of the arcing voltage, but for the comparative measurements of this testing it can be ignored.

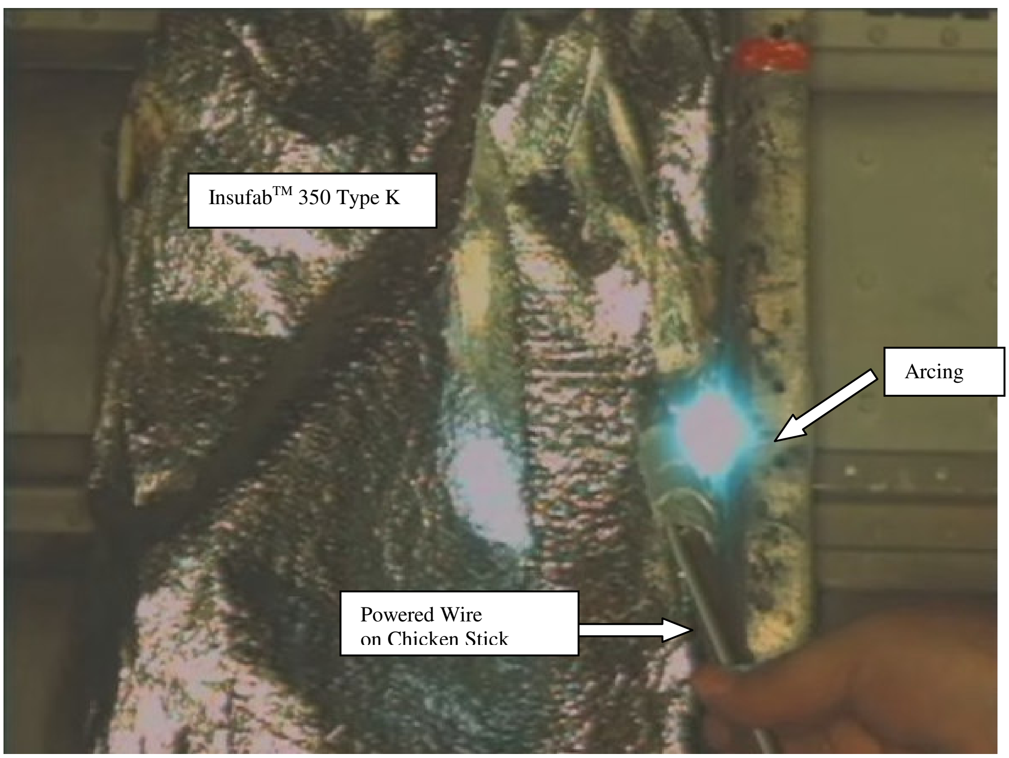


Figure 3. Blanket Test Set-Up.

2.2.3 Results

The sum of the results from the previous blanket tests from the DOT/FAA/AR-TN00/20 "Flammability of Aircraft Insulation Blankets Subjected to Electrical Arc Ignition Sources" was recreated using similar methods described within the report. In addition to monitoring the flame damage, voltage and current waveforms were taken to assess the amount of electrical energy necessary to initiate ignition. The amount of electrical energy to ignite the different types of blankets varied from 179 to 1107 Joules (J), as shown in

Table 1. Blanket ignition depends upon where the arcing occurred; for example, most ignitions occurred when the edge of the blanket was exposed to the arcing, or the film material edge became exposed due to arcing damage. High-speed video revealed that ignition occurred after charring of the blanket insulation material, and visible flame from the consumption of the out-gassed material occurred. It was difficult to detect whether the ignition occurred from the plasma column of the arcing event or from the molten material (spew). However, in each of the ignitions, a brief visible flame was present and sustained. Damage from the arcing on the different types of blankets is shown in Figures 4. to 7.

Table 1. Blanket Ignition Testing.

Waveform	Maximum Fault Current (Peak)	Total Energy (J)	Comment
Pats Blanket Film	288.8	1106.8	Minimum shots for ignition to occur
Pats Test 7	366.5	741.95	Type 3 0.6 PCF High Current, Ignition, No thermal Breaker Trip
Pats Test 9	338.6	444.9	Type 3, 1.5 PCF, High Current, Ignition, No Thermal Breaker Trip
Pats Test 10	353.7	417.1	Type 3, 1.5 PCF, High Current, Ignition, Thermal Breaker Trip
Pats Test 27	346.4	186.3	Type 3,1.5 PCF High Current, Ignition, Thermal Breaker Trip
Pats Test 36	343.5	179	Type 1, High Current, Ignition, No thermal Breaker Trip

Figure 4. Plain Mylar™ 0.6 PCF
Arc Damage (front side film totally consumed).

Figure 5. Plain Mylar™ 1.5 PCF
Arc Damage (Only the edge damaged).

Figure 6. Insufab™ 350 Type K
Arc Damage (Large open flame/both sides of film consumed).

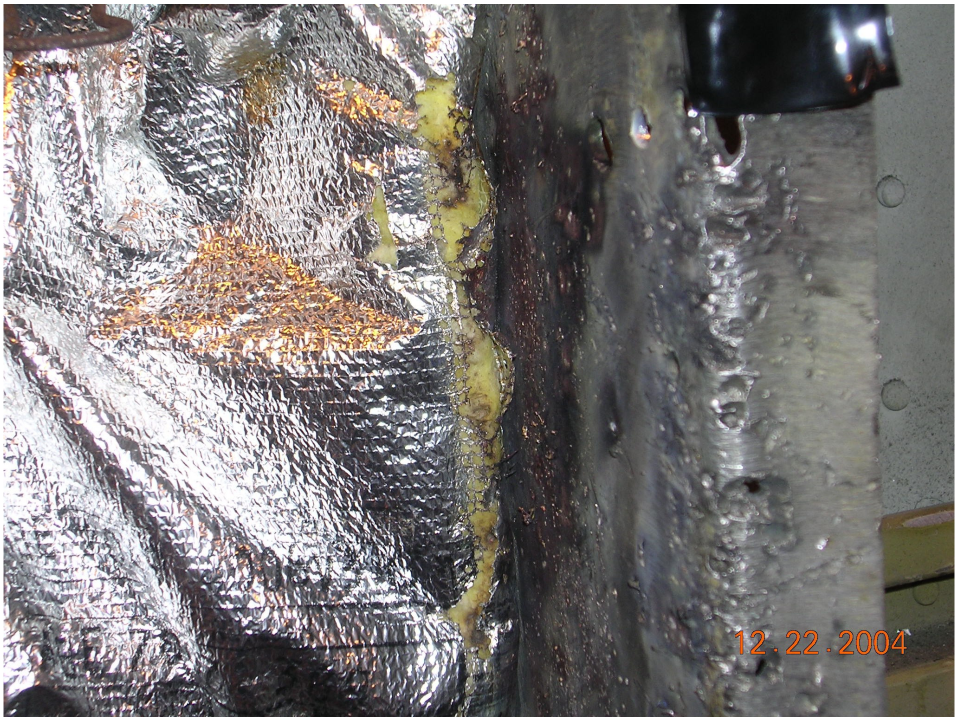


Figure 7. Low current damage to blanket.

2.3 Mitigation

Tests for arc damage mitigation were conducted using the Insufab™ 350 Type K blanket. This type of blanket was selected because it took the least amount of energy to ignite in both the previous FAA tests and in this study. This blanket also showed the greatest amount of damage when ignited by electrical arcing.

2.3.1 Reduced Fault Current Test

The Insufab™ 350 Type K blanket was tested with the fault current reduced, using 100 feet of Number 22 AWG wire. In low-fault current testing set-up sample blankets were tested, as many as ten times, without recurrence of ignition. The range of energy that blankets absorbed, on one particular test run, was approximately 5373 J, as shown in Table 2. The energy increased (in comparison to the high fault current test); however, the arc peaks were reduced from 400 amps to approximately 93 amps. The reduction in fault current amplitude reduced the width of the plasma column. Due to the smaller plasma column, the wire would weld and short for brief periods of time to the frame. The damage obtained by the blanket was minimal; however, some carbonization of the metalized film was noted. At no time during testing did a sustained open flame occur after repeated testing. During examination of the video, occasional small open-flames were noted in the high-speed video.

Table 2. Low-Current Blanket Test, with 20-amp Thermal Breaker

Waveform	Max. Peak Current (A)	Energy (J)
Arc Fault Low Current 1-10	95.7	5372.97
	92.83	886.78
	92.28	1558.33
	95.88	674
	91.02	1223.62
	95.4	1001.58
	89.67	1134.45
	94.35	761.42
	92.5	835.34
	91.68	1160.33
	Total J =	14608.82

2.3.2 Arc Fault Protection

The Insufab^{TM} 350 Type K Blanket was tested using several 7.5amp AFCB from three different manufacturers (see Figure 8.); testing used both high and low currents test set-ups. The energy absorbed by the blanket was reduced dramatically, as shown in Table 3. The amount of damage the blanket obtained was cosmetic (see Figure 9). While one AFCB let 627 J of energy pass before tripping, most of the breakers were tripped with less than half of the energy shown to ignite the blanket. When testing with low-fault current levels, the amount of energy required to trip the AFCB was an order-of-magnitude less than that recorded energy level required to ignite the blanket. Figure 9 shows the damage obtained by the blanket to be minimal.

Figure 8. Arc Fault Circuit Breakers.

Table 3. Updated Arc Fault Circuit Breaker Blanket Testing.

Waveform	Max Peak Current (A)	Energy (J)	Comment
Pats Blanket Film 6	293.43	55.17	High-Current, AFCB Tripped
Pats Blanket Film 7	282.48	627.26	High-Current, Indication of arcing trip on the first burst, however did not trip until the third burst AFCB Tripped
Pats Blanket Film 8	233.4	52.22	High-Current, AFCB Tripped
AFCB LC 4	89.9	8.05	Low Current, AFCB Tripped
AFCB LC 6	79.35	12.39	Low Current, AFCB Tripped

Figure 9. AFCB Protected Blanket.

