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INCREASING THE RELIABILITY OF
GENERAL PURPOSE BOMB FUZING IN
PRECISION STRIKE WARFARE

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Mitchell Ralph Conover

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DEDICATION

This thesis is dedicated to my wife,
Rebecca Conover,
whose support has been instrumental through the years.

ABSTRACT

The advent of modern high-precision guided airborne weapons has increased the need for extremely reliable bomb fuzing systems. An electro-mechanical bomb fuzing system is currently used in U.S. Navy and Air Force General Purpose bomb based-weapons to include Joint Direct Attack Munition and Laser Guided Bombs. The demonstrated reliability of that fuzing system in combat operations on average has been less than perfect. The operational commanders have expressed that this is unacceptable since any dud results in coalition forces being held at additional risk because a duded bomb could be utilized as an Improvised Explosive Device by enemy forces. Just as the Precision Guided Munitions transformed operational users' mindset of one weapon, one kill, this same transformation has led to the expectation for greater reliability for the bomb fuzing system. It is the purpose of this thesis to describe and discuss a conceptual airborne bomb fuzing system intended to improve the reliability of airborne weapon delivery sufficiently to meet the newly-established operational requirements.

This thesis will cover the components and reliability of the current bomb fuzing system, substantiate the requirement for a more reliable fuze system as a result of the precision strike revolution, and an approach to meet that requirement while balancing safety and reliability. The fuzing system concepts discussed are ones

resulting from an effort performed as part of the High Reliability Fuzing System Study for the Precision Strike Weapons Program Office based at Naval Air Station Patuxent River, Maryland. The study is an ongoing effort conducted by the In-Service Fuzing Systems Team, for which the author is Chief Engineer. Concepts to which the author has made significant personal contributions include an approach on how a certain sequence of events while time windowed will satisfy the safety requirement that a fuzing system design possesses an independent detection of the intent to launch and the post launch environments.

The thesis also contains the author's analysis of how the proposed concept will enhance mission accomplishment and increase overall reliability through the simplification of the system buildup, the elimination of points of failures inherent in the external components of the current system, and the system's ability to produce failure feedback. Since in the mind of the operational user that reliability is measured at the target, the failure feedback from the proposed system will be the main contributor to increasing reliability for the system and improving overall mission accomplishment by preventing a dud from occurring.

PREFACE

A portion of the information contained within this thesis was obtained during a Naval Air Systems Command sponsored program. References to existing fuze systems and the high reliability fuze concepts were obtained during an Analysis of Alternatives study conducted at the Naval Air Warfare Center, Weapons Division based at China Lake, California for the Precision Strike Weapons Program Office based at Naval Air Station Patuxent River, Maryland. The research, results and conclusions, and recommendations presented are the opinion of the author and should not be construed as an official position of the United States Department of Defense, the United States Navy, the Naval Air Systems Command or Naval Air Warfare Center, Weapons Division.

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LIST OF ABBREVIATIONS

\$K	thousands of dollars
\$M	millions of dollars
AIM	Air Intercept Missile
AOA	Analysis of Alternatives
BIT	Built-In-Test
COPE	Conventional Ordnance Proficiency Evaluation
DC	Direct Current
DLY	Functioning delay
DMLGB	Dual Mode Laser Guided Bomb
EED	Electro-Explosive Device
EMI	Electro-Magnetic Interference
ESAD	Electronic Safe & Arm Device
ESD	Electro-Static Discharge
EOD	Explosive Ordnance Disposal
FESWG	Fuze Engineering Standardization Working Group
FET	Field-Effect Transistor
FFCS	Fuze Function Control Set
FISTRP	Fuze and Initiation Systems Technical Review Panel
FMU	Fuze Munition Unit
FWST	Fleet Weapon Support Team
FZU	Fuze Related Unit or Fuze Initiator
GCU	Guidance Control Unit
GP Bomb	General Purpose Bomb
GPS	Global Positioning System
HERO	Hazards of Electromagnetic Radiation to Ordnance
HiRel	High Reliability Fuzing System
IED	Improvised Explosive Device
IM	Insensitive Munition
INST	instantaneous
JDAM	Joint Direct Attack Munition
JSOW	Joint Stand Off Weapon
lbs	pounds
LEEFI	Low Energy Exploding Foil Initiator
LGB	Laser Guided Bomb
MTBF	Mean Time Between Failures
MIL-STD	Department of Defense Design Criteria Standard
ms	milliseconds
NAVAIR	Naval Air Systems Command

NAWCWD	Naval Air Warfare Center, Weapons Division
NDIA	National Defense Industrial Association
OFP	Operational Flight Program
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
PGM	Precision Guided Munition
PIP	Product Improvement Program
PMA-201	Precision Strike Munitions Program Office
PMA-265	F/A-18 Aircraft Program Office
RAD-HAZ	Radiation Hazard
S&A device	Safety and Arming device
SCS	Software Configuration Set
T_0	Time zero
T_i	Time of impact
TVS	Trans Voltage Suppressor
USN	United States Navy
UXO	Unexpended Ordnance
v	volts
WSESRB	Weapon System Explosives Safety Review Board

DEFINITION OF TERMS

Armed. A fuze is considered armed when any firing stimulus can produce fuze function.

Arming delay or arm time. The time elapsed, or distance traveled by the munition, from launch to arming.

Booster and lead explosives. Booster and lead explosives are compounds or formulations which are used to transmit and augment the detonation reaction.

Dud. A munition which has failed to function, although functioning was intended.

Early Burst. A weapon detonating after completion of the arming delay but before hitting the intended target.

Enabling. The act of removing or activating one or more safety features designed to prevent arming, thus permitting arming to occur subsequently.

Environment. A specific physical condition to which the fuze may be exposed. Combinations of environments that can be reasonably expected to occur must also be considered within the context of credible environments.

Explosive ordnance disposal. The detection, identification, field evaluation, rendering safe, recovery, and final disposal of hazardous unexploded explosive ordnance.

Explosive train. The detonation or deflagration train (i.e., transfer mechanism), beginning with the first explosive element (e.g., primer, detonator) and terminating in the main charge (e.g., munition functional mechanism, high explosive, pyrotechnic compound).

Function. A fuze “functions” when it produces an output capable of initiating a train of fire or detonation in an associated munition.

Fuze (Fuzing System). A physical system designed to respond to one or more prescribed conditions, such as elapsed time, pressure, or command, and initiate a train of fire or detonation in a munition. Safety and arming are primary roles

performed by a fuze to preclude ignition of the munition before the desired position or time.

Initiator. A device capable of directly causing functioning of the fuze explosive train.

Interrupted explosive train (out of line). An explosive train in which the explosive path between the primary explosives and the lead and booster (secondary) explosives is functionally separated until arming.

Main charge. The explosive charge which is provided to accomplish the end result in the munition; e.g., bursting a casing to produce blast and fragmentation. These explosives, because of their relative insensitivity, ordinarily require initiation by a booster explosive.

Premature function. A fuze function before completion of the arming delay.

Safe separation distance. The minimum distance between the delivery system (or launcher) and the launched munition beyond which the hazards to the delivery system and its personnel resulting from the functioning of the munition are acceptable.

Safety and arming device. A device that prevents fuze arming until an acceptable set of conditions has been achieved and subsequently effects arming and allows functioning.

(MIL-STD-1316E, 1998)

Chapter 1

INTRODUCTION

BACKGROUND

Several recent military campaigns have shown that precision strike warfare has increased the expectations of individual free-fall weapons performance. In years past, the engagement tactics ranged from multiple bombs on a single target to the carpet bombing of area targets. With the development of Precision Guided Munitions (PGM) and their demonstrated accuracy, tactics have changed so that now, only one weapon is allocated to each target. Example strike mission briefs are contained in appendix A. But, the underlying problem with regards to reliability is that the fuzing system has not changed. The current inventory of free-fall bomb fuzes was designed to be produced at a high rate and at the lowest possible cost. In the arena where multiple warheads were dropped, target defeat could be achieved with fuzing systems designed with a lower reliability requirement compared to what is required in the guided missile world of “one shot-one kill.” The capabilities of these new PGMs have allowed the evolution of operational tactics that support the objective of mission success with the philosophy of “one target-one bomb.” This has lead to the expectation of that “one bomb” working properly with a degree of reliability that far exceeds the original design requirements of the current stockpile of free-fall weapons. Also, the cost of delivery platforms and weapon systems have increased and the

criticality of rapid resolution of campaigns place large demands on first strike lethality of weapons. Finally, each bomb which fails to detonate must be cleared by Explosive Ordnance Disposal (EOD) teams before ground forces can continue or worse it could become an Improvised Explosive Device (IED) for the enemy because they just received “several hundred pounds of high explosive in a convenient, natural fragment forming, steel container” (Clessas, 2005, p. 2).

STATEMENT OF THE PROBLEM

The purpose of this study was to evaluate the concept of a more reliable fuze system, the High Reliability (HiRel) Fuzing System, which attempts to achieve a higher reliability for General Purpose (GP) bomb bodies as utilized in Precision Guided Munitions (PGMs). The author’s analysis was based on information attained during a U. S. Navy developmental test program, however all conclusions and recommendations are independent of the test program. The author’s role in this program was as chief engineer for U.S. Navy in-service fuze programs. The study revealed that there is a definite need, or operational requirement, for increased reliability with the current inventory of the electrical fuzing system. Operational users employing Precision Guided Munitions have the expectation that GP bombs with current fuzes work 100% of the time and plan and employ like they do. GP bombs do not function 100% of the time and there is a need to increase the reliability of the current inventory of fuzes.

The study also revealed how a more reliable fuzing system enhances mission accomplishment and produces a potential return on investments if a new fuzing system is pursued. An increase in reliability will improve overall mission accomplishment by reducing passes over the target, increasing first time strike success, and reducing Unexpended Ordnance (UXO) and Improvised Explosive Devices (IEDs). Also, if the fuze had a means to communicate its status after a Built In Test (BIT), the user would know not to employ the weapon because of the known failure, further reducing the number of UXOs and IEDs.

