F-16 Wiring Harness Training – Advanced eBook

By John Ashour

President

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InterConnect Wiring

5024 W Vickery Blvd

Fort Worth, TX 76107

1-817-377-9473

www.interconnect-wiring.com

Dedication

InterConnect Wiring dedicates this eBook to all the maintainers, trainers, program managers, engineers, buyers, logisticians, commanders, and pilots who support the F-16 worldwide. Thank you for your hard work and commitment!

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Introduction

This eBook is an advanced eBook because it contains more technical information than other eBooks that InterConnect Wiring (InterConnect) has previously released. When a person goes to college to study electrical engineering they might take a course in their freshmen year called Engineering 101. In their sophomore year they might take Electrical Circuits 201. In their junior year they might take Electronics 301. In their senior year they might take Advanced Theory of Electrical Circuits 401. If this eBook was a college course, it would be entitled Potential Safety of Flight Issues Concerning F-16 Wiring Harnesses 401, a senior year course!

So, for you college seniors who like to study about potential safety of flight issues of F-16 wiring harnesses, this eBook is for you. The purpose of this eBook is to train F-16 maintainers, program managers, pilots, engineers, etc. about advanced issues regarding F-16 electrical wiring harnesses. This eBook is divided into four main sections: (A) Breaches in the Insulation of F-16 Wires, (B) Inherent Viscosity of F-16 Wires, (C) Mean Time Between Failure (MTBF) for F-16 Wiring Harnesses, and (D) Arc Tracking of F-16 Wiring Harnesses.

Section A – Breaches in the Insulation of F-16 Wires

It is amazing that breaches in the insulation of wires is disregarded in the F-16 community. Many of these people think it's not a big deal. However, if these same people have an extension cord at home that has a nick in it they will immediately throw it away because they know it can lead to problems. They simply go to a hardware store and buy a new replacement extension cord.

If they have an appliance such as a coffee maker that has a nick in the cord they will throw away the whole coffee maker because they know it is a safety problem. It is an easy decision; if the wire has a problem with it, it should be replaced! Even one small nick in a wire should be replaced! So why is the F-16 community so accepting of nicks (AKA breaches) in wires? The answer to this important question is that the people who maintain the F-16 do not see the breaches because the breaches are underneath the braid. Braid is the outer cloth material that surrounds the wires in a wiring harnesses. Just looking at a wiring harness, you cannot tell if there are any nicks underneath the braid material. The problem with nicks is that they can lead to intermittent problems with system equipment. Sometimes a wire might have a nick, but the nick is closed so the system equipment will work fine. However, if the nick is not closed and the wire is flexed during normal aircraft operations, intermittent problems and even fires can result.

What is worse than an intermittent problem is when two wires near each other are both nicked. These wires can have electrical arcing from one nick to the other nick. If the arcing is fierce enough, fires can result. In fact, all the wires in the wire bundle can be damaged due to arcing. Even worse, there is an event called arc tracking that can cause many more problems due to the high temperature of the fire. When arc tracking starts, there is a small explosion. The arc tracking event will keep burning along a wire harness bundle for more than 10 seconds. Arc tracking is a very scary event for aircraft wiring harnesses. Arc tracking is discussed in much more detail (including videos) in Section D (Arc Tracking) of this eBook.

Chapter 1: How Many Breaches in the Insulation of F-16 Wire is Acceptable?

Occasionally a customer will ask InterConnect how many breaches in a wire's insulation is acceptable. The answer is an easy one; there should not be any breaches in the insulation of any wire inside an aircraft. So why is that? And, what is a breach?

A breach in the insulation of a wire is when the insulation no longer covers the conductor. Figure 1 shows a breach in F-16 Kapton wire. This breach was probably caused by chaffing of the wire against an object.

Figure 1 Breached F-16 Kapton Wire

Figure 2 shows more F-16 wires that are breached. Older F-16's were made with Kapton insulation. These older F-16's were color-coded according to a wire's gauge. The color code scheme is as follows:

1. Black: 26 gauge
2. Green: 22 gauge
3. Red: 20 gauge
4. White: 18 gauge
5. Yellow: 12 gauge

The green color shown in Figure 2 represents 22-gauge wire. When you look at these wires you see: (a) green, which is the paint for the color code, (b) orange, which is the Kapton insulation, and (c) silver, which is the conductor of the wire. The wire on the far left has a small breach that you can see because the silver conductor is apparent. The middle wire has a large breach. The green paint is breached as well as the orange Kapton insulation leaving the silver conductor exposed. The wire on the far right is not breached to the conductor. The green paint is breached but the Kapton insulation is not.

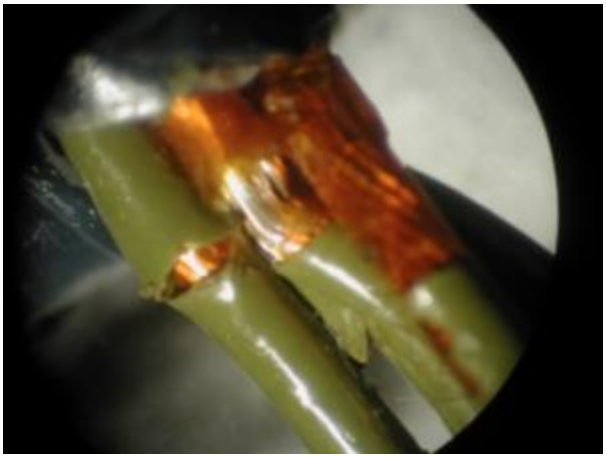


Figure 2 Multiple F-16 Wires Breached

The breaches observed in Figure 2 were probably caused by bending of the wires around an object. Because there are two wires adjacent to each other this breach is worse than others. When there are two or more breaches next to each other there is a chance of a short circuit which can lead to intermittent signals, arcing, and fires.