2.4 Arcing Bundle Testing

2.4.1 AFEL Test Method

The wire bundle test method was developed in an attempt to mimic previously recorded arcing incidents. One wire was chafed (conductor exposed), which was the only wire to carry power; the other six wires, in the bundle, were used for damage assessment. The bundles were tested using the same generator and fault current restrictions used for the blanket tests. The bundles were tested in two configurations: the first, with all the same wire insulation types; the second, with a polyimide arcing wire (wire 6 Figure 10.) and different wire insulation type for the damage assessment bundle (wires 1-5,7 Figure 10.). The first series of tests were conducted by tapping the exposed conductor against a piece of electrically grounded aviation hydraulic line. After the first series of tests, it was discovered that by moving the bundle in a circular arc and hitting the hydraulic line, more electrical arcing and less shorting was produced. During testing, fault current arcing and supply voltages were monitored and recorded.

2.4.2 Wire Types and Configurations

Commercially used aircraft wire types were used in this study. Seven wire bundles were constructed, where one designated power wire was on the outside of the bundle (see Figure 10). The different types of wires are shown in Table 4.

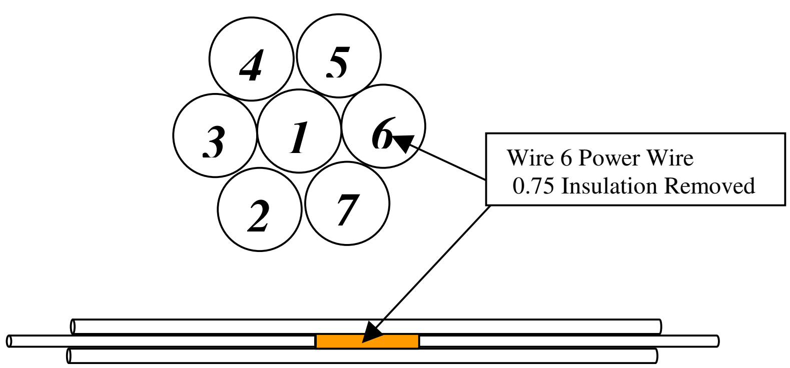


Figure 10. Seven Bundle Wire Configuration**.**

Table 4. Wire Types.

Material	Desig.	Group No
Polyimide MIL-DTL-81381/11	A	I
PVC MIL-W-5086/1	B	II
PVC Glass MIL-W-5086/2	C	III
PTFE AS22759/9	D	IV
PTFE AS22759/11	E	V
PTFE AS22759/43	F	VI
Bundle	Bu	
Power Wire	PW	

2.4.3 Procedure

Experiments were conducted in a cylindrical section of a DC 10 Fuselage (see Figure 1). Using a 400 Hz three-phase 115-volts generator, where each phase (wire) was connected to a 7.5 amp aircraft thermal circuit breaker or 7.5-Amp AFCB. The seven wire bundle will had one power wire on the outside of the bundle which, with a section of the insulation removed to expose the metal conductor. The power conductor powered a constant lighting load. The bundle was electrically arced to the grounded hydraulic line, tied to the structure (see Figures 11 and 12). The testing variables are shown in Table 6. Damage on the six "dummy" wires was assessed after each arcing experiment. The amount of energy in the event and the dummy wire damage were the evaluation criteria used to assess the performance of the arc mitigation technique. Each bundle type underwent at least four different arcing tests: thermal breaker high-fault current, thermal breaker low-fault current, AFCB high-fault current, and AFCB low fault current.

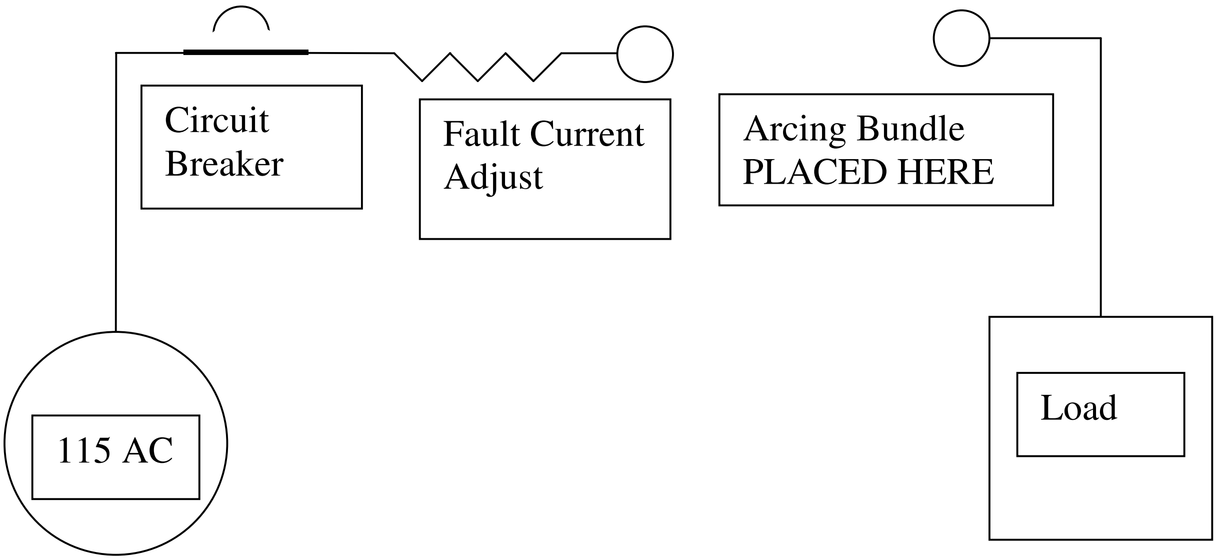


Figure11. Wire Bundle Test Schematic.

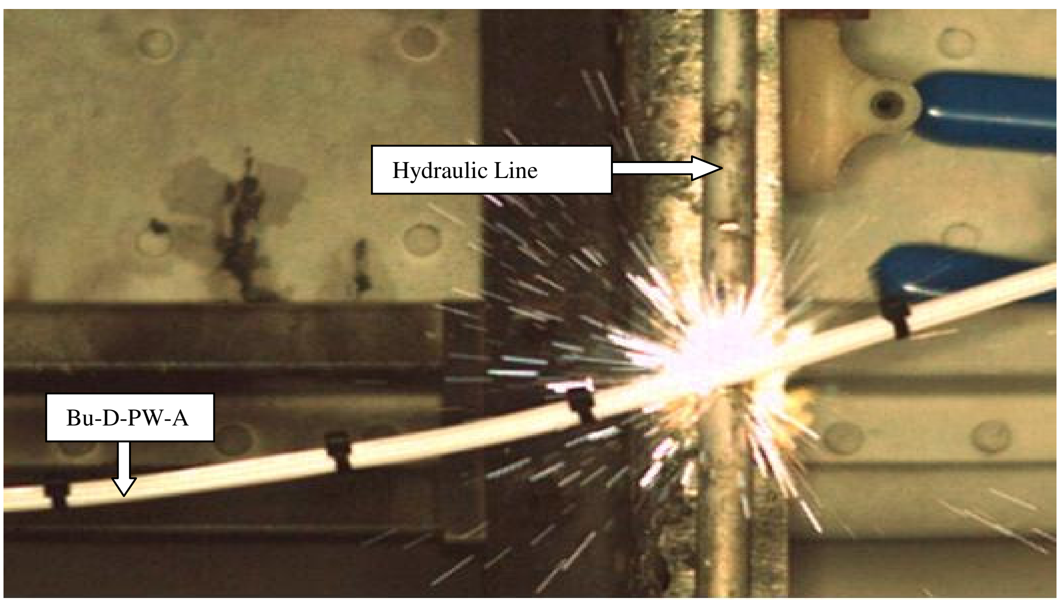


Figure 12. Wire Bundle Test Set-Up.

Table 6. Testing Variables

Group I Testing	Thermal Breaker	Low Current	High Current	AFCB Breaker
Bu-A-PW-A	x		x	
Bu-A-PW-A	x	x		
Bu-A-PW-A			x	x
Bu-A-PW-A		x		x
Bu-B-PW-A	x		x	
Bu-C-PW-A	x		x	
Bu-D-PW-A	x		x	
Bu-E-PW-A	x		x	
Bu-F-PW-A	x		x	

2.4.4 Results

The amount of damage a particular test generated was dependent upon the amount of arcing and shorting occurring during the test. If the sample was welded to the hydraulic line (shorting), very little damage occurred to the wire bundle independent of the type of insulation and fault current used. When the experiment contained a great deal of arcing, wire insulation type, and fault current played a much greater role. Fault current also played a large role in the amount of damage a bundle would receive. In reduced fault current tests the arcing wire was more likely to weld to the hydraulic line; the normal thermal breaker seemed sufficient to protect the bundle from extreme wiring damage. The high-fault current test showed more damage and would arc for a longer periods of time without mechanical prodding to continue arcing. Due to the arc tracking properties of the polyimide wire and the increased arcing found in the high-fault current test, all arc insulation mitigation tests were conducted with a polyimide arcing wire and high-fault current.

2.5 Mitigation

2.5.1 Reduced Fault Current

In the tests run, with reduced fault current, both thermal protected and AFCBs had a tendency to weld to the hydraulic line, the tack had to be broken to show arcing effects. Many of the tests showed thermal protection stopped the event before the wire bundle or the hydraulic line was destroyed (Figures 13-15.). The reduction in fault current showed dramatic improvement over the high-fault current thermally protected circuit alone. The damage results were evident on the wire bundle and the hydraulic line.

2.5.2. AFCB

The AFCB worked very well on both low- and high-fault current setups. The amount of damage on the wire bundle was minimal. In some cases, the carbon from the event could only be seen in the close examination of the wire. The AFCB showed more damage when an event included intermittent shorting, along with arcing. High-current events were detected quickly (Figure 13 and 15) and when power was interrupted the event stopped. Low-fault current arcing events protected by an AFCB showed very little damage similar to the high-fault current event (Figure 14 and 15). All of the AFCB protected bundles showed very little damage; however, when testing with low-fault current, sometimes the bundle would tack to the line and the normal thermal protection would prevent further damage.