The bomb fuze has an impressive demonstrated reliability by itself, but the limiting factor is the overall bomb-fuze-aircraft system. Continued efforts to increase the reliability of the electro-mechanical fuze alone are futile because of its reliability dependency on the less reliable elements in series and the assembly of those elements. Therefore, included in the author's analysis are problems and solutions identified to demonstrate that increased reliability is feasible with the removal of unreliable components in the current system and the simplification of buildup. This thesis will illustrate the attributes of the HiRel system and recommend a road ahead for developing and acquiring the HiRel fuze system. Several fuzing system concepts were developed and evaluated while considering weapon compatibility, safety constraints, technical risks, and cost during an Analysis of Alternatives study conducted at the Naval Air Warfare Center, Weapons Division (NAWCWD) at China Lake, California. Portions of this study

were used by the author in developing this paper. The proposed approach within this thesis was considered to adequately balance the technical risks and cost within the bounds of the safety constraints.

SCOPE OF THE STUDY

This study evaluated the potential replacement of the Fuze Munition Unit 139 (FMU-139) fuzing system as utilized on the FA-18 Hornet aircraft. This thesis will briefly describe the current fuzing system components and their individual reliability. A reliability summary will be included for the two employment modes of the fuzing system: Pulse power (referred to as Navy mode) and Continuous power utilizing a Fuze Related Unit (FZU) (referred to as Air Force mode). This study did not evaluate any particular Strike Fighter Mission or employment tactics. This study evaluated the potential use of the HiRel fuzing system as utilized in the General Purpose bomb families to include Joint Direct Attack Munition (JDAM) and Laser Guided Bombs (LGB). This study evaluated two proposed arming environments to validate compliance with safety requirements delineated in Department of Defense Design Criteria Standard (MIL-STD) 1316E. A review of pertinent literature and military standards delineating safety criteria for fuze design, coupled with the author's extensive personal experience as an FA-18 test pilot and chief engineer for U.S. Navy in-service fuze programs were used as the basis of research.

Chapter 2

REVIEW OF THE LITERATURE

DESCRIPTION OF CURRENT BOMB FUZING SYSTEM

The current fuzing system is comprised of several components. Some of these components are 30 years old with some of their specifications adding ten years onto that. The system can be divided into two major subsystems, which are the aircraft and the weapon. The FA-18 aircraft subsystems that affect weapon release and reliability include: aircraft software, AWW-4 Fuze Function Control Set (FFCS), aircraft wiring, connections, decoders, and bomb racks. The weapon subsystems include: a MK-122 safety arming switch with M70 bomb cable assembly or a FZU-48 bomb fuze initiator with a coil power cable, a FMU-139 Electro-mechanical fuze, a bomb tail section, and MK-3 arming wire. The fuzing system is identical when used in “dumb” free-fall bombs and “smart” LGBs or JDAMs because they are all based on legacy MK-80 series bomb bodies. The major components of the fuzing system are shown in figure 1. The current U.S. Navy FMU-139 electro-mechanical bomb fuze within the bomb fuzing system receives power from either the aircraft Fuze Function and Control Set (FFCS) by a pulse through the MK-122 arming switch and M70 cable assembly or continuously from a FZU-48 air turbine. The fuze does not receive power until the bomb is separated from the aircraft for both bomb fuzing configurations. Only Navy aircraft have an FFCS and so this mode is sometimes referred to as



Figure 1
Major Components of the Fuzing System
Source: Mr. Gary Evans, U.S. Navy

“Navy mode.” The Air Force were first to utilize the air turbine to power their fuzes and not until 2001 have Navy aircraft used the air turbine mode so this mode is sometimes referred to as “Air Force mode.”

INDIVIDUAL COMPONENT DESCRIPTION

FMU-139 Series Electro-Mechanical Bomb Fuze

The FMU-139 Series consists of FMU-139A/B, FMU-139B/B, and FMU-139C/B. The FMU-139 was originally designed from 1978 to 1979. The research and development phase began in 1980 and the fuze was fielded in 1985. Approximately 790,000 fuzes were produced from 1985 to 1992 (Ash, 2006).

The FMU-139A/B was reconfigured to FMU-139B/B when the booster material was upgraded to an Insensitive Munition (IM) material. The most recent modification and fuze currently entering production, FMU-139C/B Fuze, provides 4 minute fuze operation for high altitude, long time of fall application, compared to the FMU-139B/B which has only 60 second fuze operation. The fuzes, hereafter referred to as the FMU-139, are Joint-Service (Navy/Air Force) fuzes with multiple settings and can be employed in a high-drag (retarded) or low-drag (unretarded) delivery as shown in figure 2. The FMU-139 Fuze is an electronic impact or impact delay fuzing system. It is a solid state, microcomputer, tail or nose fuze used in MK-80 Series General Purpose bombs, including LGBs and JDAMs. The major physical differences from other Navy

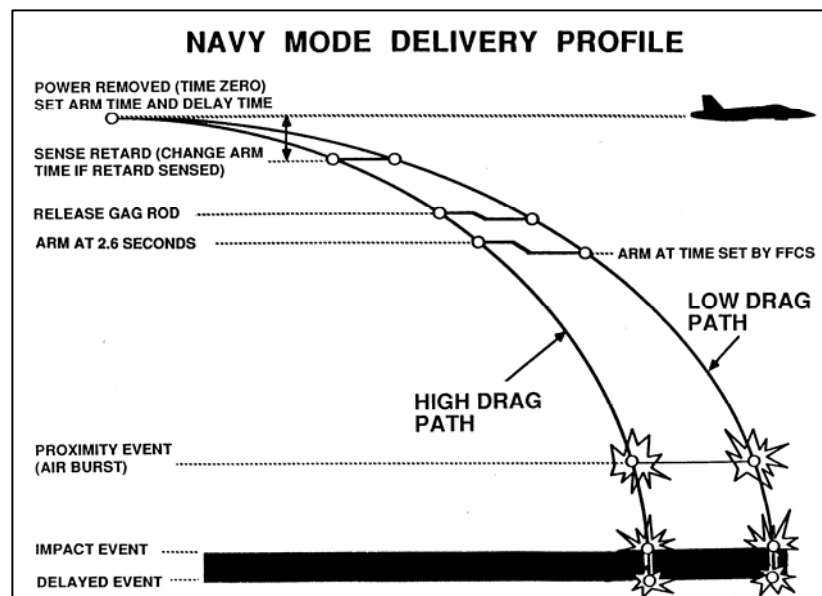


Figure 2
Delivery Profiles for High and Low Drag
Source: Mr. Wayne Steege, Alliant Techsystems



Figure 3
Faceplate of the FMU-139B/B
Source: Precision Strike Weapons Bomb Systems Commodities

electrical fuzes are that the gag rod and arming wire housing are located in the center of the faceplate and the fuze is secured in the tail-fuze well of the bomb by a separate closure ring, which is screwed into the fuze well. The faceplate, as seen in figure 3, contains a low-drag arm time rotary switch, a high-drag arm/delay rotary switch and a 2.0/instantaneous (INST) interlock button.

The fuze has two basic operational modes and it evaluates the type of power to determine the mode. One mode is the pulse power employment mode, referred to as Fuze Function Control Set (FFCS) power or Navy mode. The other mode is the continuous power employment mode, referred to as Fuze Initiator (FZU) power mode or Air Force mode. These two operating modes, which are summarized in figure 4, are described in detail below.

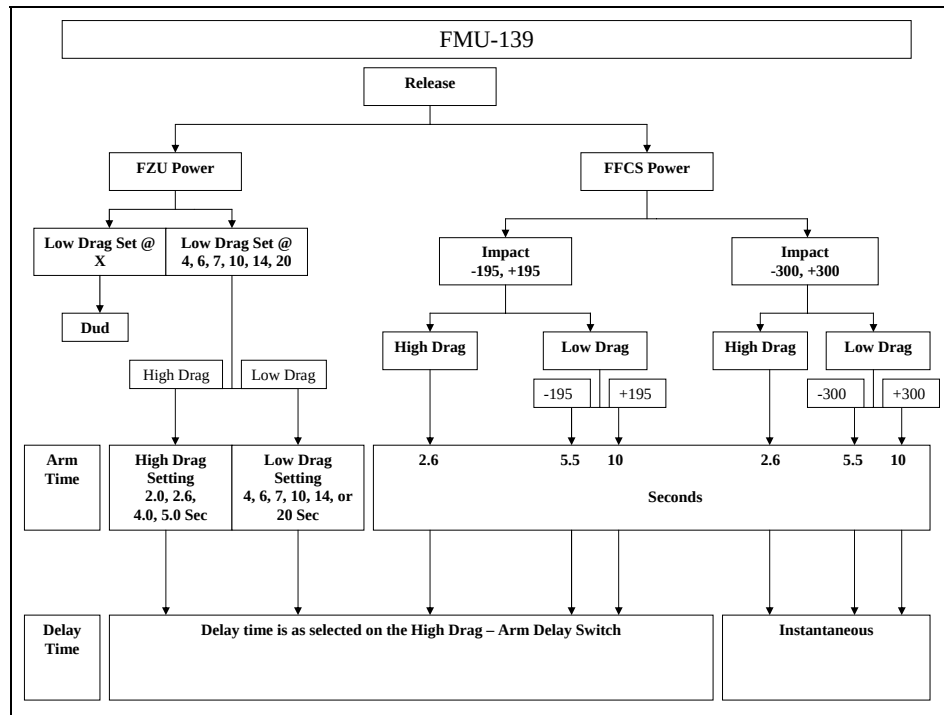


Figure 4
FMU-139 Arm and Delay Flow Chart
Source: Mr. Tom Strickland, U.S. Navy

During the FFCS power mode, the fuze receives a voltage pulse from the aircraft via the MK-122 Safety Arming Switch and M70 Series cable. The arming times for this mode are in-flight selectable and determined by the voltage's polarity. The fuze incorporates three arming times (2.6, 5.5, and 10.0 seconds) when used with FFCS which requires the low-drag arm time switch in the X position. When the voltage is positive the arm time is 10 seconds and when it is negative the arm time is 5.5 seconds. But, if a high drag environment is sensed by the fuze, then the fuze overrides the 5.5 or 10 second command with a 2.6 second arm time. The functioning delay (high-drag arm/delay switch) must be set during weapon

assembly and turned on or off by the voltage's amplitude during the FFCS mode. If the FFCS voltage is 195 volts, then the fuze reads and stores the function delay value of the high-drag arm/delay switch. If the voltage is 300 volts, then the fuze ignores the delay value and functions instantly on impact. The FMU-139 has three functioning delays (10, 25, 60 milliseconds). The fuzing options for FFCS mode are summarized in table 1.