Aircraft wires are designed to be resistant to breaches. At the same time, they are designed to be lightweight and small in diameter. Thus, aircraft design engineers must make a decision as to how much protective insulation should cover wires, while at the same time try to reduce the size and weight of the wires on an aircraft.

When InterConnect makes wiring harnesses, none are shipped with breaches. If we accidentally nick or damage a wire during the manufacturing process, we replace the wire. It is unacceptable to have breaches in any wire. Breaches can lead to many problems in an aircraft and can even cause the loss of an aircraft, pilot and crew. InterConnect uses DITMCO wiring analyzers to test each wiring harness to make sure there are no breaches in any wire.

Bottom line is any breach in a wire's insulation is bad.

Chapter 2: How Many Breaches are there in the Wiring of a 20-Year-Old F-16?

Two common questions that InterConnect receives are: (1) "How many wiring harnesses are there in an aircraft?" and (2) "How many miles of wire are there in an aircraft?" This chapter will answer these questions as well as one more question which is "How many breaches are there in the wires of a 20-year-old F-16?" Before these questions are answered, let's do a quick review. The first chapter discusses what a breach is and how many breaches are acceptable in a wire's insulation. Put simply, a breach in the insulation of a wire is when the insulation no longer covers the conductor. It is an opening in the insulation that goes all the way to the conductor. For any aircraft (including an F-16) there should be no breaches in the insulation of any wire.

Older F-16's (20+ years old) typically have ~250 wiring harnesses. If you sum all wire lengths in an F-16, there is about 15 miles of wire (this equals 79,200 feet of wire). Over the past 25+ years, InterConnect has completely or partially rewired many different military aircraft including F-16's. Multiple times InterConnect has sent the removed ~20-year-old wiring harnesses to a professional test laboratory in Virginia named Lectromec for testing and analysis. As part of the scientific analysis, Lectromec determines how many breaches there are in the removed wiring harnesses. The results of Lectromec analyses are shown in Table 1.

No	Year Wiring Harnesses Removed	Number of Wiring Harnesses Analyzed	Number of Breeches Per 1,000 Feet of Wire	Total Amount of Wire (Miles)	Total Amount of Wire (Feet)	Estimated Total Number of Breeches
1	2006	33	5.4	15.0	79,200	428
2	2008	33	4.3	15.0	79,200	341
3	2010	24	1.0	15.0	79,200	79
4	2015	23	8.2	15.0	79,200	649
		Average				374

Table 1 Number of Breaches in an F-16

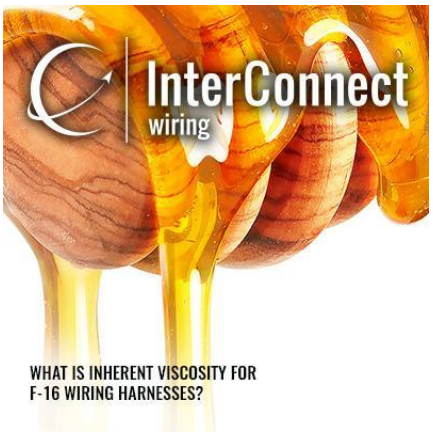
Any breach in a wire is a safety of flight issue. Breaches in any wires are bad. A wire in an aircraft with a breach should be replaced. Based on the results of the previous laboratory studies, breaches existed in all cases. The total number of estimated breaches is scary! A breach can lead to intermittent problems or fires. Two breaches close to each other can lead to arcing which in-turn can lead to arc tracking. If you have F-16's in your fleet, you can expect to have around 375 breaches in your wiring. That's a huge number and is a huge "flight safety issue"! The only solution to this problem is to replace old wiring harnesses with new ones that have no breaches.

Section B – Inherent Viscosity of F-16 Wires

Last year, I saw a partially opened-up F-16 fuselage that has been sitting outside for many years. Besides the structure of the F-16 fuselage there was also wiring harness bundles. The bundles were so deteriorated that the Nomex braid material was no longer present. All that was left was wires that were bundled together. This fuselage was used many years (over 30 years) to help design wiring harnesses for future F-16 models. What fascinated me was that I could see the Kapton insulation that surrounded the conductors of the wire. It was obvious that the Kapton was old and deteriorated but it was still there. I used my finger with minor pressure and rubbed the outside of the Kapton. Like I expected, the Kapton insulation simply fell off. The Kapton had deteriorated so much that it could no longer hold itself together. When I barely rubbed the Kapton that the only thing left was the inside conductor of the wire.

So why did I start this chapter off by telling this story. The answer is simple. Kapton insulation is a polymer. In time it will degrade and no longer serve its useful purpose. So when does Kapton degrade to the point it no longer serve its useful purpose? Kapton will degrade differently depending on the environment. For harsh environments, it will degrade much faster. For less intrusive environments, it will degrade more slowly. How do you know how much of it has degraded? The answer to this question is in a measurement called “inherent viscosity”.

Chapter 3: What is Inherent Viscosity for F-16 Wiring Harnesses?



Before we discuss “inherent viscosity”, let’s talk about what “viscosity” is. The layman’s way to think of viscosity is how “sticky” a fluid is. For instance, a cup of normal drinking water has a very low viscosity. It is not sticky at all. When you pour a cup of water it moves quickly. Compare that to a cup of honey. Honey has a much higher viscosity. It sticks together much more than a cup of water. So, when you think of Kapton insulation and inherent viscosity think of how much the Kapton is clinging to itself (how sticky the Kapton is). New Kapton is sticky. Once Kapton ages it is less sticky and is not as good an insulator as new. Kapton insulation loses its good properties over time.