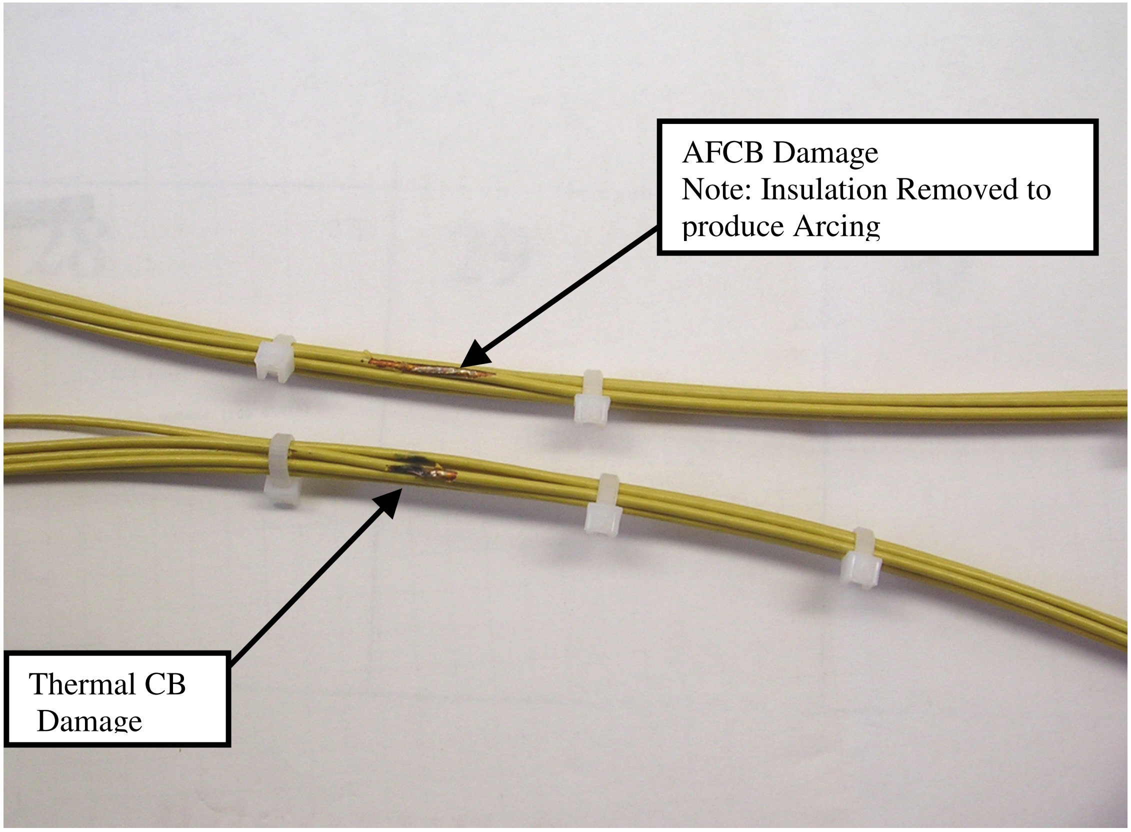


Figure 13. High-Fault Current Arc Fault Protection.

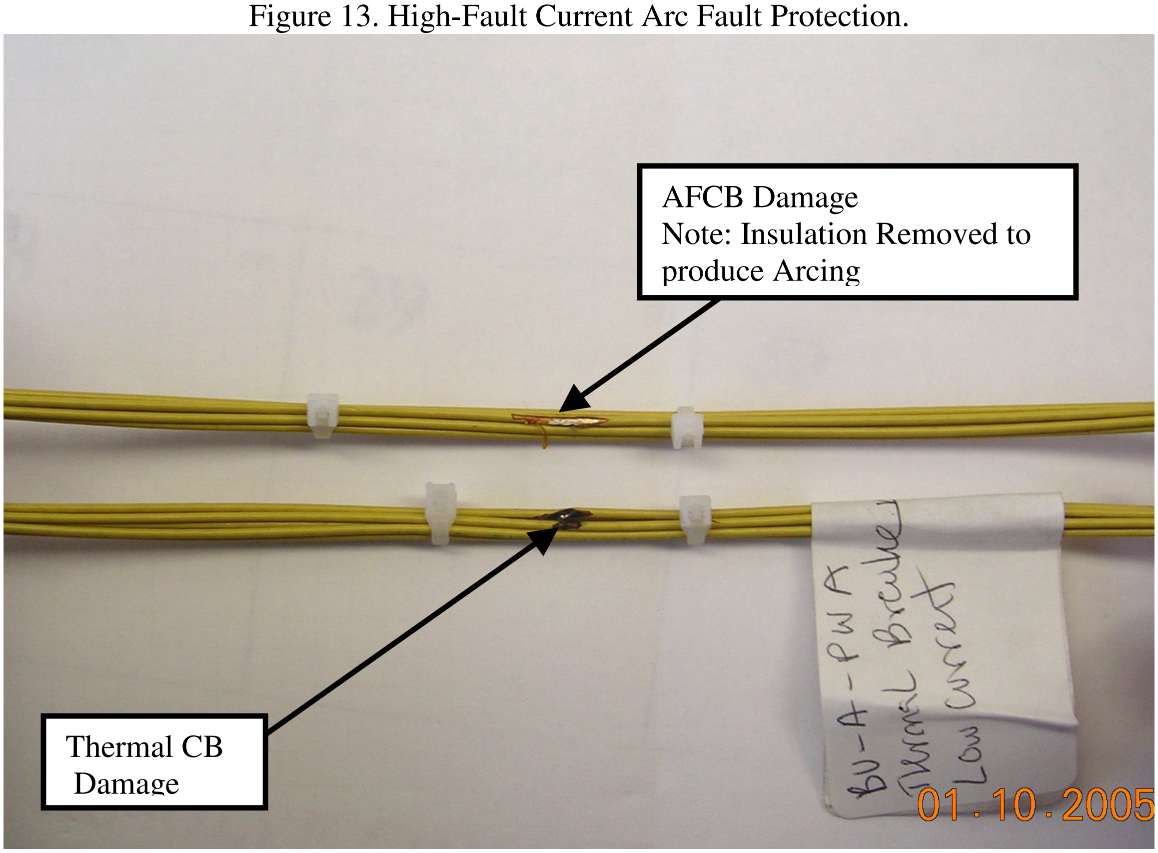


Figure 14. Low fault Current Arc Fault Protection.

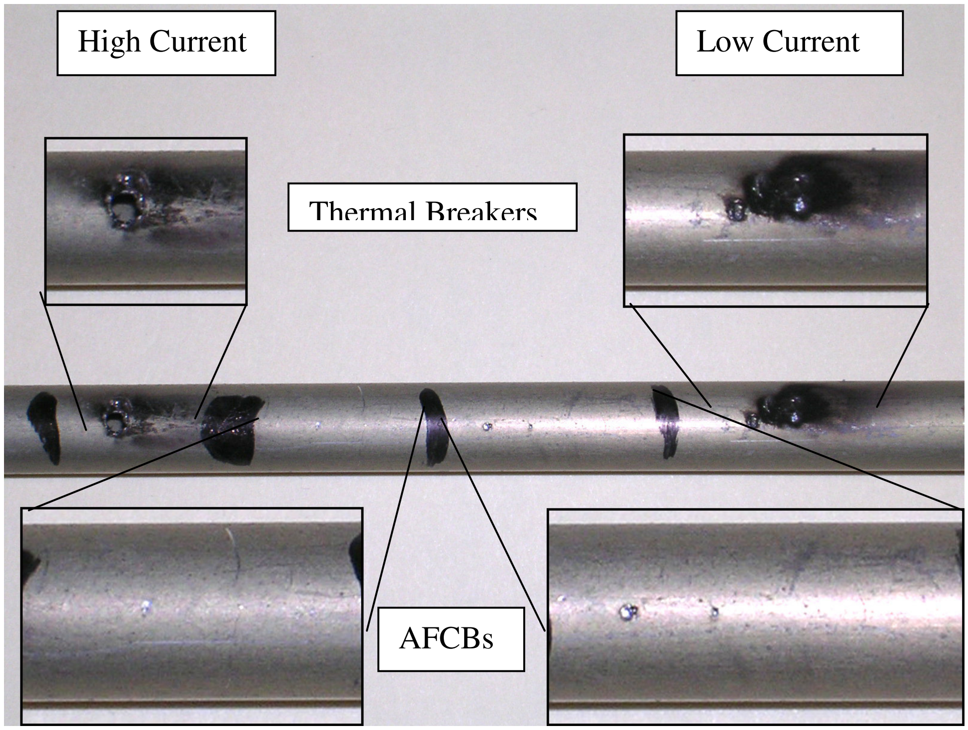


Figure 15. Hydraulic Line Damage

2.5.2. Material Insulation

All wire bundles were tested with high-fault current, a polyimide insulated arcing wire, and thermal protection. The results are shown in Table 6 and Figure 16. The PTFE wire showed little or no damage from the arcing polyimide wire. The PVC wire showed some damage and reduction in the insulation from material being melted away.

Table 6. Wire Insulation Types.