During the FZU or continuous power mode, the fuze is continuously powered by the FZU-48 air turbine and the fuze verifies the switches have valid low and high drag times selected. Valid time combinations for the fuze are when low drag arm time is greater than the high drag arm time. If they are both valid, the fuze stores the low and high drag arm times and the function delay value. The X position for the FZU mode is read as a command to remain safe (functionally – dud).

Table 1
Fuzing Options for FMU-139 in FFCS Mode

Cockpit Options	Arm Time Sec ¹	Voltage	Delay Description
OFF	-	0 v DC	dud
INST	10 Sec	+300 v DC	Instantaneous at impact
INST	5.5 Sec	-300 v DC	Instantaneous at impact
DLY1	10 Sec	+195 v DC	Preflight selected delay after impact
DLY1	5.5 Sec	-195 v DC	Preflight selected delay after impact

Note: 1 Arm time is overridden to 2.6 seconds if high drag sensed

There are two Electro-Explosive Devices (EED) that arm the fuze by aligning the detonator with the lead booster. There is no power supplied to either EED until just before the programmed arm time. The first EED is the Piston Actuator and it receives power and fires 100 milliseconds (ms) before arm time to unlock the rotor. The fuze verifies this happens before it applies power to the second EED the Bellows Motor. The Bellows Motor fires about 30 ms before arm time to turn the rotor and put the detonator in-line with the booster. After this mechanical arm position is sensed, the fuze loads the stored function delay into the detonator fire circuit and applies power to it. When either a proximity fire command or an impact is sensed, the fuze waits for the delay time to elapse and then fires the detonator. The detonator sets off the booster material which in turns sets off the main weapon charge. (Strickland, 2004)

The FMU-139 Fuze is designed for maximum safety in handling and delivery and has been tested Hazards of Electromagnetic Radiation to Ordnance (HERO)-safe. Significant safety features as delineated in the performance specification (PMA201-03-003, 2004) are as follows:

- a. The gag rod physically locks the fuze rotor in the safe position, keeping the rotor from moving. The leads to the detonator are shorted together until the fuze has armed.

- b. Red and black striping is marked on the gag rod/sleeve. This striping makes unsafe positioning of the gag rod immediately visible.
- c. If a charging voltage is applied to the fuze for more than 500 milliseconds, the fuze automatically duds. This ensures safety during a hung store.
- d. The fuze automatically duds if impact occurs between 1.8 seconds after release and arming. This safeguards the delivery aircraft from detonations caused by bomb to bomb collisions.
- e. The impact and proximity sensors are discontinued for 80 milliseconds after arming. This prevents the fuze from functioning (detonating the bomb) on any spurious electrical signals or mechanical vibrations generated during arming.
- f. Arming time for FFCS mode does not begin until the aircraft release circuit indicates that the MK-122 power cable has disconnected from the bomb rack and weapon has dropped 6 inches from the aircraft.
- g. Two Trans Voltage Suppressors (TVSs) are incorporated to reduce Electro-Static Discharge (ESD) vulnerability.

AAW-4 Fuze Function and Control Set (FFCS)

The AAW-4 FFCS provides electrical fuzing power to the fuze via the MK-122 Safety Arming Switch and the M70 Series cable as described above. During the three years prior to a systems engineering investigation in 1999 conducted by Naval Air Systems Command (NAVAIR), the AAW-4's past performance record in the FA-18 of over 2000 flight hours per maintenance action exceeded its specified Mean Time Between Failures (MTBF) of 1000 hours. (Evans, 1999). The AAW-4 FFCS power output is specified at 500 ma, which is powerful enough to provide an arming signal to several weapons simultaneously. The FA-18 does not currently perform a BIT to verify the AAW-4 FFCS is functioning properly. This has the potential to allow an electrically fuzed bomb to be released unarmed if an unknown malfunction is present.

MK-122 Safety Arming Switch

The MK-122 Safety Arming Switch, as shown in figure 5, provides the interface between the weapon and the aircraft armament power circuits during the Pulse power employment mode, sometimes referred to as FFCS or Navy mode. It also provides a positive Radiation Hazard (RAD-HAZ) barrier by blocking any signal to the weapon. The MK-122 controls the available power connect time to charge the fuze storage capacitor by the difference in length between the arming lanyard and the co-axial cable. During release, MK-122 configured bombs receive power from the aircraft FFCS after the MK-122 lanyard is pulled from the switch

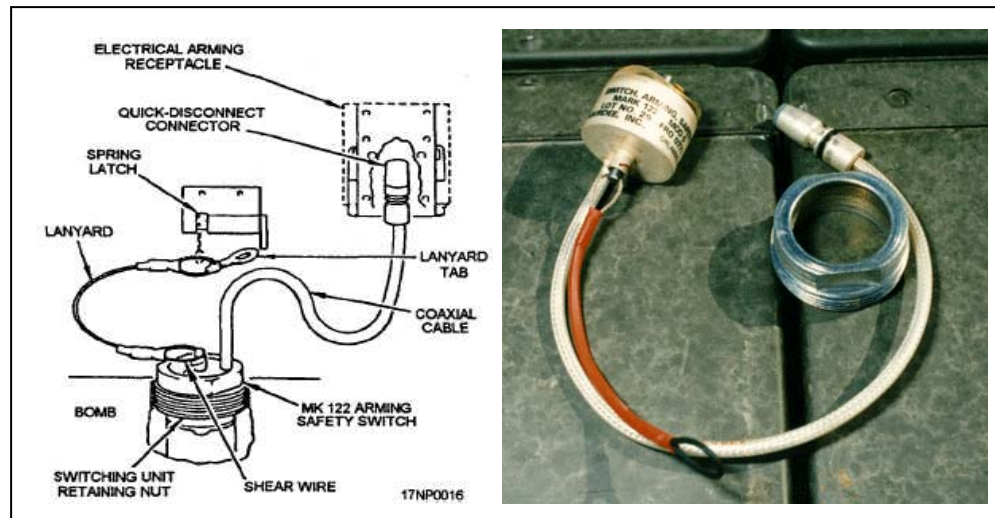


Figure 5
MK-122 Safety Arming Switch
Source: Precision Strike Weapons Bomb Systems Commodities

closing the circuit to the fuze when the weapon falls 4 inches from the station. At this point, the weapon is receiving fuze function power through the MK-122's coaxial cable, until the weapon has fallen to the end of this cable, which is then pulled from its receptacle on the bomb rack (Precision Strike Weapons Bomb Systems Commodities Guide, 2006). Also, the MK-122 fuze safety switch disconnects power from the fuze prior to the aircraft software removing power. Current aircraft Operational Flight Programs (OFP) provide a longer power-on time after pickle release to ensure the bomb will dud as expected via the internal FMU-139 arming logic if the store hangs on the bomb rack (Evans, 1999).

M70 Series Cables

The M70 Series Cable Assemblies are the method used to transfer fuze power from the aircraft to electric bomb fuzes to initiate the energetic explosive during the Pulse power employment mode, sometimes referred to as FFCS or Navy mode. There are three cable assemblies: M72, M73, and M74A. All are identical except in length. The M72 is used on the 500 pounds (lbs) MK-82 Series bombs. The M73 is used on the 1,000 lbs MK-83 Series bombs. The M74A is used on the 2,000 lb MK-84 Series bombs. The M70 Series cables are installed during the explosive filling process at the ammunition plant. When used in conjunction with the MK-122 Safety Arming Switch, electric bomb fuzes receive pulse arming power (± 195 or ± 300 v DC) directly from the delivery aircraft during the release sequence. A M70 Series cable and MK-122 Safety Arming Switch are shown in figure 6.

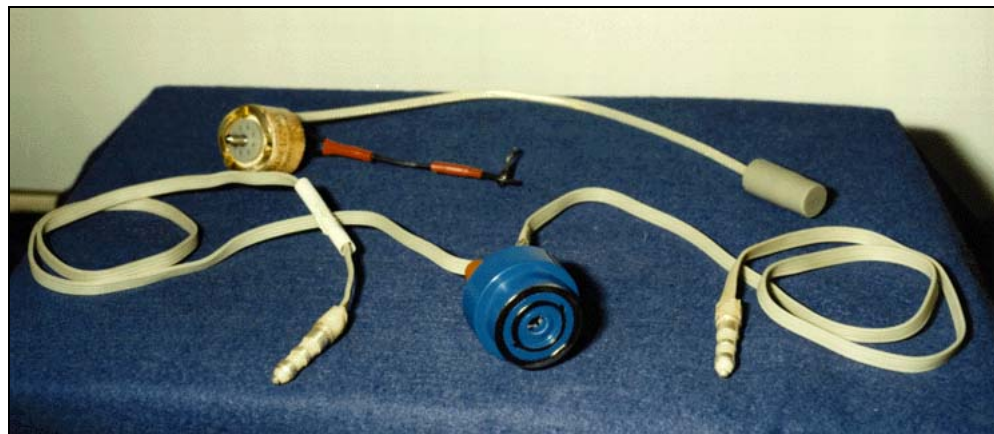


Figure 6

M70 Series Cable Assembly

Source: Precision Strike Weapons Bomb Systems Commodities

FZU-48 Bomb Fuze Initiator

The U.S. Navy has traditionally powered the FMU-139 Series fuze with the FFCS. After the advent of weapons with a longer time of fall like JDAM, the Navy needed to use the FZU-48 Bomb Fuze Initiator. The FZU-48 is connected to the FMU-139 Fuze with a power cable to operate longer than 60 seconds, which is the current limitation of the FMU-139 A/B and B/B Fuzes. However, the FMU-139C/B, once produced, eliminates the need to use the FZU-48 because this fuze provides 4 minutes of fuze operation with FFCS power. The FZU-48 generates and supplies power to arm the fuze during the Continuous power employment mode and is activated at release by the FZU-61 Lanyard. With a FZU-48, the FZU-61 Lanyard is pulled as the weapon separates from the aircraft pulling the ram air turbine into the air stream. With greater than 150 knots of air flow, the turbine generates the power required by the fuze. The FZU-48 Bomb Fuze Initiator and power cable are shown in figure 7.