Simply put, in terms of F-16 wires, Inherent Viscosity is a measurement of the relative age of the Kapton insulation. If inherent viscosity is high, that is good. The insulation of the wire is conforming to design

parameters and thus is doing its job. If inherent viscosity is low, that is bad. The insulation is not doing what it is supposed to do, which is to protect the inner metal conductor.

Inherent viscosity for new Kapton wiring is generally about 1.8. If a batch of Kapton is made and its inherent viscosity is 0.9 or less, it is rejected and regarded as non-conforming. For the F-16, InterConnect uses 0.9 as the cut-off point of when replacement of the wiring on the F-16 should strongly be considered. If the inherent viscosity is 0.9 or less the Kapton has lost much of its good properties and is suspect.

Since 2006, InterConnect has sent old F-16 wiring harnesses to a professional laboratory to have inherent viscosity measured. In order to measure it, the laboratory must conduct a destructive test on the Kapton insulation. As one would expect, inherent viscosity of the Kapton wire varies throughout the F-16 due to the environment (i.e. where the F-16 wiring harness is installed). In some areas, the Kapton is like new. In other areas it has seriously degraded. Table 2 shows the results (i.e. the lowest values found in each area tested) of laboratory studies of F-16 Kapton wiring. Notice that it varies depending on the where the wiring harness is installed.

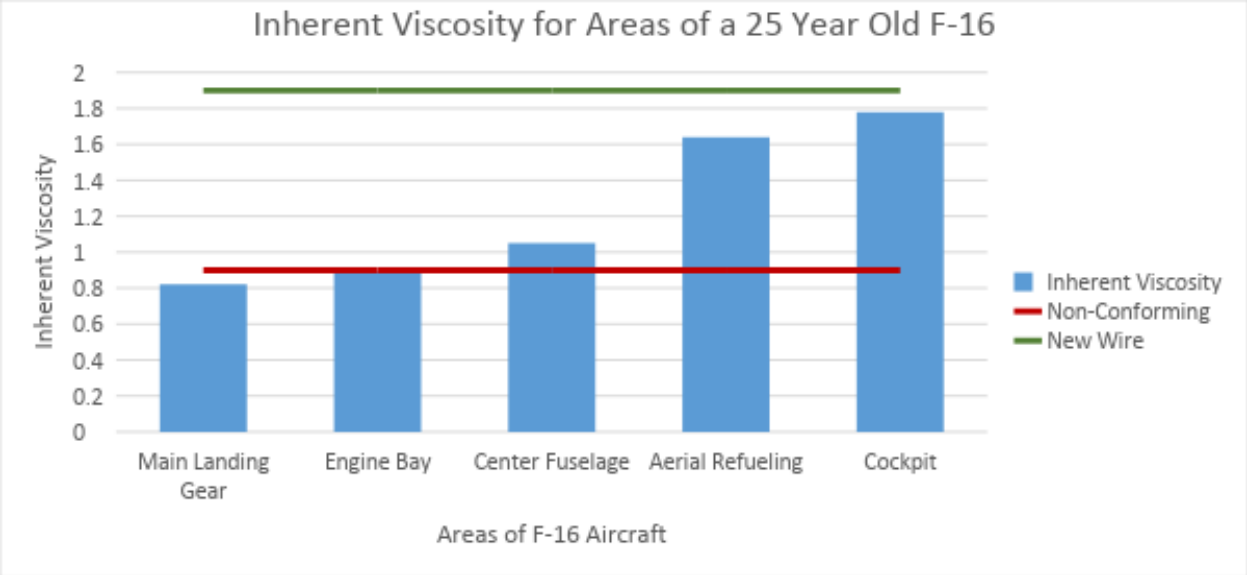


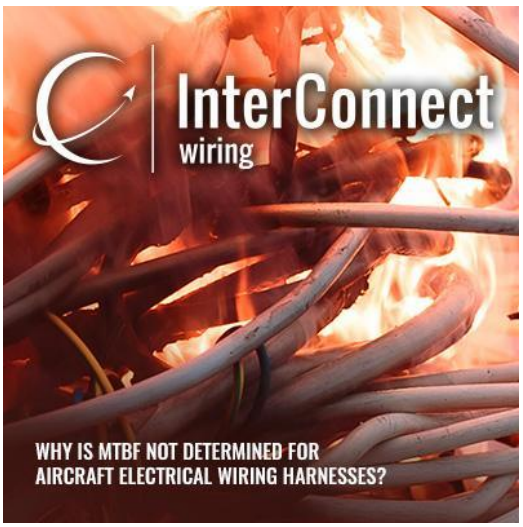
Figure 3 Inherent Viscosity for Areas of a 25-Year-Old F-16

The bottom line of the laboratory results is that when aged, the Kapton wiring has degraded beyond the recommended cutoff value of 0.9, the Kapton is a safety of flight issue, and the wiring should be replaced.

Section C – MTBF for F-16 Wiring Harnesses

One subject that InterConnect has been bringing-up now for many years is, “Why is there no set values for Mean Time Between Failure (MTBF) for F-16 wiring harnesses?” Another way to ask this question is “How often should wiring harnesses be replaced?” Is it every 5 years, every 20 years, every 50 years, or even only after 100 years?? This section of this Advanced eBook addresses this question. Read on and decide for yourself!

Chapter 4: Why is MTBF Not Determined for Aircraft Electrical Wiring Harnesses?



There are four main reasons why MTBF is not calculated for aircraft trunk wiring harnesses: (1) No widely accepted method to calculate it in a laboratory, (2) MTBF changes for wiring harnesses depending on where they are installed in an aircraft, (3) The cost to an aircraft owner if MTBF’s were established, and (4) No organization exists that cares to tackle this difficult subject.