Bundle Wire Type	Damage
BU-B-PW-A	Damage on Wires 5, 1. Cosmetic Damage on Wire 7
BU-C-PW-A	Damage on Wires 5, 1, 7. Wire 6 Burn Thru
BU-D-PW-A	Damage on Wires 5,1,7. Cosmetic Damage on Wire 2. Wire 6 Burn Thru
BU-E-PWA	Cosmetic Damage on Wires 1, 5, 7
BU-F-PW-A	Cosmetic Damage on Wire 5

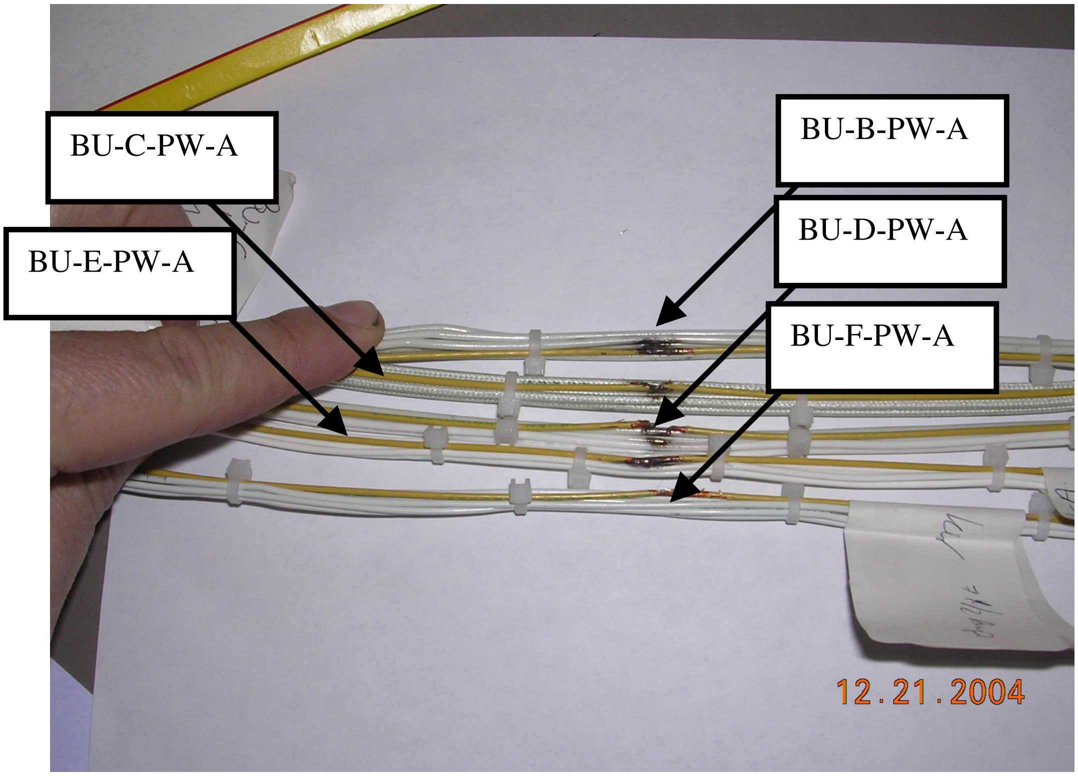


Figure 16. High-Fault Current Bundle Tests.

3.0 Conclusions

Blanket ignition is more dependent upon the location of the arcing event and the amount of spew in the arcing event than the amount of energy absorbed by the material.

All mitigation techniques tested proved effective in reducing arcing damage.

Testing techniques evaluating arcing events (i.e. guillotine, wet arc, and shaker table) can play a large role in the results. Comparative evaluation of arcing events must include measurements of arc voltage and fault current. The wave shape of the arcing fault can play a definitive role in the arc detection based on the arc protection algorithm used in the device.

Designers have many tools to reduce the effects of arcing incidents. Just like circuit protection, one method does not fit all applications. The reduced fault current mitigation technique will not work well with motor startup, and general AFCBs will not protect explosive environments. However, combinations of these techniques will complement one another.

Arcing mitigation can be controlled through circuit protection, material selection, and fault current management.

Testing techniques evaluating arcing events can play a large role in the results. Comparative evaluation of arcing events must include measurements of arc voltage and fault current. The wave shape can play a definitive role in the protection use based upon the arc protection algorithm.

3.1 Recommendations

Continued study in damage assessment of arcing incidents is necessary. Once a criterion for damage assessment is established, the true value of the mitigation technique can be found. The seven wire bundle technique used in this study proved extremely valuable in the evaluation of the mitigation technique.

Arc fault mitigation techniques must be evaluated in an environment reflecting documented arcing incidents. This has been difficult due to the lack of information and documentation of these problems. However, arcing incident reporting has been improving with increased awareness from maintenance personnel. As this improved data becomes available, it will be used to develop better functional testing of arc mitigation techniques.

Arcing with mixed power sources needs to be explored to obtain a full picture of what occurs to arcing in a bundle. This study attempted to understand arcing damage from one power source; however, a wire bundle usually contains more than one power source.

The reduction in fault current available proved to be an effective technique to reduce arcing damage. This technique could be implemented with relatively inexpensive and simple components. Once implemented the voltage drop created could lead to better load protection. An evaluation of how this technique could be used and its effect on aviation loads would prove valuable.

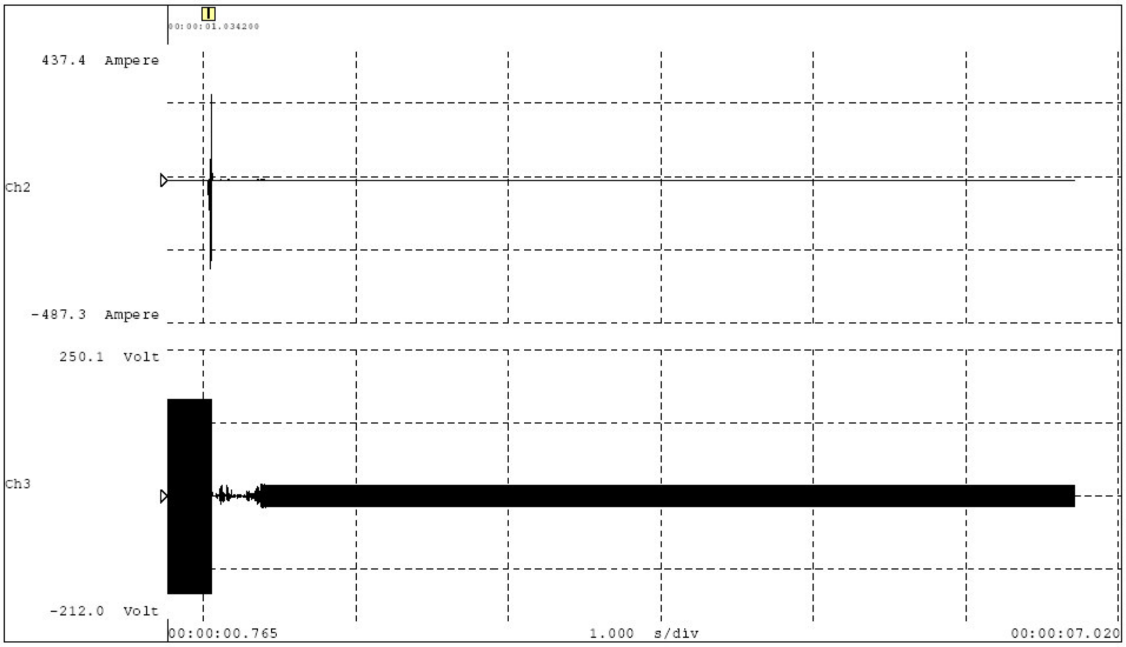
3.2 Further Testing

This study was only intended as an initial study in arcing mitigation techniques. Future tests will include ignition quantification of additional blanket material, conduit, control cables, ac/dc arcing damage quantification, mitigation of mixed wire bundles, different phase power wires in a bundle, and the use of sleeving and conduit and additional wire types.