Figure 7

FMU-139 Fuze with FZU-48 Bomb Fuze Initiator and Power Cable

Source: Naval Air Warfare Center, Weapons Division

Aircraft Software

The Operational Flight Program (OFP) aircraft software is the overarching operating system for the aircraft analogous to Windows® for a personal computer. The OFP manages the controls and displays of the aircraft. Upon a cockpit selection of an arm or delay time, the OFP communicates that to the fuze through the FFCS with the use of voltage amplitude and polarity as described above. Also, the OFP controls the solenoids that pull arming wires and lanyards. Early aircraft software OFP 89A installed in older FA-18s contained an error that could cause electrically fuzed bombs to dud. A fix was available to the fleet in early 1995 that corrected this deficiency. All OFP loads subsequently undergo a testing process to preclude an error similar to this from recurring. During the systems engineering investigation in 1999, all software loads for the FA-18 were verified in lab ground tests. No anomalies were identified and in all tests the electrical fuzing signal provided was within specified limits and of a sufficient duration and magnitude to fully arm the fuze. The analysis revealed that no correlation existed between unknown dud bomb rates and aircraft software changes. (Evans, 1999)

General Purpose (GP) Bombs

The design of low drag General Purpose (GP) bombs originated in the early 1950s. The bombs are identified as low drag by their streamlined cigar-shaped body. Douglas Aircraft Company had designed the A4D Sky Hawk as the Navy's

light attack aircraft and one of the designers recognized the incompatibility of the jet with the current “fat bomb” it was intended to carry. The bombs were a source of considerable drag and aircraft combat radius or capacity could be improved with the newer shapes. The A.O. Smith Corporation of Milwaukee drew up the original production engineering drawings and was the first production activity of GP bomb bodies. The armed services used specific bombs for a specific mission such as armor piercing, semi-armor piercing, fragmentation, or demolition. All of those bombs have been replaced by the GP bomb, but the GP bomb is degraded compared with specific bombs in some of the specific mission areas. There are four types of GP bombs and they are the 250 lbs MK-81, the 500 lbs MK-82, the 1,000 lbs MK-83, and the 2,000 lbs MK-84. The MK-81 has since been suspended and removed from service. Approximately 50% of the bomb weight is actual explosive. (Precision Strike Weapons Bomb Systems Commodities Guide, 2006). These GP bombs are sometimes referred to as MK-80 series GP bombs and an example of one is depicted in figure 8 with a MK-122 installed. The external outlines of the MK-80 series bombs are similar, and other than their diameter, length, and weight, they have similar characteristics. They have a slender body made of steel with two fuze wells in the forward and aft section of the bomb. Also, there are three smaller wells centrally located on the top of the bomb body, two for suspension lugs and one for an MK-122 Safety Arming Switch or an FZU-48 air turbine. Unguided free fall

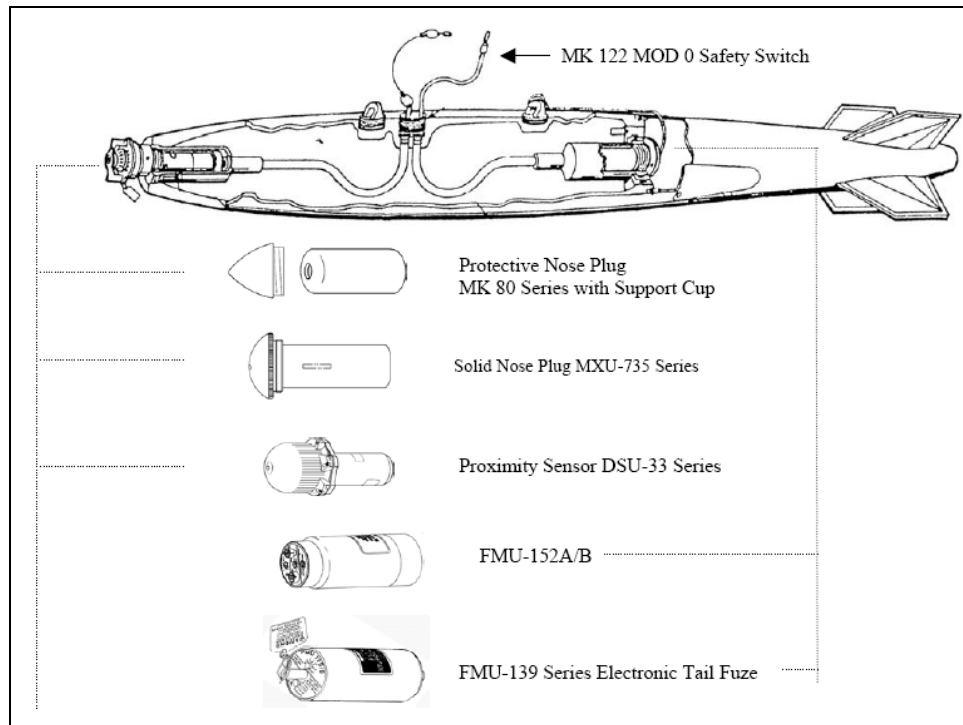


Figure 8
General Purpose Bomb with MK-122 Safety Switch
Source: Precision Strike Weapons Bomb Systems Commodities

bombs, LGBs, and JDAMs all utilize the MK-80 series GP bombs and the FMU-139 electro-mechanical fuze with its associated components.

CURRENT BOMB FUZING SYSTEM BUILDUP

The General Purpose bomb fuzing system is one of many weapon systems that both aircrew and ordnance technicians must be familiar with. The GP family of bomb bodies is the basis for several weapons and they all contain very detailed weapon assembly. “Current bomb fuzing performance is sensitive to the many connections and level of attention afforded by ordnancemen and aircrew.”

(Clessas, 2005, p. 12) There are almost a hundred steps solely for the components pertaining to the fuzing portion of the weapon as summarized in appendix B. From start to finish, experienced ordnance crews can assembly an individual weapon in about 20 minutes. It is common practice to establish an assembly line like installation and buildup of several weapons whereby that same experienced ordnance crew would take about 5 to 10 minutes per weapon (McComb, 2006). The fuze design and mode of operation drives assembly. All U.S. Navy GP bomb bodies come off the production line with the M70 Series cable routed through the conduit. If operational requirements dictate the use of a FZU-48 for time of fall purposes, the M70 series cable is removed and set aside while the FZU's power cable is routed through the bomb body. The weapon could be flown on several missions in which the weapon was not expended and then returned to be re-plumbed with the M70 cable for use with the MK-122 switch in the FFCS mode. Operational commitments and procedures have turned the GP bomb fuzing system from a one time assembled system into a multiple time assembled system subsequently degraded the components.

There are several critical steps in assembling a weapon. These steps are littered with important warnings, cautions, and notes which directly equate to areas that if not done correctly, the system will not operate properly. Any loose, poorly seated connection or bent pins (figure 9) would lead to intermittent power or a power transient for which the current FMU-139 has a known susceptibility to cause at



Figure 9
Bent Pins on FZU-48 Bomb Fuze Initiator
Source: Author

best a dud at worse an early burst. The FZU-48 power cable has ongoing issues with durability, ergonomics, and vibration. Recent early burst investigations have suggested that the improper seating of the bayonet connector locking mechanism of the power cable, shown in figure 10, is a possible source of failure. The investigation concluded that it is extremely difficult to correctly make the connection between the power cable and the fuze receptacle. Assembly crews then use inappropriate tools on the delicate filter section, which is a known weak point in the system (Naval Air Warfare Center, Weapons Division, 2005).

Also, incorrect setting of a faceplate switch or a lanyard not connected properly, which are both not intuitively obvious, will result in the fuze not functioning

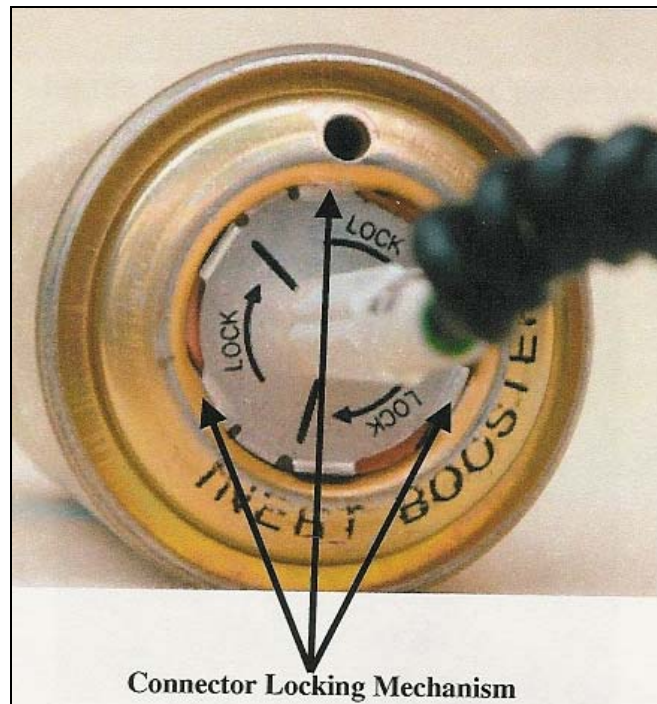


Figure 10
FZU-48 Power Cable Connector and FMU-139 Fuze Receptacle
Source: Naval Air Warfare Center, Weapons Division

properly. The current bomb fuzing system buildup is not foolproof with very little room for error. The major drawback for the current bomb fuzing system buildup is that there are no indicators of improper assembly or failed components. The lack of feedback results in aircraft launching on a strike to only find out when the weapon hits the ground and duds that something was wrong with it.