The first reason that there is no MTBF for wiring harnesses is because there is no widely accepted method to calculate it. For most aircraft equipment, there are ways to calculate MTBF by cycling the piece of equipment in a laboratory faster than normal use in an aircraft. The purpose of aircraft wiring harnesses is to transmit electrical signals. If you put an aircraft wiring harness in a laboratory and cycle electrical signals, the wiring harness will probably last over 100 years. The problem with this test method is that the laboratory does not simulate the environment where wiring harnesses are installed inside an aircraft. The laboratory does not simulate environmental changes such as: (1) huge temperature swings, (2) high G forces, (3) dust and other contaminants, (4) liquids including hydraulic fluid and jet fuel, (5) pieces of equipment near wiring harnesses that chafe the wiring harness, and (6) flexing and bending of the wiring harness during flight or when equipment is replaced that is connected to a wiring harness.

The second reason there is no MTBF for aircraft wiring harnesses is that MTBF actually differs depending on where wiring harnesses are installed inside an aircraft. A section of an aircraft that is more exposed

to a harsh environment, such as the aerial refueling area, will have a lower MTBF than other areas that are not as harsh. In the past, InterConnect released a blog on their website that describes the most harsh areas inside an F-16 for wiring harnesses. The harsher the environment that a wiring harness is installed the lower the MTBF. A company that designs and manufactures aircraft wiring harnesses cannot say that the MTBF for every wiring harness for an aircraft is X number of years. The MTBF changes according to the environment.

The third reason, unfortunately, is one of the main reasons why MTBF is not provided for aircraft wiring harnesses. The bottom line is cost. When an aircraft is assembled, the first step is to attach the structural components together such as the forward part of the fuselage to the mid part. After the structure, the next step is to install the wiring harnesses throughout the aircraft. After the wiring harnesses are installed, equipment is installed that covers up the wiring harnesses. After the equipment is installed, exterior panels are installed. If you open up one of these panels you do not see wiring harnesses because they are buried inside the aircraft. If MTBF's were defined for aircraft wiring harnesses, then the harnesses would have to be replaced and would be a costly endeavor. Someone must "open up" the aircraft to access them. Opening-up an aircraft is time-consuming and costly. This wiring harness replacement cost can be expensive and most aircraft manufactures prefer not to address it.

The fourth and final reason that MTBF's are not provided for aircraft wiring harnesses is that there is no organization that is pushing for MTBF's to be established for wiring harnesses. InterConnect knows of only two organizations that are concerned with aircraft wiring harnesses: (1) Wire Harness Manufacturers Association (WHMA) and (2) Joint Services Wiring Action Group (JSWAG). WHMA is not solely focused on aircraft wiring harnesses. WHMA includes manufactures of wiring harness for many industries such as: (a) household appliance, (b) automotive, (c) medical, and (d) oil. No group inside WHMA addresses aircraft wiring harnesses. IPC/WHMA-A-620 comes close but MTBF for wiring harnesses is never covered. JSWAG, however, does address aircraft wiring harness issues. JSWAG is for military services only and their discussions are not for public disclosure. Perhaps JSWAG has started discussing MTBF for military aircraft wiring harnesses.

The bottom line is that there are no established MTBF's for aircraft wiring harnesses. Aircraft wiring harnesses are installed and forgotten. If there is a problem with a wiring harness they are replaced. The documentation of when wiring harnesses have problems or are replaced is generally poor. Wires inside a wiring harness are used for many different systems. For aircraft records, problems discovered are categorized by the system for a piece of equipment. There is no system for wiring harnesses. Hopefully, sometime in the future, MTBF's will be established for aircraft wiring harnesses.

Chapter 5: What is the MTBF for F-16 Wiring Harnesses?

Many readers probably do not know what the term Mean Time Between Failure (MTBF) means. MTBF is a measurement of the number of days (or years) that a device will fail based on test results or past performance. In the aerospace industry, MTBF is calculated for just about every piece of equipment that has active mechanical or electrical components. In theory, MTBF is a preventative action tool where a piece of equipment is replaced or overhauled before it fails. Commercial airlines as well as Original Equipment Manufacturers (OEMs) like Lockheed Martin, Boeing, and Airbus spend millions of dollars developing and refining MTBF's for just about everything on an aircraft. This holds true for military aircraft including the F-16.

Here is an example of how MTBF is used in the aerospace industry. Let's say Lockheed Martin is designing a new aircraft. As part of the design, Lockheed hires another company to design a new hydraulic pump. Included in the design-work, the company is also responsible for setting an initial MTBF. The company can do this task based-on previous performance of other similar hydraulic pumps, or they cycle (or age it) repeatedly before it fails. Let's say the MTBF for this pump is 1,200 hours. Once this baseline is established, the owners of the aircraft know that they need to remove and replace (and/or overhaul) this pump before 1,200 hours. After MTBF is established for a piece of equipment, effort is made to determine ways to improve the design of the pump to increase its MTBF. If the cost to improve the design is less than the cost of replacing/overhauling the pump, the user of the aircraft saves money.

Any guess what the MTBF is for F-16 wiring harnesses? Look at Table 2 and guess the number of days an F-16 wiring harness will last.

Option	Years	Days per Year	Total Days
1	5	365	1,825
2	10	365	3,650
3	15	365	5,475
4	20	365	7,300
5	25	365	9,125
6	30	365	10,950

Table 2 Possible MTBF Values for F-16 Wiring Harnesses

How many days did you guess? That is, when will an F-16 wiring harness fail? If you guessed none of the above then you are correct. The correct answer is infinity or said in a different way, there is no MTBF for F-16 wiring harnesses. It is assumed that once you install a wiring harness inside an F-16, it will never fail. It will continue to work as designed until the aircraft is done and sent to the scrapyard or graveyard. One interesting point to mention is that although many F-16's were retired and sent to the graveyard (or boneyard), they are now being taken out of the boneyard for refurbishment. Bulkheads and other structures are replaced to extend the lifetime of the aircraft but there is little thought about replacing the old wiring harnesses. Isn't that crazy for aircraft over 20 years old???!!!