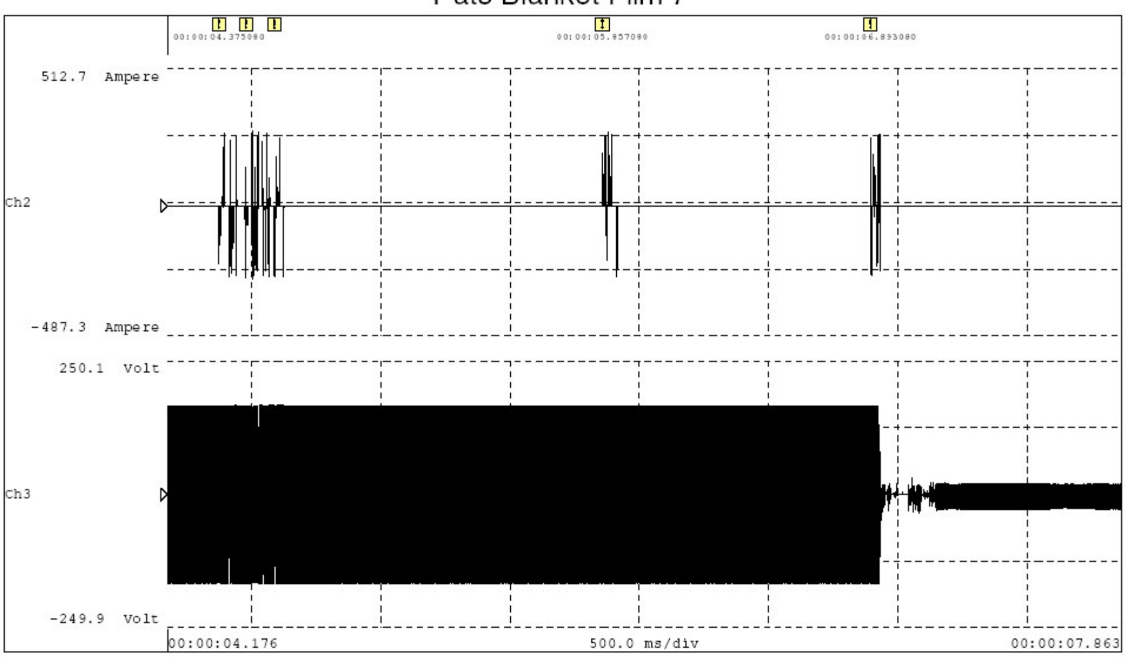
Appendix

Waveforms

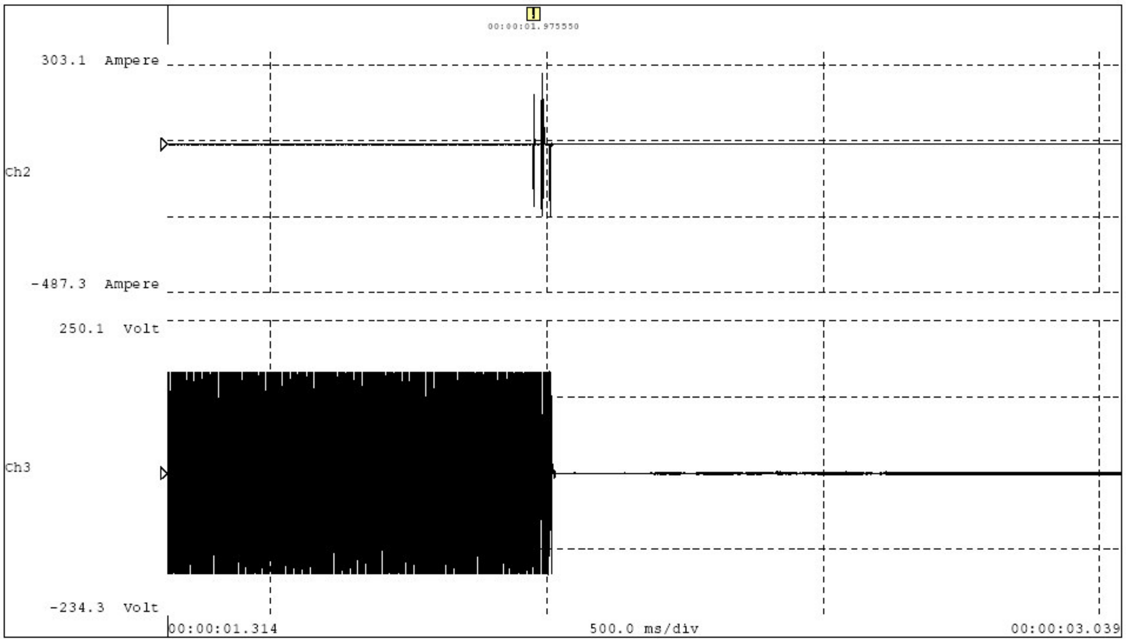
Pats Blanket Film 6



Pats Blanket Film 7



Pats Blanket Film 8



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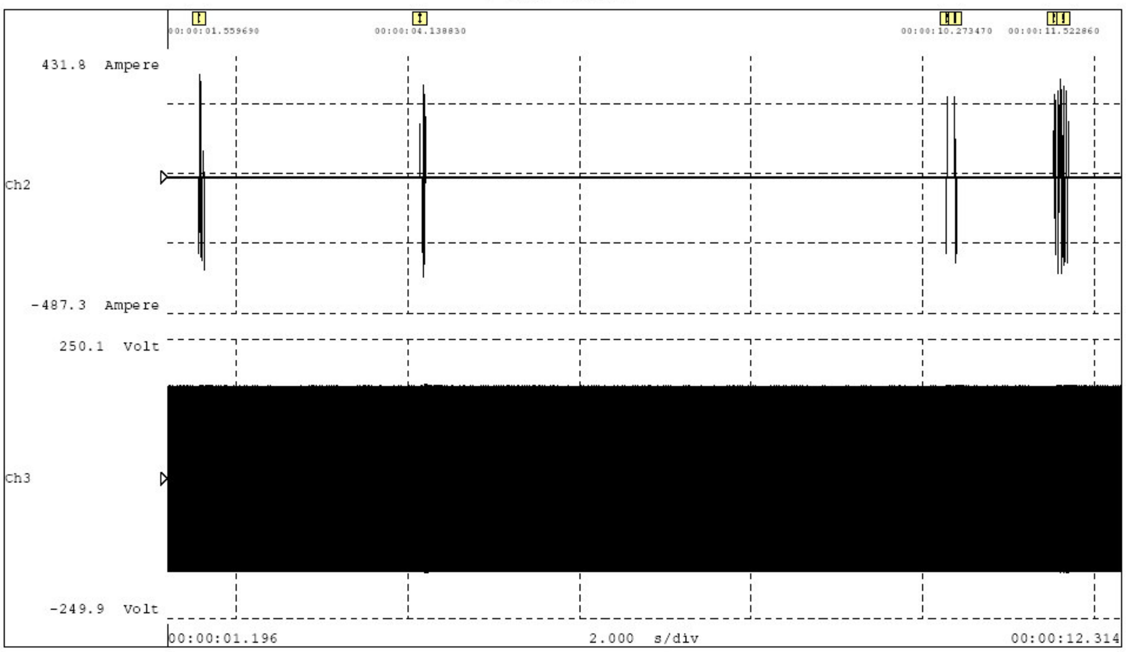

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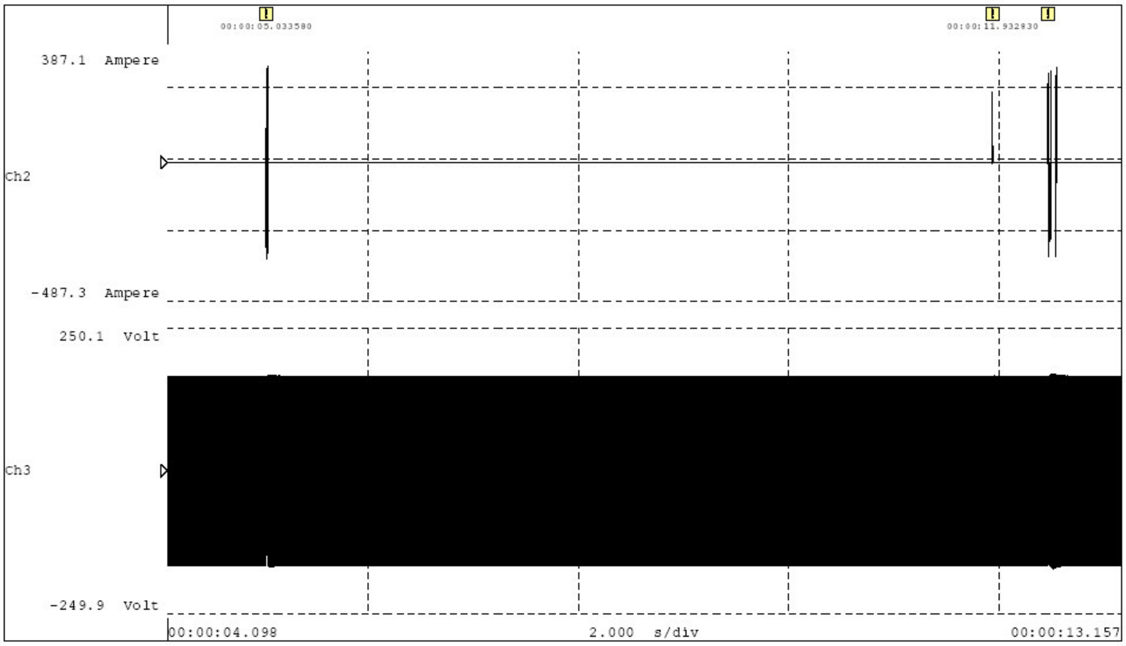
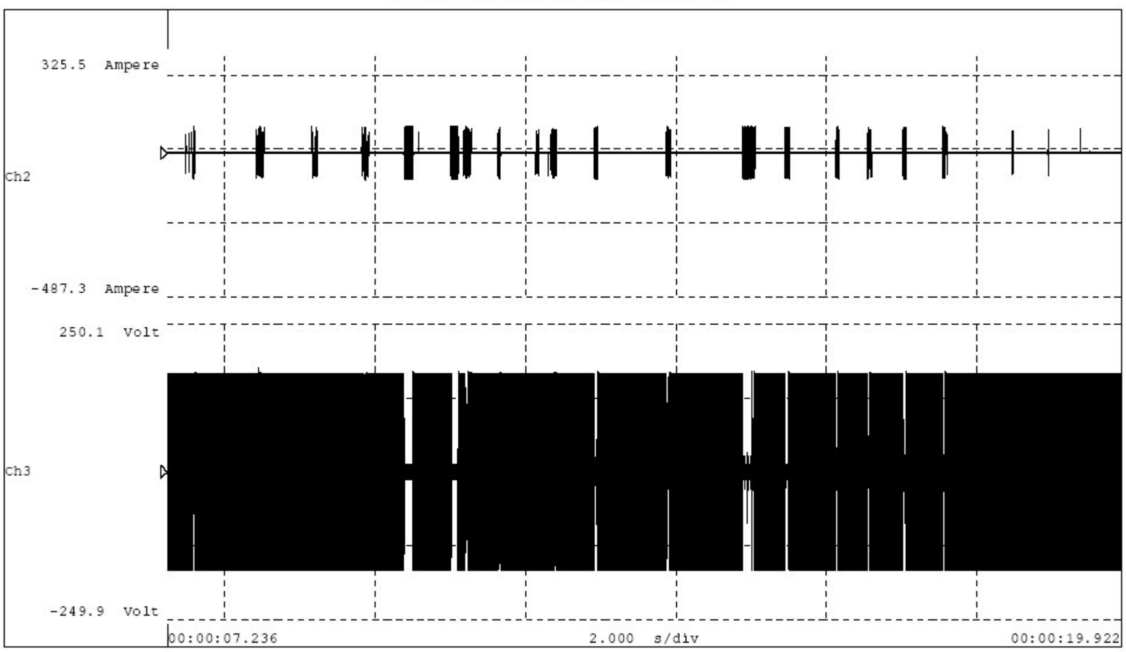


Arc Fault Low Current 10



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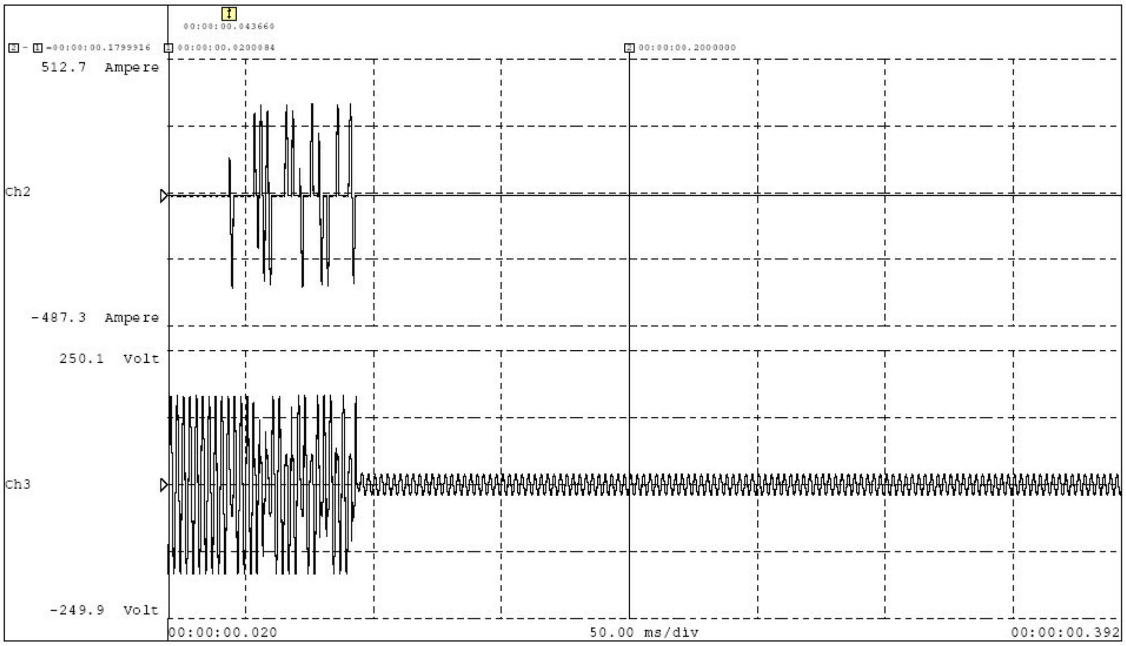