HISTORICAL PROGRESSION OF RELIABILITY FOR DIRECT ATTACK WEAPONS

The fuzing systems for the U.S. Navy's inventory of free-fall weapons based on legacy MK-80 series bombs have significantly improved in the area of safety and

reliability over the past 30 years. The greatest contribution to an improvement was the change from pure mechanical fuzing systems to electrically operated out-of-line systems. An “out-of-line” system is a combination of an electrical and mechanical system whereby the firing train physically has to get “in-line” to detonate from its initial condition of “out-of-line.” The change to an electro-mechanical system provided both safety benefits and improved demonstrated reliability from approximately 80% to over 90%. The electro-mechanical bomb fuze receives power from either an internal capacitor charged by the aircraft or a ram air turbine which opens after the bomb is separated from the aircraft. Even though the fuze by itself has a relatively high demonstrated reliability, there is degradation in the demonstrated reliability of the overall bomb/aircraft/fuze system. Therefore, improvements to only the fuze will not correct the issue of bomb dud problems.

The current fuzing system was designed and developed in the mid 1980s with minor improvements through the 1990s. The smaller, more capable modern electronics support development of a higher reliable bomb fuzing system. This legacy fuzing system with its historically low reliability levels forced operators in the fleet to consider dual fuzing with diversity, mechanical and electro-mechanical and/or using multiple weapons to destroy a single target. The associated increase in aircraft, aircrew, and weapon loadouts was not the optimum use of resources and it was determined that dual fuzing slightly reduced reliability and warhead

effectiveness against some targets. There was an incorrect fleet perception that considered the electro-mechanical fuze to be the primary cause of the high dud rates. The FA-18 was experiencing a failure rate of approximately 12% when employing bombs with the FMU-139 electro-mechanical bomb fuze. This rate was higher than in any other fleet aircraft at the time. A full system engineering investigation of the elements that affect fuzing reliability for the U.S. Navy was commissioned to identify the root cause of dud electro-mechanical fuzed bombs. This investigation analyzed the electrical fuzing components, their specifications, and operating histories. The engineering evaluation, completed by Mr. Gary Evans in 1999, utilized six years of data from over 800 FMU-139 single fuzed weapons release attempts showing an overall system reliability of 88% and identified three categories of weapon failures: hardware malfunctions, undetermined, and delivery errors. A known hardware malfunction was defined as a malfunction that was identified by the aircraft systems or by post flight maintenance. A known delivery error was defined as either improper aircrew switchology or improper aircraft positioning for weapons employment. Undetermined failures were those that had no identified cause to include hardware and weapon failures. A summary of the overall system reliability and system failure by cause is depicted in figure 11.

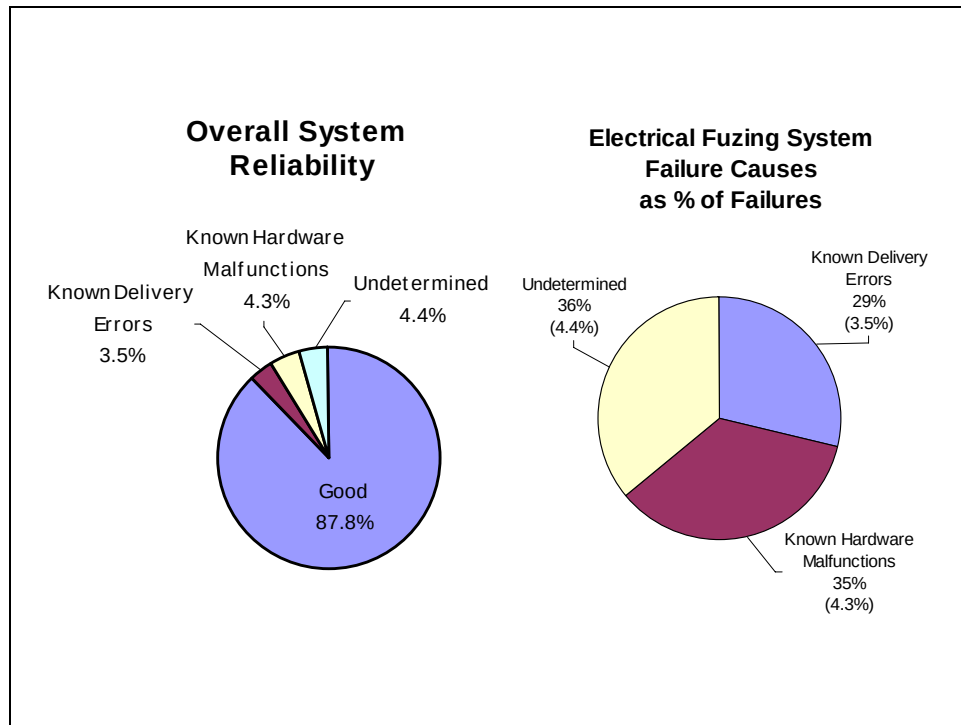


Figure 11
1999 Engineering Evaluation Overall System Reliability and Failure by Cause
Source: Mr. Gary Evans, U.S. Navy

A further effort was initiated to determine the root cause(s) of arming failures. This coordinated effort between the FA-18 Aircraft Program Office (PMA-265) and the Precision Strike Munitions Program Office (PMA-201) was to develop a systems approach for project planning and to gather additional data for known hardware and undetermined failures. A Conventional Ordnance Proficiency Evaluation (COPE) team observed flight operations to gather additional data for the categories of known hardware failures and delivery errors. The individual component reliability below is a result of those efforts. A summary of the overall system reliability and system failure by cause is depicted in figure 12.

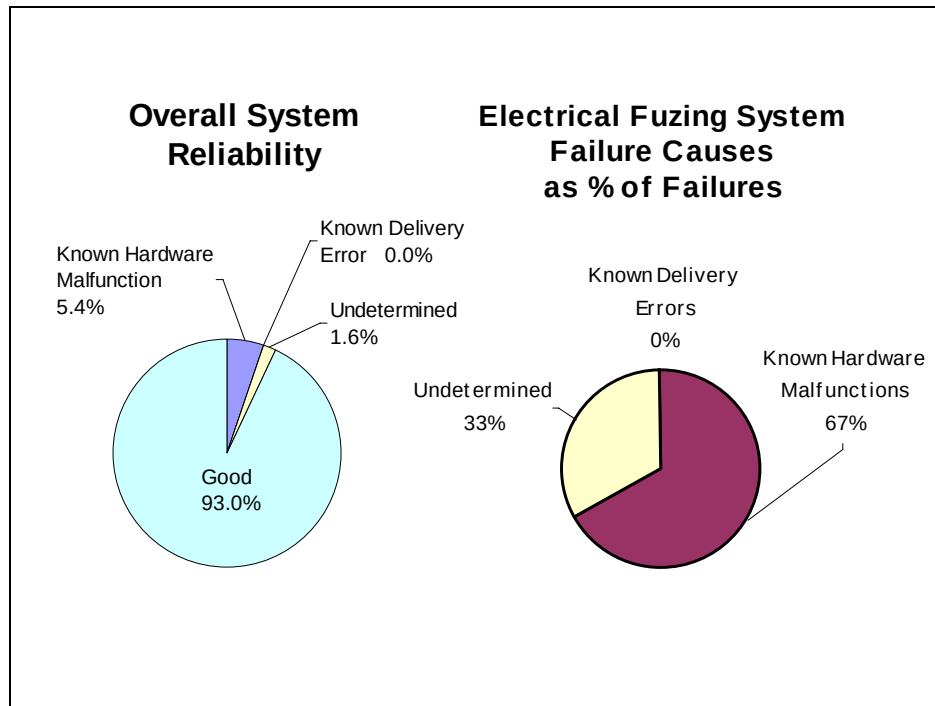


Figure 12
 2002 Performance Investigation Overall System Reliability and Failure by Cause
 Source: Conventional Strike Weapons Program Office

The absence of delivery errors were attributed to the use of more experienced pilots compared to the average fleet pilots used in the previous evaluation. Also, personnel were aware that they were being observed. The cumulative total of known hardware malfunctions and undetermined categories of 8.7% and 7% respectively from the two evaluations were comparable.

Point papers by Mr. George Clessas and Mr. David Riggs in 2005 followed which examined the feasibility of attaining greater reliability for general purpose bombs which lead to an Analysis of Alternatives (AOA) to vet out concepts for a high reliability fuzing system.

CURRENT BOMB FUZING SYSTEM RELIABILITY SUMMARY

Theoretical Bomb Fuzing System Reliability

As described above, there are many components that are contained in the bomb fuzing system. Only the main components were included to calculate the theoretical bomb fuzing system reliability and they are the FMU-139 Fuze, MK-122 Safety Arming Switch used in conjunction with FFCS, and the FZU-48 Bomb Fuze Initiator. The performance specification reliability numbers for each of these items were used to calculate the current mathematical reliability and they were 95% for the FMU-139 Fuze, 98% for the MK-122 Safety Arming Switch used in conjunction with FFCS, and 95% for the FZU-48 (PMA201-03-003, 2004). Therefore, the best case theoretical reliability the Department of the Navy paid for removes the human factor by assuming perfect handling and installation of the bomb fuzing system and flawless employment by aircrew. The theoretical reliability is summarized for both operational modes in figure 13.