What's even crazier is that the MTBF of wiring harnesses of new aircraft such as the F-35 is also infinity. There is no planning or preventive maintenance for wiring harnesses even on a 5th generation fighter!

InterConnect prides itself on being the world's leader in F-16 wiring harnesses and F-16 electrical panel assemblies. After 25+ years of extensive research, we have recommendations on what the MTBF should be for F-16 wiring harnesses.

Chapter 6: What are the Ten Most Problematic Areas for Kapton Wiring in F-16's?

Like most airplanes, the F-16 is made up of four basic structures: (1) fuselage, (2) wings, (3) horizontal tail, and (4) vertical tail. Inside each of these structures are smaller sections that house: (a) other structures such as bulkheads, (b) equipment (both electrical and mechanical), (c) tubing/ducting, and (d) electrical wiring harnesses. Tubing/ducting and electrical wiring harnesses are unique since they are routed through many sections of an aircraft. A wiring harness can start in the cockpit and run back to the engine bay. Most wiring harnesses are a part of multiple systems and thus wiring harnesses are not typically named after a system. Very seldom would you see a wiring harness named something like "The

External Lighting System Wiring Harness". Instead, they are generally named by what fuselage station (FS) they start and what fuselage station they end such as "Wiring Harness – FS 341 to FS 446".

With this type of nomenclature in mind for wiring harnesses, when discussing the most problematic areas for Kapton wiring inside an F-16 it should be noted that part of a wiring harness may be installed inside an area where the environment is not very harsh, while other parts of the same wiring harness are routed into other areas that are severely harsh.

InterConnect Wiring has been designing and manufacturing F-16 wiring harnesses for over 25 years. InterConnect has also performed many laboratory tests on F-16 wiring harnesses that have been installed inside F-16's for over 20 years. Based on: (1) laboratory tests, (2) physically taking apart and assessing the condition of used F-16 wiring harnesses, and (3) analyzing worldwide spare parts orders of F-16 wiring harnesses, Table 3 lists of the ten most problematic areas for Kapton wiring inside an F-16. The list is from the worst area (number 1 on the list) to the least area (number 10 on the list).

Number	Area
1	Leading Edge of the Wings
2	Main Landing Gear Wheel Well
3	Nose Landing Gear
4	Aft Fuselage (Especially the wiring harnesses attached to the battery and the 10KVA Generator)
5	Aft Equipment Bay (Especially the Wiring Harnesses attached to the Gyros)
6	Engine Bay
7	Aerial Refueling Cavity
8	Fuel Cell Areas (Especially the Wiring Harnesses made with Convoluted Tubing)
9	Cockpit
10	Forward Fuselage

Table 3 Ten Most Problematic Areas for F-16 Wiring Harnesses

The cockpit and forward fuselage are listed as the least problematic because they typically undergo many major modifications; thus, these wiring harnesses are replaced much more often than any other area of the aircraft. Two such large avionic upgrades for F-16's that replace almost all of these wiring harnesses are MLU (Mid Life Update) and CCIP (Common Configuration Implementation Program).

Finally, it should be noted that many people forget that F-16 pylon wiring harnesses also live in a harsh environment. Since pylons are not a permanent structure of an F-16 they were left off the list. If they were included, they would be listed as number 3.5.

Chapter 7: What are the MTBF Recommendations for F-16 Wiring Harnesses?

The short answer to "What are the MTBF Recommendations for F-16 Wiring Harnesses?" is unfortunately, "It varies."

As you would expect, the most problematic wiring harnesses should have the least MTBF's (i.e. their mean time between failure is less than other F-16 wiring harnesses). To phrase this another way, you should replace the most problematic wiring harnesses more often than other wiring harnesses inside an F-16. This concept seems basic but gets complicated because some misinformed people think that aircraft wiring harnesses, once installed, should never be replaced. Oftentimes, wiring harnesses are

installed and forgotten. InterConnect believes in preventive action (especially for F-16's that have Kapton insulated wiring). Table 4 lists InterConnect's recommended MTBF's for the F-16.

Number	Area	MTBF or How Often to Replace (Years)
1	Anti-Skid Wiring Harness	4
2	Nose Wheel Stering	5
3	Main Landing Gear	6
4	Engine Wiring Harness (Spider Harness)	7
5	Battery Wiring Harness	8
6	Pylon Wiring Harnesses	9
7	Gyro Wiring Harnesses	11
8	10 KVA Generator	12
9	Ejection Seat Wiring Harness	13
10	Leading Edge Wing	14
11	Aft of Staion 341	15
12	Forward Fuselage	16
13	Power Panel Wiring Harnesses	17
14	Cockpit	18
15	Mux Panel Wiring Harnesses	19
16	Relay Panel Wiring Harnesses	20
17	Fuel Cell Wiring Harnesses (Convoluted Tubing Only)	21
18	Aft Equipment Bay	22

Table 4 MTBF Recommendations for F-16 Wiring Harnesses

Chapter 8: What is the Priority List of Wiring Harnesses to Replace on a 20-Year-Old F-16?

InterConnect offers many wiring harness replacement programs, sometimes calling them rewire programs. InterConnect's most popular F-16 rewire program is for wing Leading Edge (LE) wiring harnesses. InterConnect has built more of these wiring harnesses than any other. The total list of rewire programs that InterConnect offers is: (1) Wing LE Flap, (2) Falcon Wire, (3) Wiring Harnesses replaced at the same time as the Service Lift Extension Program (SLEP), (4) H16DW2602 (the largest wiring harness on older F-16s), (5) Flight Control Wiring Harnesses, and (6) Convoluted Tubing Fuel Cell Area Wiring Harnesses. Additionally, F-16 pylon wiring harnesses have Kapton insulated wire and should be considered for rewiring.