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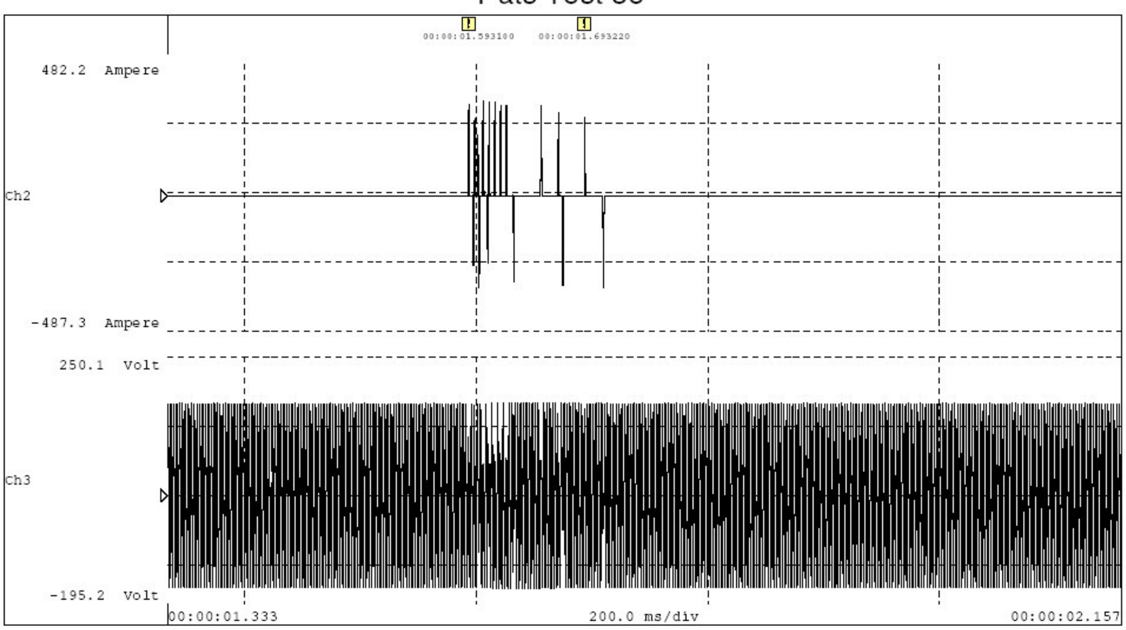
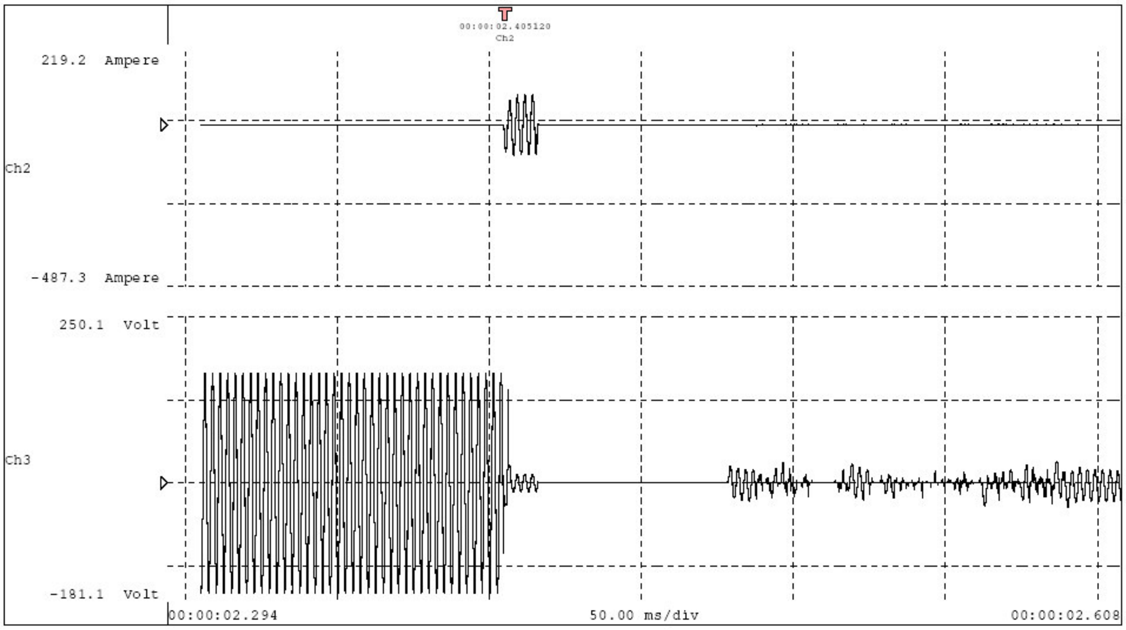


AFCB LC 4



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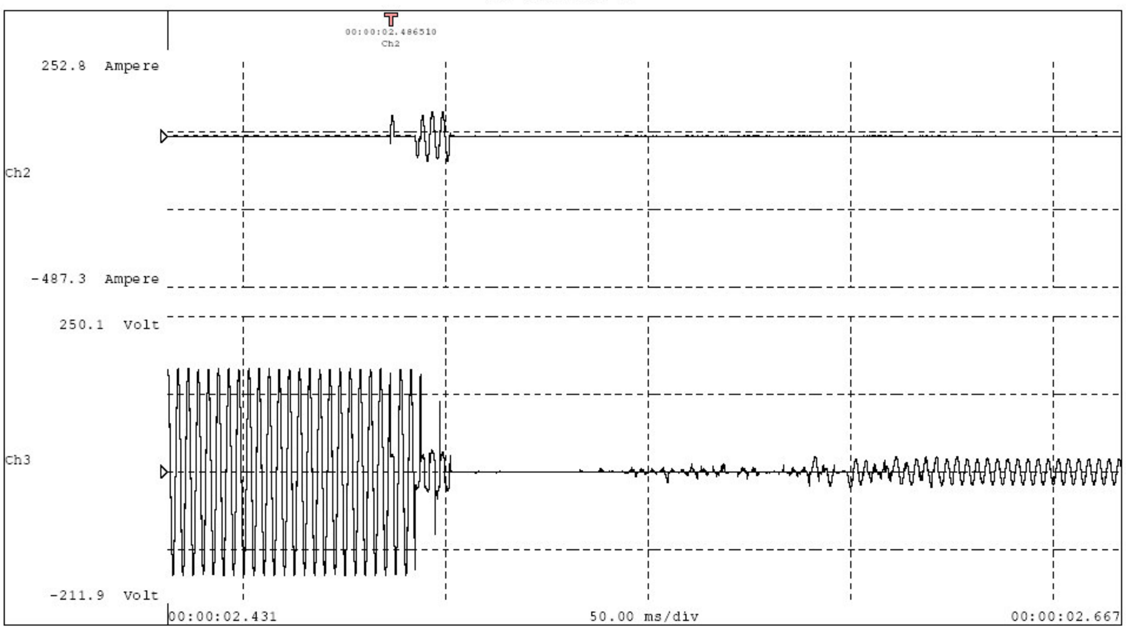
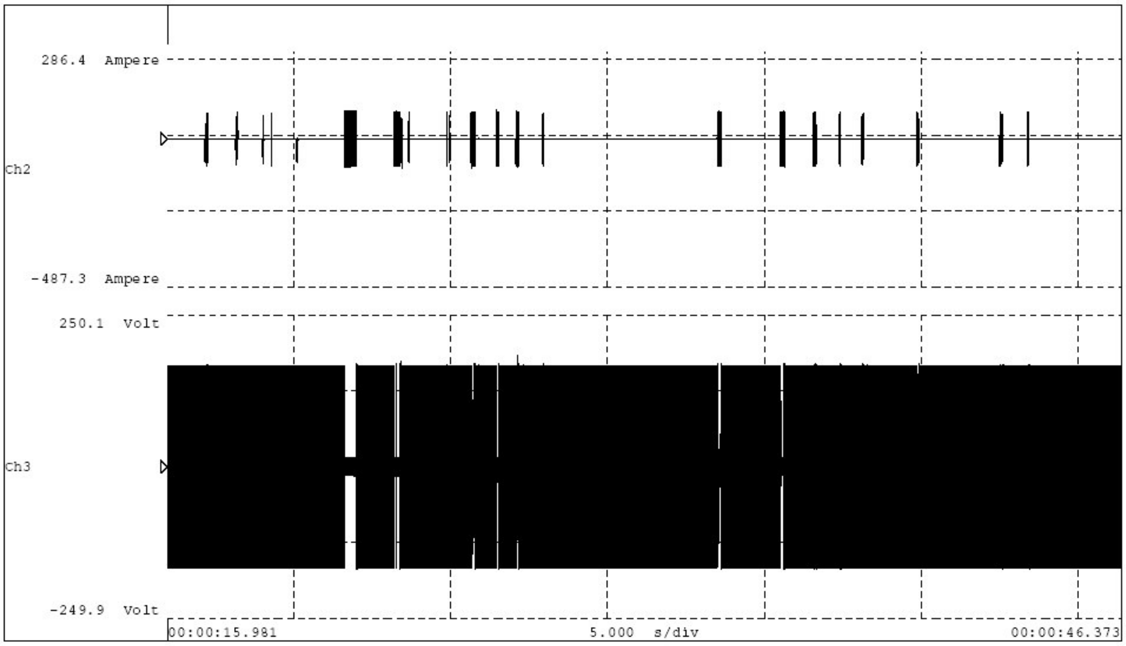
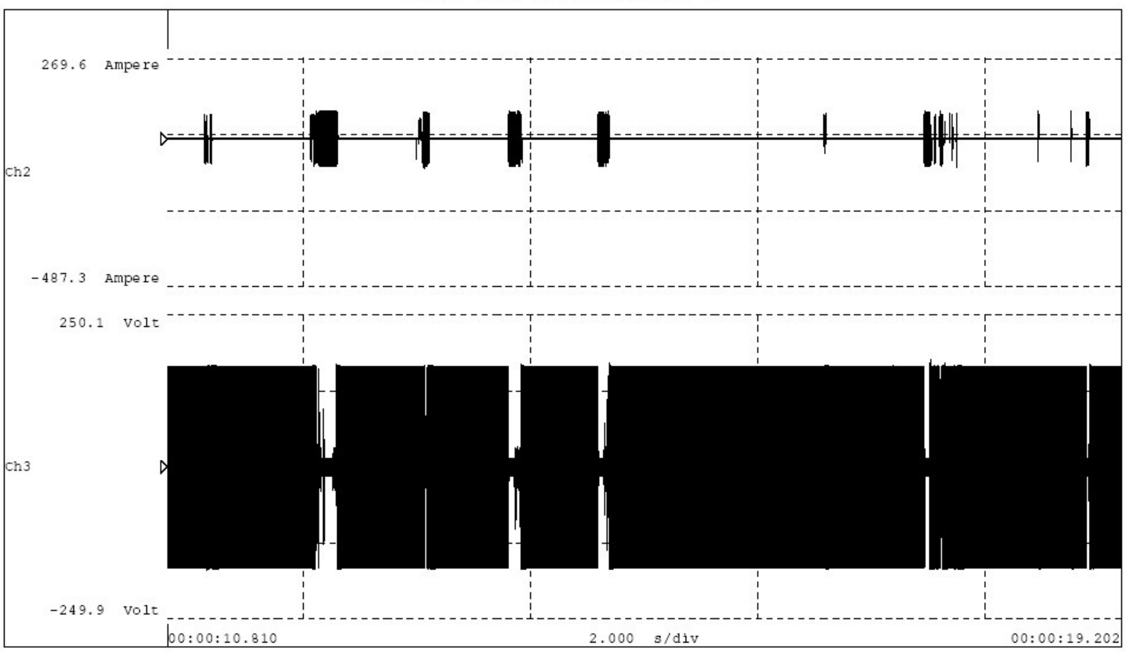