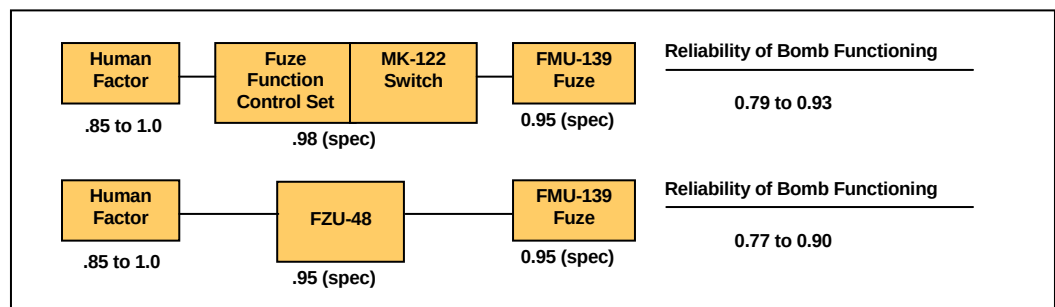


Figure 13
Theoretical Bomb Fuzing System Reliability
Source: Author

Demonstrated Bomb Fuzing System Reliability

Unlike during the Electrical Fuzing System Performance Investigation where the reliability of each component was researched, the fleet end user views weapon system performance as a whole and their metrics are gathered with that in mind. There are large variations observed in demonstrated fuzing system reliability. The current system buildup procedure, as described above, require multiple steps with no active feedback to the assembler to verify that connections are making electrical contact and lanyards are adequately secured. Also, since the MK-122 Safety Arming Switch and the FZU-48 Bomb Fuze Initiator were designed as one time use mechanical items, they cannot be tested prior to use in the field. The largest variations in demonstrated bomb fuzing system reliability surface when a new air wing recently arrives in theater. An air wing of tactical aircraft in support of Operation Iraqi Freedom in 2004 reported a dud rate of nearly 30% immediately after arriving in theater. Operational commanders considering this unsatisfactorily submitted a deficiency report to Naval Air Systems Command (NAVAIR) to investigate and to correct the deficiency. In response to the deficiency report, NAVAIR dispatched a Fleet Weapon Support Team (FWST) to conduct an engineering investigation. No root cause was discovered but installation and refresher weapon assembly training was conducted as well as the ordnance crews were monitored. No further evidence was discovered but the air wing had only a few more duds out of a couple hundred weapons after the

FWST's visit. Training and attention to detail appear to maximize the performance of the system.

This pattern is very repeatable and air wings' bomb fuzing system reliability consistently drops upon arrival in theater. The next air wing in support of Operation Iraqi Freedom in theater in 2005 also struggled their first month of deployment. One squadron within the air wing had a dud rate again of nearly 30% within the first month. The remainder of their tour though, they only had a few more duds within hundreds of weapons being expended which increased the overall reliability to near the specification value of the bomb fuzing system reliability. The increased operations tempo and harsh desert environment are probable causes to the consistent dip in reliability. As experience and lessons learned are incorporated into weapon build up and employment, the dud rate reduces to a rate less than 10%, which is near the design reliability limits of the overall system. To maintain this lower dud rate, constant vigilance is required to ensure connectors are kept clean, clear of defects like bent pins, and properly secured.

Dual Fuzing

In an attempt to improve system reliability, one air wing, that had an extremely high dud rate after first arriving in the theater of operations, proposed dual fuzing as an option to improve the performance of LGBs in combat. The air wing requested authorization even with strong opposition from their "engineering

conscience,” NAVAIR, to dual fuze LGBs by installing a second FMU-139 into the nose fuze well as shown in figure 14 (Denihan, 2006). The air wing misconstrued the primary cause of the dud rate to be a low reliability of the FMU-139 revealing a misunderstanding of the system by the end user and the reason for their inappropriate request for dual fuzing. At the same time of their request, the FWST team arrived in country to examine the air wing’s processes and determine if there was a hardware failure. Subsequently, there was a significant rise in reliability after the FWST arrival. But after dual fuzing was authorized and incorporated into operations, the dud rate actually increased slightly nearing the design reliability of the system (Denihan, 2006).

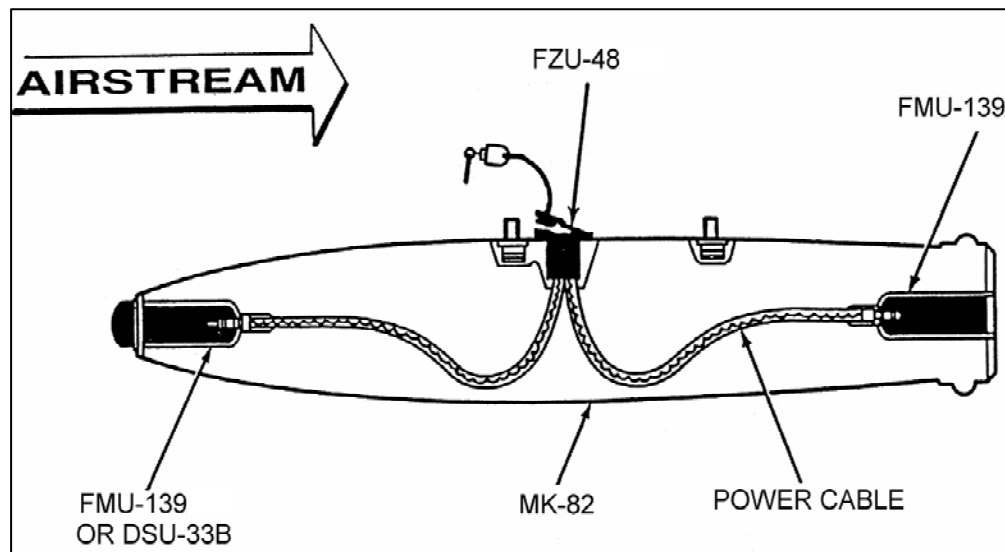


Figure 14
Dual Fuzed General Purpose Bomb
Source: Mr. Wayne Steege, Alliant Techsystems

Ultimately, the reason for the increase dud rate after authorization of dual fuzing is unknown, but there are some very strong hypotheses that could possibly explain it. A second FMU-139 Fuze does nothing for the overall reliability of the bomb fuzing system because the connection to the MK-122 or FZU-48, depending on employment mode, is a single point failure. Therefore, any failure with FFCS/MK-122, the FZU-48, or connections thereof would result in both the nose and tail fuze duding. Also, the FMU-139 Fuze is one of the strongest links in the fuze chain with a very high individual demonstrated reliability (Conventional Strike Weapons Program Office, 2002). Additionally, the GP bomb series is a blast fragmentation weapon and is not designed for use against hardened targets. But when required, a GP bomb used against a hardened target would utilize a steel nose plug in the nose fuze well to improve the penetration characteristics. But, if a second FMU-139 Fuze is placed in the well during a dual fuzing scenario, the nose fuze would be crushed on impact and there is an increase in the likelihood of the bomb case breaking up rendering the entire weapon useless. Therefore, it was concluded by the Precision Strike Weapons Program Office that dual fuzing is authorized but not recommended because it should not improve overall bomb fuzing system reliability (Denihan, 2006).

SAFETY CONSTRAINTS

Safety Standards and Reviews

The purpose of the MIL-STD-1316, Department of Defense Design Criteria Standard, Safety Criteria for Fuze Design, is to establish design safety criteria for fuzes and Safety and Arming (S&A) devices that are subsystems of fuzes. Each service has a safety review board that reviews the fuze's design against the MIL-STD-1316 be it an imbedded fuze in an air to air missile, a surface to surface missile, an artillery shell, or an air to surface free fall weapon. The constraints of the safety community delineated by the MIL-STD-1316 are all encompassing for all these weapon systems and therefore in the effort to cover all circumstances, vague or general requirements could result which may lead to misinterpretations. The Department of Defense Fuze Engineering Standardization Working Group (FESWG) the custodian of MIL-STD-1316, released the latest version, E, in an attempt to reduce the ambiguities and clarify any misunderstandings. Also, the advent and rapid advancement in solid state electronics has furnished alternatives for fuze safety design where historically fuzes have utilized physical interrupted explosive trains. New technology for explosive initiation elements has provided an option for eliminating mechanical means of controlling the arming process. The application of these technology advances is addressed in that revision as well.

The safety and arming requirements delineated in the MIL-STD-1316 are mandatory fundamental elements of design, engineering, production, and

procurement of fuzes. Any weapon system that is going to be fielded in the U.S. Navy must be reviewed in its entirety by the Weapon System Explosives Safety Review Board (WSESRB). In turn, the design, engineering documentation, production and procurement plans for the fuzing system must be reviewed by the Fuze and Initiation Systems Technical Review Panel (FISTRP), the arm of the WSESRB, which holds any fuzing system to the requirements of the MIL-STD-1316. The FISTRP then recommends fleet release of the fuzing system to the WSESRB, who in turn provides a safety concurrence for fleet release of the weapon system.

Two Arming Environments Defined

Most of MIL-STD-1316 and quite a few other standards dealing with Electro-Magnetic Interference (EMI) and other environmental concerns that apply to a fuzing system will become more pertinent once the design becomes more robust. One of the greatest hurdles to meet within MIL-STD-1316 is the requirement of two independent arming environments. With the intentions of limiting the scope of this study, the main focus with regards to safety constraints on a fuzing system for this study will revolve around meeting this requirement. This attribute of the system is the most difficult and has the most impact on the overall design of the system. Paragraph 4.2.1 of MIL-STD-1316E which describes the requirement of two arming environment is displayed below:

“Safety redundancy. The safety system of fuzes shall contain at least two independent safety features, each of which shall prevent unintentional arming of the fuze. The stimuli enabling a minimum of two safety features shall be derived from different environments. Utilization in the fuze design of environments and levels of environmental stimuli to which the fuze may be exposed prior to initiation of the launch cycle shall be avoided. Operation of at least one of these safety features shall depend on sensing an environment after first motion in the launch cycle, or on sensing a post-launch environment. An action taken to initiate launch may be considered an environment if the signal generated by the action irreversibly commits the munition to complete the launch cycle.”

Events and signals can be combined to form arming environments. The first arming environment can be pre-launch if it is part of the launch cycle and if it is irreversible. The only exception to irreversible is an actual failure of the launching system prohibiting the weapon from being expended. Failures do occur and therefore the requirement of having that second arming environment to prevent completing of the arming cycle is beneficial. The second arming environment is after first motion or post launch. The intent of the second arming environment is to confirm that the weapon has launched and it should indicate that the weapon is in actual flight.