The prefix for F-16 wiring harnesses is H16DW. There are about 350 wiring harnesses in each F-16. F-16 wiring harnesses can be grouped into four categories: (1) trunk wiring harnesses (these are the larger ones that are the most common), (2) power feeders (these are usually very small but have large gauge wire), (3) coax or Radio Frequency (RF) wiring harnesses, and (4) panel harnesses (these are installed inside of electrical box assemblies such as cockpit panels). For a Block 15 F-16, Table 5 lists the number of harnesses in each category.

No	Item	F-16A	F-16B
1	Wiring Harness Types		
2	Trunk Harnesses	212	221
3	Panel Harnesses	82	101
4	Coax Harnesses	35	43
5	Power Feeders	8	10
6	Total Wiring Harnesses	337	375

Table 5 Number of Wiring Harnesses Inside an F-16

When people ask, "How many wiring harnesses are in an F-16?" generally they are not including the wiring harnesses inside of the boxes (such as the matrix assemblies, the power distribution panels, the cockpit panels, etc.); thus, InterConnect's response is usually 250 wiring harnesses (trunk plus coax plus power feeders).

InterConnect Wiring has shared many educational articles that describe some of the reasons to replace old F-16 wiring harnesses. To sum them all up, the main reason is this: older F-16s were made with Kapton insulated wire. After Kapton gets old and brittle it starts to have nicks in the insulation. The nicks, in turn, can lead to arcing between wires. Arcing can lead to intermittent problems in aircraft systems. When the arcing gets bad, arc tracking fires can occur which can ultimately result in aircraft mishaps including the total loss of the aircraft and crew.

Many years ago, the US Navy did multiple Kapton wiring replacement programs for their aircraft. InterConnect won a large contract from the US Coast Guard to replace Kapton wiring on their MH-60 helicopters. The US Army also followed suit and did wiring harness replacement of their Kapton wiring. InterConnect won numerous contracts to totally replace Kapton wiring on UH-60 Alpha model helicopters. Finally, the US Air Force started undertaking Kapton wiring harness replacement on their aircraft; especially F-15 C/D models. InterConnect won a large contract to supply over 70 ship sets of F-15 wiring harnesses to replace all the Kapton on those aircraft. Finally, and just recently, the US Air Force has decided to replace many wiring harnesses on F-16 aircraft while SLEP is being implemented on their Block 40 and 50 F-16s. Hence, now all the US armed services have rewired Kapton insulated wiring harnesses on various fixed-wing and rotary aircraft.

InterConnect has been a part of many of the US armed services rewire programs. Now, InterConnect has taken the lead role in educating F-16 operators and maintainers throughout the world about Kapton issues. As a part of this effort, InterConnect has developed a list of F-16 wiring harnesses that should be replaced on 20+ year-old F-16's. These wiring harnesses, shown in Table 6, are listed in order of importance.

Priority	Part Number	Area	Priority	Part Number	Area	Priority	Part Number	Area
1	H16DW2801	LE Wing	36	H16DW2609	Mid Fuselage	71	H16DW703	Fuel Cell
2	H16DW2802	LE Wing	37	H16DW2610	Mid Fuselage	72	H16DW704	Fuel Cell
3	H16DW2803	LE Wing	38	H16DW656	Mid Fuselage	73	H16DW707	Fuel Cell
4	H16DW2804	LE Wing	39	H16DW657	Mid Fuselage	74	H16DW717	Fuel Cell
5	H16DW2805	LE Wing	40	H16DW661	Mid Fuselage	75	H16DW721	Fuel Cell
6	H16DW2806	LE Wing	41	H16DW663	Mid Fuselage	76	H16DW722	Fuel Cell
7	H16DW2807	LE Wing	42	H16DW668	Mid Fuselage	77	H16DW723	Fuel Cell
8	H16DW2808	LE Wing	43	H16DW669	Mid Fuselage	78	H16DW724	Fuel Cell
9	H16DW2809	LE Wing	44	H16DW677	Mid Fuselage	79	H16DW725	Fuel Cell
10	H16DW2810	LE Wing	45	H16DW678	Mid Fuselage	80	H16DW726	Fuel Cell
11	H16DW2811	LE Wing	46	H16DW681	Mid Fuselage	81	H16DW727	Fuel Cell
12	H16DW2812	LE Wing	47	H16DW683	Mid Fuselage	82	H16DW711	Fuel Cell
13	H16DW2813	LE Wing	48	H16DW684	Mid Fuselage	83	H16DW712	Fuel Cell
14	H16DW2814	LE Wing	49	H16DW685	Mid Fuselage	84	H16DW713	Fuel Cell
15	H16DW2815	LE Wing	50	H16DW692	Mid Fuselage	85	H16DW714	Fuel Cell
16	H16DW2816	LE Wing	51	H16DW693	Mid Fuselage	86	H16DW741	Aft Fuselage
17	H16DW2817	LE Wing	52	H16DW695	Mid Fuselage	87	H16DW742	Aft Fuselage
18	H16DW2818	LE Wing	53	H16DW696	Mid Fuselage	88	H16DW743	Aft Fuselage
19	H16DW2819	LE Wing	54	H16DW698	Mid Fuselage	89	H16DW744	Aft Fuselage
20	H16DW2820	LE Wing	55	H16DW735	Aft Fuselage	90	H16DW1155	Mid Fuselage
21	H16DW2821	LE Wing	56	H16DW736	Aft Fuselage	91	H16DW1156	Mid Fuselage
22	H16DW2822	LE Wing	57	H16DW781	Aft Fuselage	92	H16DW1501	Cockpit
23	H16DW2823	LE Wing	58	H16DW1604	Cockpit	93	H16DW1502	Cockpit
24	H16DW2824	LE Wing	59	H16DW771	Engine Bay	94	H16DW1503	Cockpit
25	H16DW2825	LE Wing	60	H16DW782	Engine Bay	95	H16DW1504	Cockpit
26	H16DW2826	LE Wing	61	H16DW783	Engine Bay	96	H16DW1525	Cockpit
27	H16DW651	Mid Fuselage	62	H16DW784	Engine Bay	97	H16DW1533	Cockpit
28	H16DW652	Mid Fuselage	63	H16DW745	Engine Bay	98	H16DW1701	Mid Fuselage
29	H16DW653	Mid Fuselage	64	H16DW748	Engine Bay	99	H16DW1703	Mid Fuselage
30	H16DW654	Mid Fuselage	65	H16DW749	Engine Bay	100	H16DW1704	Mid Fuselage
31	H16DW1523	Cockpit	66	H16DW2701	Mid Fuselage	101	H16DW401	Forward Fuselage
32	H16DW2601	Mid Fuselage	67	H16DW2702	Mid Fuselage	102	H16DW402	Forward Fuselage
33	H16DW2603	Mid Fuselage	68	H16DW2602	Mid Fuselage	103	H16DW403	Forward Fuselage
34	H16DW2604	Mid Fuselage	69	H16DW701	Fuel Cell	104	H16DW404	Forward Fuselage
35	H16DW2606	Mid Fuselage	70	H16DW702	Fuel Cell			