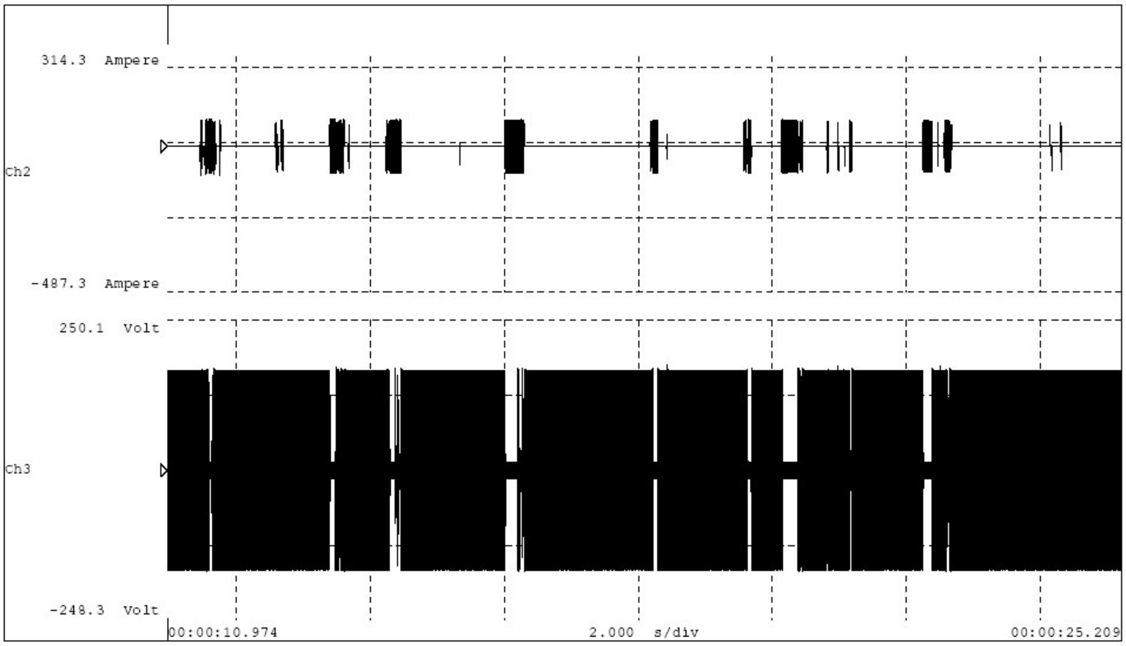
Arc Fault Low Current



Arc Fault Low Current 2



Arc Fault Low Current 3



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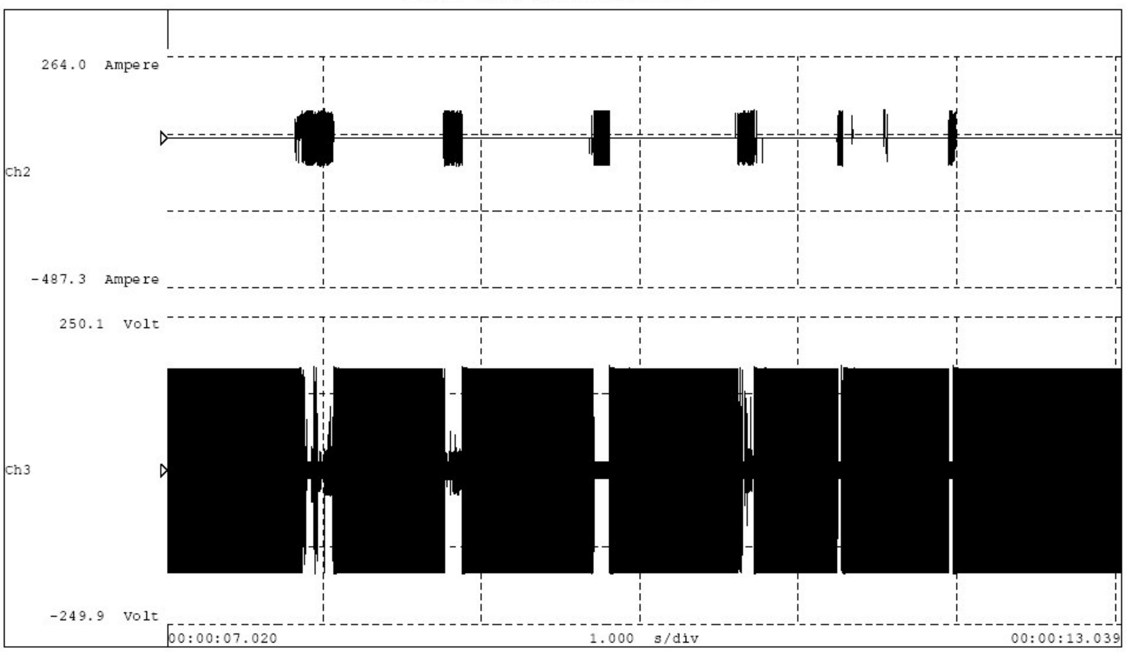
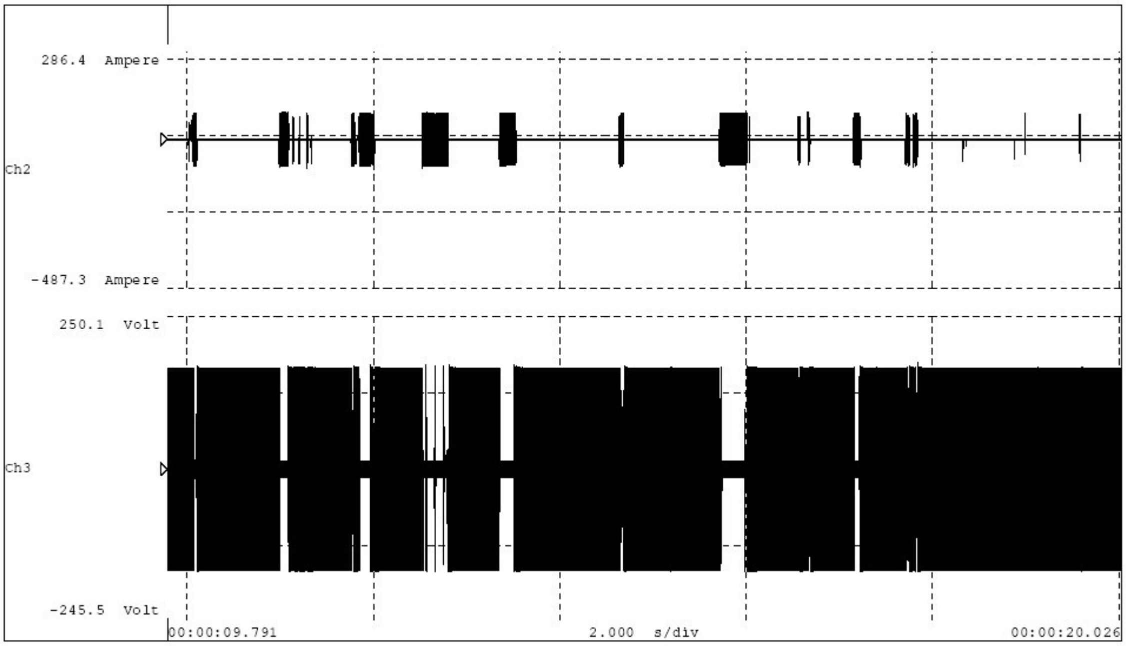
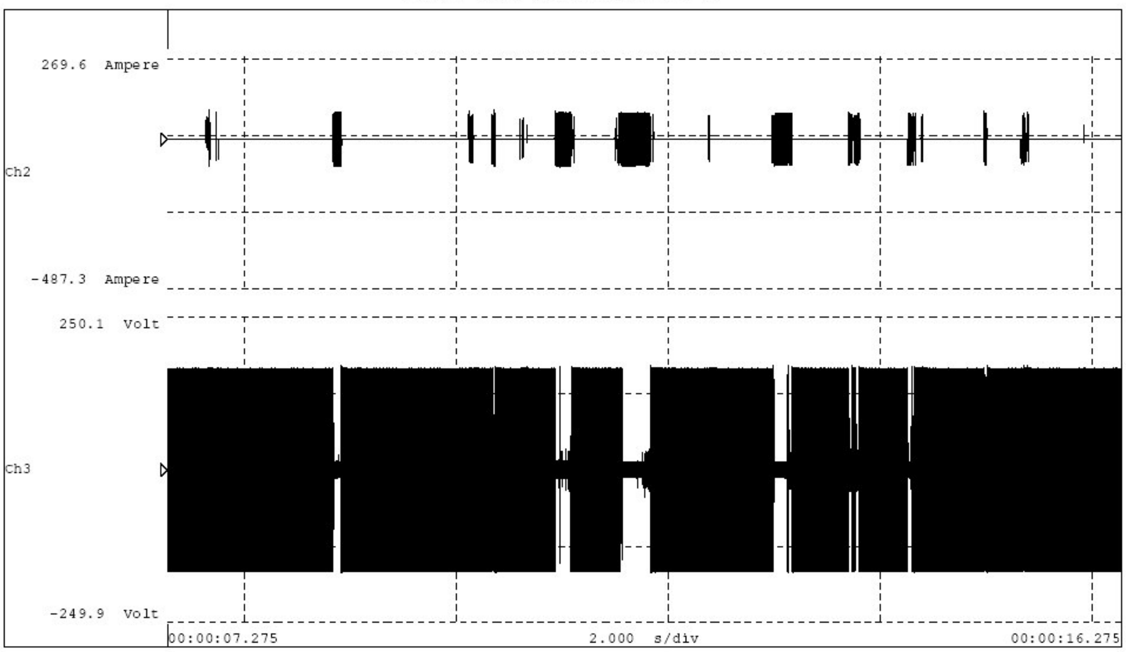