Two Arming Environments of Current Bomb Fuzing System

As described earlier, when power is applied to the fuze, it evaluates the type of power to determine the operational mode, FFCS with pulse power or FZU-48 with continuous power. The fuze handles the arming environments differently but with some similarities for these two operational modes. The first operational mode's arming environment that will be described is the pulse power mode with the use of the FFCS. The name pulse power is some what of a misnomer because the aircraft does not send a pulse of power through the system to the fuze but rather a voltage is applied but seen by the fuze only for a short period of time resulting in the two arming environments. Initially, a voltage of the correct amplitude and polarity for arm and delay time is applied to the pylon of the selected weapon stations when the weapon release button is depressed. Next, the voltage is applied to the receptacle of the MK-122 Safety Arming Switch when the hooks of the rack are open. Next, as the weapon falls away from the aircraft the shorter lanyard of the MK-122 switch is pulled completing the circuit through the MK-122 switch and applying the ± 195 or ± 300 volts to the FMU-139 Fuze's storage capacitor which establishes the first arming environment. Finally, as the weapon continues to fall away from the aircraft and reaches the distance of the coaxial cable on the MK-122 Safety Arming Switch, the coaxial cable disconnects from the pylon and the voltage is therefore removed from the fuze. The removal of the voltage is required within 500 ms establishing the second arming environment. In summary, the two arming environments for the FMU-139 Fuze

while operating in FFCS mode is the application of power then the removal of power within 500 ms, i.e. a windowed power scenario. (Ash, Bartels, 2006). Therefore, if a weapon is released with no application of power or if a weapon has power applied and fails to separate from the aircraft, i.e. a hung store, the fuze would fail safe or dud.

The FMU-139 Fuze's other operating mode is continuous power utilizing the FZU-48 Bomb Fuze Initiator. Unlike the other mode, the name continuous power describes the mode exactly. The first step in the arming process for the continuous power mode is, while the weapon is falling away from the aircraft, the FZU-61 lanyard that is attached to the aircraft pylon pulls open the FZU-48 cover to introduce the ram air turbine into the air stream. The turbine generates an AC signal that is sent through the power cable to the fuze. Initially, the positive portion of the signal is received by the FMU-139 Fuze and the fuze utilizes that power to initialize which establishes the first arming environment. The negative portion of the signal is restricted until the cover of the FZU-48 is completely opened. In the process of the cover opening, a Field-Effect Transistor (FET) enables the negative portion of the signal to pass to the fuze. This negative portion is interpreted by the fuze as a release signal and that signal is required to be received within 500 ms from the application of the positive portion establishing the second arming environment. In summary, the two arming environments for the FMU-139 Fuze while operating in continuous

power mode is the application of the positive signal then the completion of the signal or application of the negative portion within 200 ms, i.e. a windowed power scenario again. (Ash, Bartels, 2006).

The FMU-139 Fuze while operating in pulse or continuous power modes was not approved by the safety panels as a standalone unit. The FMU-139 Fuze required the use of either the MK-122 Safety Arming Switch components or the FZU-48 Bomb Fuze Initiator components to receive the FISTRP's recommendation for approval.

Chapter 3

HIGH RELIABILITY FUZE CONCEPT

ATTRIBUTES OF A SYSTEM THAT WILL YIELD HIGH RELIABILITY

A revolutionary approach must be utilized to achieve a higher reliability for free fall weapons employed by U.S. Navy tactical aircraft. In the past, the approach was focused primarily on improving the reliability of the fuze itself or updating the cables and components that make up the system. Any new bomb fuzing system needs more than just improving the fuze or components but rather a complete overhaul of the system. As described earlier, the safety architecture of the bomb fuzing system requires the use of the MK-122 Safety Arming Switch or the FZU-48 Bomb Fuze Initiator. While these components are required for the fuzing system to be considered safe by the safety board, the components also provide degradation to fuzing reliability. Also, the complexity and “no-room-for-error” buildup directly impacts the reliability as well. So with these things in mind, the following design principles are required for a new bomb fuzing concept: reduce or eliminate human factors, minimize the use of mechanical elements, and possess the ability to perform fuzing system level tests (Clessas, 2005).

Reduction or Elimination of Human Factors

As the number of steps to assembly a bomb fuzing system increases, so does the probability of a mistake. “Every human step is an opportunity for an error which increases the overall failure rate of the system” (Clessas, 2005, p. 4). A driving design principle for a new bomb fuzing system should be a simplistic design from the outside resulting in simplifying the buildup process. Assembly attributes need to be “foolproof” to prevent poor connections and improper installation which would reduce the failure rate of the overall system.

Minimize the Use of Mechanical Elements

There is a lower reliability inherent in mechanical components and the removal of them would increase bomb fuzing system reliability. Mechanical elements and mechanisms are susceptible to failure when subjected to harsh environments and long time periods of storage. U.S. Navy tactical aircraft operate in harsh environments including the flight deck of an aircraft carrier to desert airstrips exposing the bomb fuzing system to a wide range of environments. Some examples of mechanical elements are the faceplate switches utilized to set arming and delay functionality, internal retard switches utilized for high drag employment mode, and bellows motor utilized to align the mechanical portion of the fuze train for detonation. The removal of some of these elements would require a paradigm shift in bomb fuzing system mentality. The arming and delay functionality would need to be passed via electronic message traffic described

later in this paper. The removal of the retard switches would eliminate the high drag employment mode capability from this system unless another means of sensing a high drag environment was developed. If operational forces would allow it, the “all in one” in the future fuze would be lost but reliability would be gained. Ultimately, the small potted electronic components tend to survive higher vibration and shock with less degradation over time than larger mechanical elements. “Modern weapon guidance units with electrical part counts five times that of a fuze have mean time between failures greater than a hundred hours, which equates to a reliability of 0.999 for a time of flight of 5 minutes” (Clessas, 2005, p. 5).

Perform Fuzing System Level Tests

The first time aircrews know if the current bomb fuzing system is going to work is when it hits the ground. A robust aircraft, weapon, and fuzing system interface would allow the overall system to identify failures before the weapon is released. Failures could occur any time in the bomb fuzing system life cycle. Therefore, system level tests should be performed throughout that life cycle. Testing should be performed before weapon assembly to ensure all the components are operational after shipping and storage. Testing should be completed after weapon assembly to ensure connections are complete and assembled properly. Testing should be performed while airborne prior to mission to allow a spare aircraft to fill in if required to minimize a loss of a sortie. And finally, testing

should be performed before weapon release to prevent a non-operational bomb from hitting the ground resulting in a dud. The Department of Defense ultimately can not afford 100% inherent reliability, but a Built in Test (BIT) and status monitoring could be just as effective. For example, if 100 bombs are dropped and 5 dud, that is considered bad, but if 95 bombs are dropped with 0 duds that would be comparably good. “If we can achieve 95% reliability measured before the weapon is dropped but every weapon works 100% of the time when viewed by the bad guys, this is a good thing” (Hole, 2006, p. 17). The five would be brought back and would require downloading and disassembling, but there would be no concern of IEDs or UXOs. In the end, reliability is measured at the target.

WEAPON COMPATIBILITY

The primary weapons that would be in scope for the use of the HiRel Fuzing System are based on the MK-80 Series General Purpose bombs and are MIL-STD-1760 compatible weapons. The inventories of weapons that utilize or will utilize the MIL-STD-1760 connection and are based on the MK-80 Series bombs are the JDAM family of weapons and Dual Mode LGBs (DMLGBs). The existing inventory of LGBs and unguided free fall bombs would be secondary because they do not currently implement a 1760 connection but would require a new designed, developed, and tested connector and harness. The new HiRel Fuzing System would only require a single interface with the aircraft through the

existing 1760 weapon interface or new 1760 connection and would eliminate the need for ancillary components such as the MK-122 safety switch and FZU-48 therefore limiting the number of connections which will increase reliability and simplify buildup. The HiRel Fuzing System will take advantage of the established infrastructure and lessons learned of MIL-STD-1760 weapons. The 1760 compatibility will supply power and the primary means of communication with the fuzing system. The MIL-STD-1553 message traffic will transmit fuzing options to include arm times and function delay times as well as release environmental data such as valid aircraft velocity received through a transfer alignment message. Messages and commands are similar to those already provided to interface weapons such as JDAM and Joint Stand Off Weapon (JSOW). Any additional system as a terminal on the 1760 network will require an extensive modification to the aircraft and weapon OFP software. To minimize the impact of an OFP change, a fuzing system could monitor discrete signals on the 1760 line from the aircraft to the weapon providing information to establish the safety arming environments and then receive fuze data via a serial data connection directly from the weapon's mission computer. This approach would require an additional connection but would be the lesser of two evils. The moment a new system is a 1760 terminal on the aircraft, an extensive validation and verification of the aircraft OFP would be required which would be cost prohibitive for a new fuzing system (Ash, 2006).

NOTIONAL FUZING SYSTEM

The HiRel Fuzing System's design features should be focused around the very reliable Electronic Safe & Arm Device (ESAD) technology. Unlike its predecessor the FMU-139 with electro-mechanical out of line attributes, the HiRel would consist of a pure electronic fuze with an in-line explosive train. There are other ESAD fuzes in the U.S. Navy weapons inventory like the imbedded fuze in either the JSOW or the Air Intercept Missile (AIM)-9X Sidewinder missiles so HiRel would not be the first ESAD the safety community has seen. ESAD technology is a proven technology and should be the basis for the HiRel Fuzing System. An S&A device that is purely electronic and uses logic to function permits very standardized manufacturing and high automation. But since there is no physical barrier like the rotor or gag rod, the HiRel Fuzing System would require some kind of safety barrier to prevent unwanted environmental stimuli from causing the fuzing system to initiate the weapon's explosive material. First, HiRel Fuzing System would utilize a very insensitive munition as the explosive initiator and second incorporate a Low Energy Exploding Foil Initiator (LEEFI) to set off that insensitive munition. Insensitive munition technology has come along way in developing stable, plastic-bonded material which becomes difficult to initiate under adverse conditions unlike the sensitive Electro-Explosive Device (EED) in the FMU-139 Fuze. The key is getting it to detonate only under specific proper initiation from the LEEFI. A LEEFI is also somewhat of a electrical barrier designed to only accept extremely

unique electrical signatures allowing it to withstand even a lightning strike without causing the initiator to function. (Ash, 2006)

Some other basic design features that should be incorporated into the HiRel Fuzing System are a serial data interface with the weapon's Guidance Control Unit (GCU) to pass commands or messages, the ability to meet the current JDAM penetration requirements, and a pre-launch, in-flight, and pre-release status monitoring or test ability (BIT). Also, the HiRel Fuzing System should receive power first from the aircraft and then from the weapon system's battery. The fuzing system would receive aircraft power via the 1760 connection prior to the weapon's battery for communication, self tests and limited safety logic functions. There should be no self test functions of safety locks allowed to prevent any inadvertent occurrences of arming while testing the system (Cope, 2005). The weapon battery power would then be utilized for arming the system. There must be in place a strong power partition between the aircraft and weapon power to ensure that the fuze cannot arm under aircraft power. Finally, to meet the two arming environments of MIL-STD-1316, the HiRel Fuzing System should implement time window requirements, monitor the sequence of the events, and validate those prescribed events to ensure the uniqueness of the arming events. A notional block diagram of the HiRel Fuzing System is shown in figure 15.