Table 6 List of F-16 Wiring Harnesses That Should be Replaced in a 20-year-Old F-16

Chapter 9: How Many Flight Control Wiring Harnesses are there on an F-16?

InterConnect deals with many different armed services all over the world. All of them are regimented, disciplined, and professional. Although there are many phrases in common for each of them throughout the world, one that stands out is “Bottom Line Up-Front” or BLUF. When commanders get briefed by others, they want BLUF or “What is the bottom line?” The BLUF to this chapter’s question “How many flight control wiring harnesses are there in an F-16?” is 32 for a Block 15, one-seat F-16.

The F-16 is one of the first “fly by wire” aircraft in the world. Instead of cables and pulleys, the aircraft is controlled by electrical signals. The electrical signals tell the flight control surfaces how to move and how fast to move. There are 5 flight control surfaces on the F-16: (1) leading edge flap, (2) trailing edge flaps (also called flaperons), (3) horizontal tail (also called a taileron), (4) rudder (also called a vertical tail), and (5) speed brakes. Each of these structures move during flight and thus control the F-16.

Actuators are attached to the light control surfaces to move them in flight. Actuators receive electrical signals (instead of cables and pulleys). The electrical signals are sent from computers (and the pilot) via electrical wiring harnesses. Thus, the wiring harnesses are important and play a huge role in the safety of the aircraft. The wiring harnesses that contain these electrical signals are called “Flight Control Wiring Harnesses”. When working on the F-16, maintainers can easily see which wiring harnesses are flight control because they have a double white tracer in the olive-drab Nomex braid. Figures 4 and 5 show a “non-flight control” and a “flight control” wiring harness, respectively.

Figure 4 Non-Flight Control F-16 Wiring Harness

Figure 5 Flight Control F-16 Wiring Harness

Flight control wiring harnesses are installed throughout the F-16. Table 7 shows where they are generally located throughout the aircraft. The F-16 was designed with quadruple redundancy of its flight control systems. The four flight control systems are identified as A, B, C, and D. Each system sends and receives signals to computers that compare inputs and decides how to maneuver the aircraft. There are separate wiring harnesses for each of the four redundant systems throughout the aircraft. Additionally, each flight control wiring harness is installed away from the other flight control wiring harnesses to make sure that if one experiences a problem (such as bullets from small arms fire), then it will not affect the other flight control wiring harnesses.

Number	Section	Quantity
1	Aft Fuselage	4
2	Cockpit	7
3	Forward Fuselage	4
4	Fuel Cell	8
5	Mid Fuselage	9
	Total	32

Table 7 F-16 Flight Control Wiring Harness Locations

InterConnect recommends replacing flight control wiring harnesses at least every twenty years after installation. Early version F-16's had Kapton insulated wires. Kapton insulated wires have potential problems after they get old and brittle. The only solution to this problem is to replace the old wiring harnesses with new ones. The flight control wiring harnesses in the forward bay and cockpit are replaced during large avionics upgrade programs such as Mid Life Update (MLU). The other flight control wiring harnesses are a different matter. They should be replaced at least every twenty years to avoid future problems. This is called "Preventative Maintenance". InterConnect offers a flight control wiring harness replacement program (also called a rewire) for F-16's throughout the world.

Section D – Arc Tracking of F-16 Wires

This eBook has discussed breaches in the insulation of F-16 wiring, inherent viscosity, MTBF, and the most troublesome areas for wiring harnesses in an F-16. So, after reading about them, what is the significance? The answer to this important question involves something called arc tracking. If an F-16 has: (1) breaches in the insulation of wires, (2) Kapton with low inherent viscosity, and (3) no prior wiring harness replacement program, then the F-16 has safety of flight concerns. All of these factors add up to the strong possibility that an event may occur inside one of the wiring harness bundles that is called "arc tracking". Arc tracking is very dangerous and can cause lots of damage not only to the wiring harness bundle but also to the entire aircraft.

Chapter 10: What is Arc Tracking for F-16 Kapton Insulated Wiring?

Until 2001, all F-16's were manufactured with wiring harnesses that contained Kapton insulated wires. In May 2001, Lockheed Martin asked the companies who were making F-16 wiring harnesses to replace Kapton insulated wires with TKT insulated wires. Kapton is a DuPont tradename as is TKT. TKT stands for Teflon/Kapton/Teflon.