Arc Fault Low Current 5



Arc Fault Low Current 6



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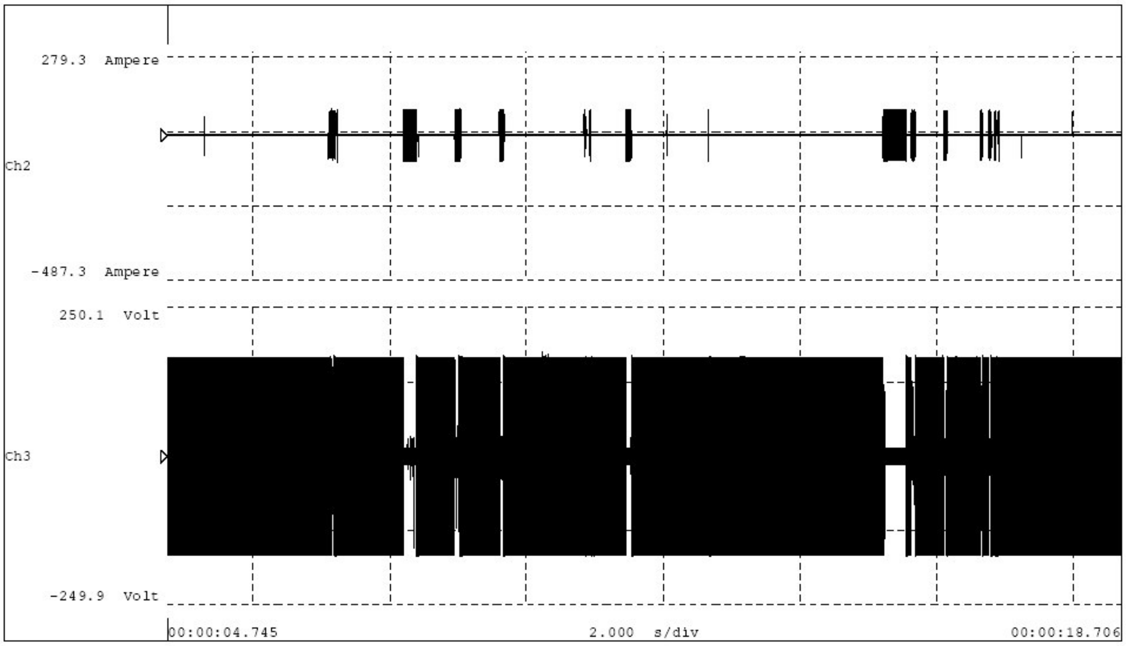
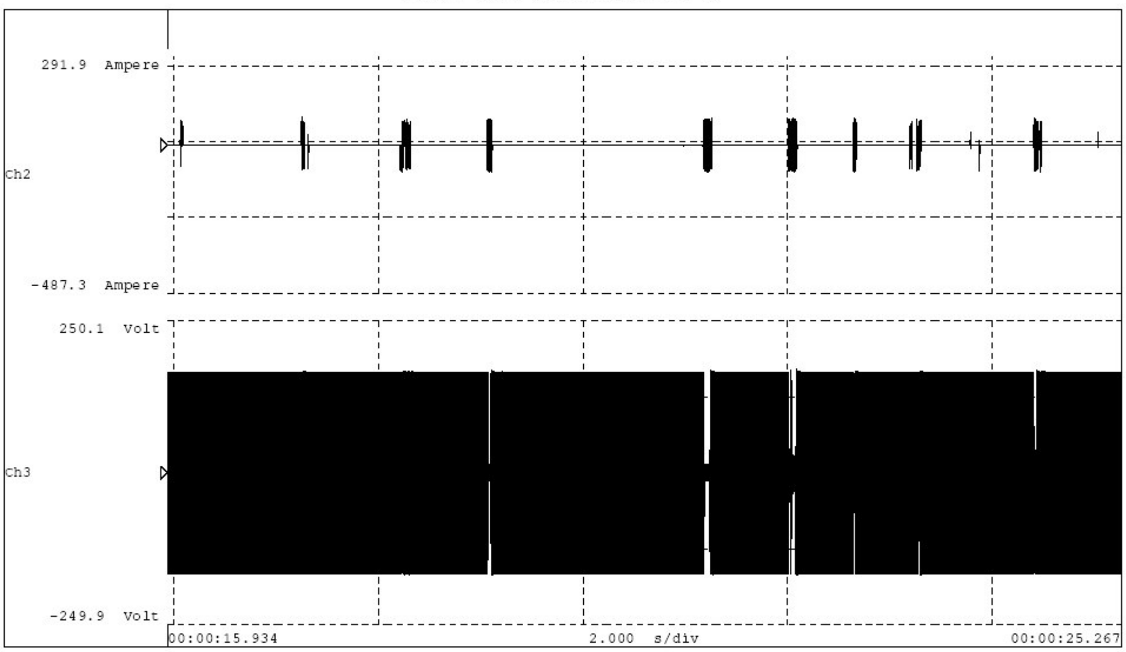


Arc Fault Low Current 8



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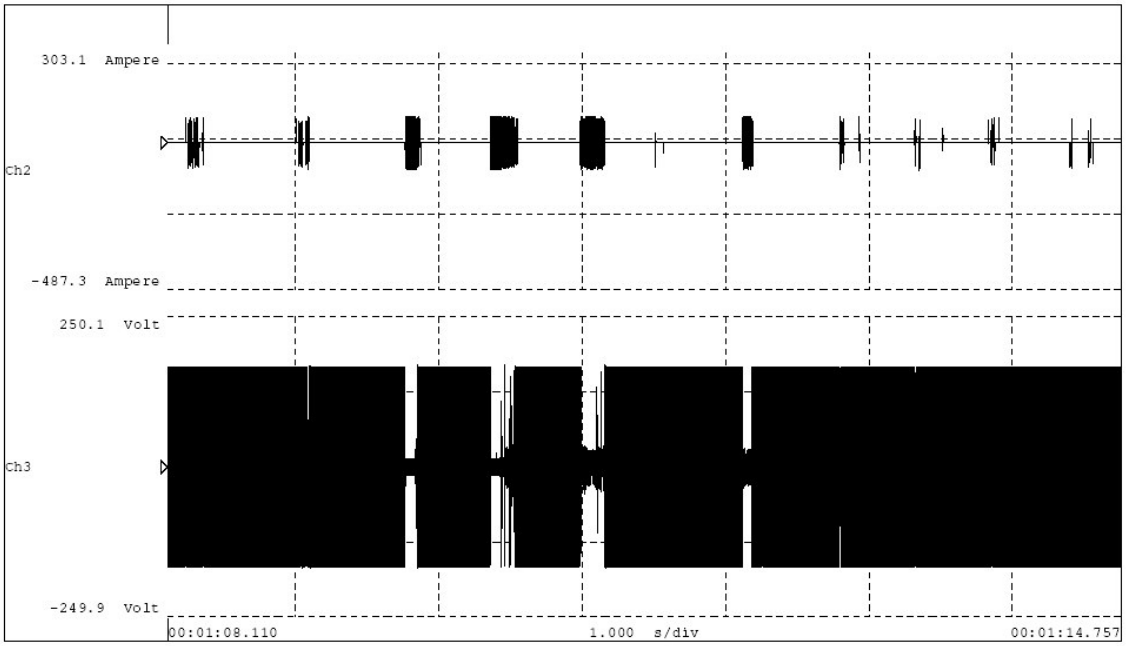

Arc Fault Low Current 10