Kapton is a light-weight insulation with many great mechanical and electrical properties. Kapton was the predominate insulation used on aircraft beginning in the 1970's. Although Kapton has many great properties it does experience hydrolysis (meaning it absorbs water). Hydrolysis can lead to stiffness and after it has aged, Kapton can be prone to chafing problems. Kapton can also experience arc tracking.

Arc tracking is an event where two or more wires experience an arcing event where a fierce fire (like an explosion) ignites and burns along the outer insulation of the wires. If two or more wires have breaches in their insulation, then an electrical arc (or a short circuit) can occur. In this video F-16 wires are purposely nicked to show what arc tracking of Kapton insulated wire looks like.

As you see in the video, arc tracking can be a long event that can cause a tremendous amount of damage to: (a) a wiring harness bundle, (b) the aircraft systems, and (c) the aircraft as a whole. The sad fact is that it could mean the loss of the lives of the airmen. Obviously, arc tracking is a safety of flight issue and one not well known in the aerospace community.

Chapter 11: Arc Tracking of F-16 Kapton Insulated Wiring Versus TKT Wiring

Most of InterConnect's website blogs in 2017 were about F-16 Kapton insulated wiring. InterConnect discussed many things about Kapton wiring including: (1) which aircraft have it, (2) when it was invented, (3) the benefits of it, (4) the problems with it, (5) what breaches are in Kapton, (6) how many breaches in wiring you can expect in a 20-year-old fighter jet, (7) the most problematic areas of Kapton wiring in an F-16, (8) inherent viscosity related to Kapton wiring, and (9) MTBF for F-16 Kapton wiring harnesses. We also covered that the replacement for Kapton insulated wire is TKT wire. The purpose of this chapter is to compare the arc tracking phenomenon of Kapton versus TKT insulated wiring.

Many of you are probably familiar with the phrase, "A photo speaks a thousand words." Well, here is another phrase, "A video speaks a *million* words." Instead of describing the differences in arc tracking between Kapton wire and TKT wire, InterConnect is going to do something much grander; we will show you a video that will surprise you! You will see that the arc tracking event of the Kapton wire is significantly greater than that of the TKT wire.

Prior to the video, let's set up what you are about to see. Instead of writing paragraphs we decided to list numbered points.

1. InterConnect sent samples of Kapton and TKT wire to a professional test laboratory.
2. Each sample wire was connected to an electrical AC circuit that simulated aircraft power (115V AC).
3. A knife was used to make breaches in each wire's insulation. Two breaches on wires that are close to each other cause arcing.
4. A video was made to show what happened next.
5. Besides AC circuits, InterConnect also had the laboratory test at 28 Volts DC. There was very little difference in arc tracking between the AC circuits and DC circuits.

Video 1: Kapton Wire

Video 2: TKT Wire

As you can see in the videos, there is a **huge** difference in arc tracking between Kapton and TKT insulation. The Kapton burned the aircraft wiring much longer. Arc tracking was tougher to ignite on the TKT samples. InterConnect has hours of videos of various arc tracking experiments. If you would like to see more, please contact us at www.interconnect-wiring.com or +1-817-377-9473. As a synopsis, here are the results of our study:

Kapton Wire

1. Arc Tracking occurred in just about all tests.
2. Typical damage was more than 5 inches and lasted more than 10 seconds long.

TKT Wire

1. Arc Tracking occurred but much less.
2. Typical damage was less than 2 inches and lasted less than 2 seconds.

Based on these videos and if I am an Air Force fighter jet pilot, I would certainly choose wiring harnesses made with TKT wire and **not** Kapton wire. The same goes for the Army, Navy, Marines, and Coast Guard who fly fixed or rotary wing aircraft with Kapton wire. It is strongly recommended to rewire those aircraft as well.

Summary

InterConnect hopes that you found this eBook educational. There are only four key 'takeaways' to this eBook:

1. **Nicks in the insulation of wires in an F-16 are a very bad problem. They are a safety of flight issue. There should be no nicks at all in the insulation of wires for any aircraft in the whole world.**

2. **F-16 wiring harnesses should be replaced if the Kapton's inherent viscosity goes below 0.90.**

3. **InterConnect has recommendations as to how often (in years) each wiring harness inside an F-16 should be replaced.**

4. **Arc tracking of Kapton wiring inside an F-16 is a very dangerous event. Arc tracking can lead to loss of an F-16 and its crew.**

Final Exam

Take the final exam, without looking at the answers. Please let InterConnect's VP of Business Development, Clare McGarrey, (clare.e.mcgarrey@interconnect-wiring.com) know how you did.

1. How many nicks in the insulation of a wire for all the wires in an F-16 is acceptable?
2. What type of insulation replaced Kapton insulation for F-16's?
3. How many breaches in the insulation of wires can you expect to find in a 20-year-old F-16?
4. Should an F-16 wiring harness be replaced if its inherent viscosity is below 0.90?
5. What does MTBF stand for?
6. What are the top 3 most problematic areas for Kapton insulated wiring inside an F-16?
7. What is InterConnect's recommended MTBF for the F-16 main landing gear wiring harnesses?
8. In general, how many wiring harnesses are there on an F-16?
9. How many flight control wiring harnesses are there in a Block 15, one-seat F-16?
10. Is arc tracking worse for Kapton or TKT insulated wiring?

Answers to Final Exam

1. Zero (0)
2. TKT
3. 374
4. Yes
5. Mean Time Between Failure
6. F-16 Section:
    1) Leading Edge of the Wings
    2) Main Landing Gear Wheel Well
    3) Nose Landing Gear
7. 5 Years
8. 250
9. 32
10. Kapton is much worse.