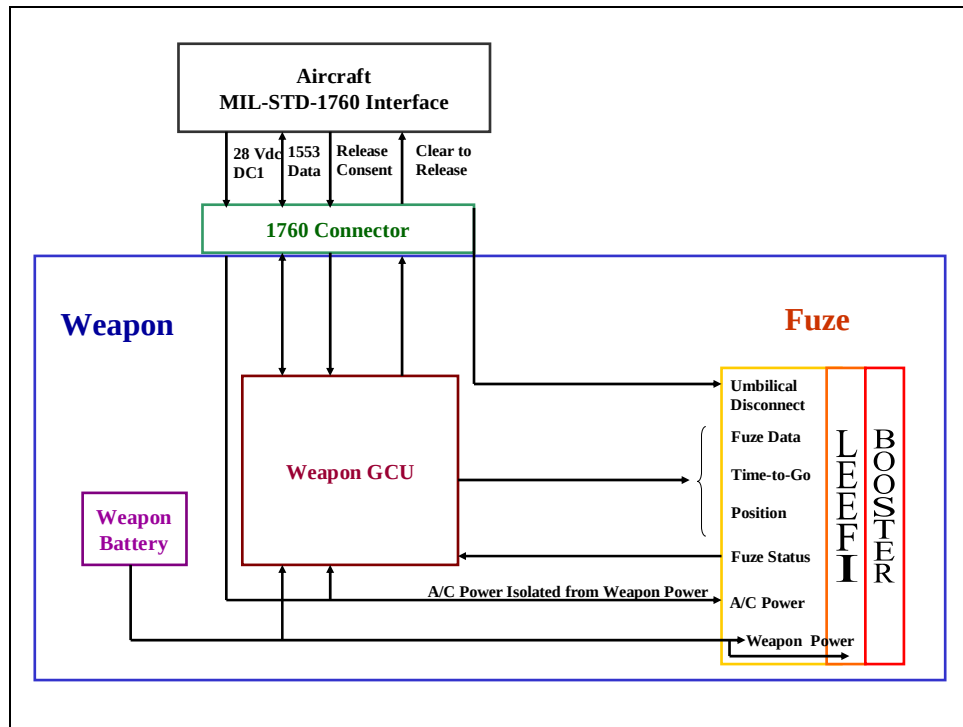


Figure 15
Notional Block Diagram of the HiRel Fuzing System
Source: Author

Following is a notional launch sequence for the HiRel Fuzing System:

1. Upon aircraft power up and store initiation, fuzing system identifies itself to weapon GCU and performs start-up BIT.
2. Fuze data, no-earlier-than-arm and detonation delay times, are transferred from aircraft to fuze from cockpit selection or mission planning tool and fuze sends status to weapon.

3. After takeoff and every time the weapon is selected, the fuze performs periodic BITs and sends status to the weapon.
4. Pilot maneuvers aircraft into the weapon launch envelope, selects master arm, and presses the weapon release button.
5. Aircraft sets release consent signal and fuze receives it via the MIL-STD-1760 connection. The fuze performs a final BIT as the weapon battery is squibbed powering the weapon GCU and the fuzing system. The fuze determines all conditions have been met in the correct sequence and responds to the weapon which in turn sends a clear to release signal to the aircraft.
6. Aircraft commands weapon rack to release the weapon and the weapon proceeds to separate.
7. As the fuze is sensing the proper weapon ejection acceleration profile, the umbilical disconnects within the correct time window and the safe separation timers start.
8. The fuzing system receives time to go and position to independently calculate time to go to validate free flight and then commands power to the arming module of the fuze.

9. The arming module charges the capacitors for firing the LEEFI at the minimum time to impact if the safe separation timers have surpassed the no-earlier-than-arm time.
10. Upon weapon impact and after programmed detonation delay if any, the LEEFI is fired and the booster of the fuzing system detonates setting off the weapon's main charge.

SAFETY CONSIDERATIONS, CONSTRAINTS

The major design driver for any fuzing system while it is complying with MIL-STD-1316 is the requirement of possessing two independent safety features derived from different environments. The HiRel Fuzing System is required to have an independent detection of the intent to launch and the post launch environments. The events and signals in the operational sequence of a fuzing system can be combined to form the arming environments. To recall, the first arming environment can be pre-launch if the environment is part of the launch cycle and if it is considered irreversible. "An action taken to initiate launch may be considered an environment if the signal generated by the action irreversibly commits the munition to complete the launch cycle" (MIL-STD-1316, Para. 4.2.1). The following events combined in the correct sequence and time windows derive an irreversible intent to launch and the first arming environment as shown in figure 16: release consent signal from the aircraft and power change over from aircraft power to weapon battery power. The release consent signal is a high

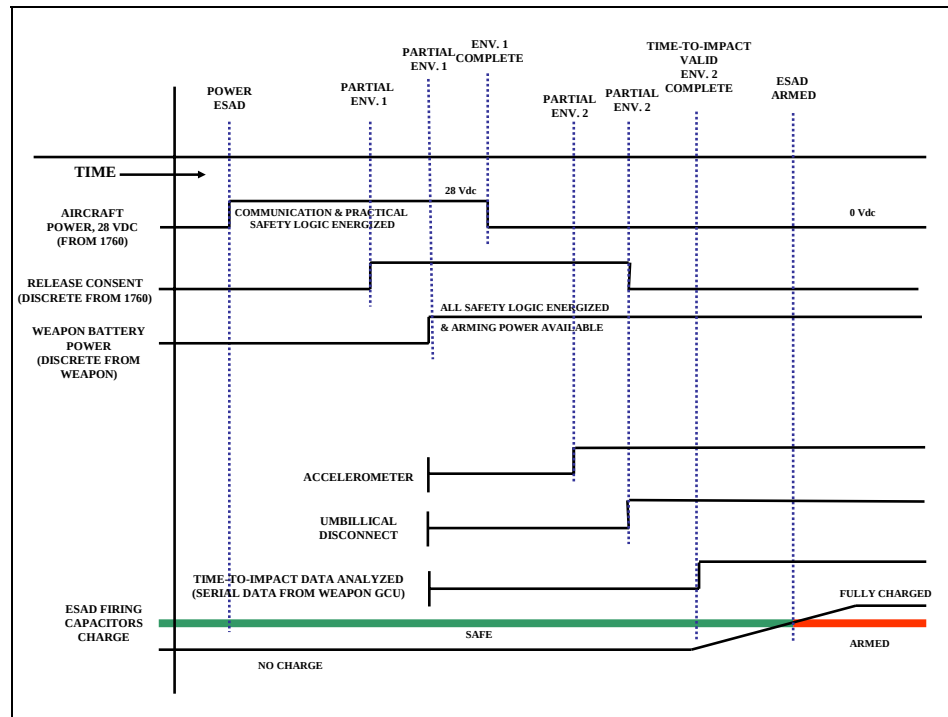


Figure 16
HiRel Fuzing System Arming Environment Timeline
Source: Author

integrity discrete signal generated by the aircraft when the aircrew presses the weapon release button with the intent to release a weapon (Clessas, 2005). This signal is passed via the 1760 connection and would require monitoring by the fuzing system. The signal is also used by 1760 compatible weapons to initiate the weapon release process such as initiating the weapon battery. So to fulfill the first arming environment, the fuzing system monitors the power change over by first checking the absence of weapon battery power while the aircraft powers the fuze non-safety logic circuitry. Then, the fuzing system detects the presence of weapon battery power; the arming power source is now available. And, within a

predetermined time period, the fuze senses the removal of aircraft power completing the first arming environment. The release consent signal and the squibbing of the weapon battery are irreversible satisfying the requirements of the first environment defined in MIL-STD-1316. Also, the fuzing system should have a safety feature whereby it duds if aircraft power is sensed after the fuzing system senses the removal of that power.

Next, the second arming environment occurs after first motion or post-launch. “Operation of at least one of these safety features shall depend on sensing an environment after first motion in the launch cycle, or on sensing a post-launch environment” (MIL-STD-1316, Para. 4.2.1). This event is to confirm that the weapon has launched and should indicate that the weapon is actually in flight. The following events combined in the correct sequence and time windows derive the second arming environment as shown in figure 16: umbilical disconnect, proper weapon ejection acceleration profile from the rack, and time to target decreasing as determined by the fuzing system with data supplied by the weapon. To determine umbilical disconnect, the fuzing system would monitor weapon address lines of the MIL-STD-1760 connection to determine when the connector is fully released. Currently, the JSOW monitors six address lines in the connector to generate a signal for its fuzing system (Clessas, 2005). The umbilical disconnect must occur after power changeover therefore the weapon battery is being used to power the fuze circuitry and the disconnect must occur within a

specified timeframe. Following the umbilical disconnect, the fuzing system would sense the proper weapon ejection acceleration profile as the weapon is being jettisoned from the rack also within a specified timeframe from umbilical disconnect. An example weapon ejection acceleration profile of a 500 lbs JDAM released from an aircraft is shown in figure 17. The fuzing system would have imbedded accelerometers to sense the accurate profile. The accelerometers would be imbedded so that they are independent of the weapon system allowing for one more barrier of safety. Since this fuzing system is needed for weapons with varying weights, the heaviest class weapon will drive the profile limits. The correct sequence of events and the specified timeframes are required to make these occurrences unique in establishing the basis for the second arming environment.

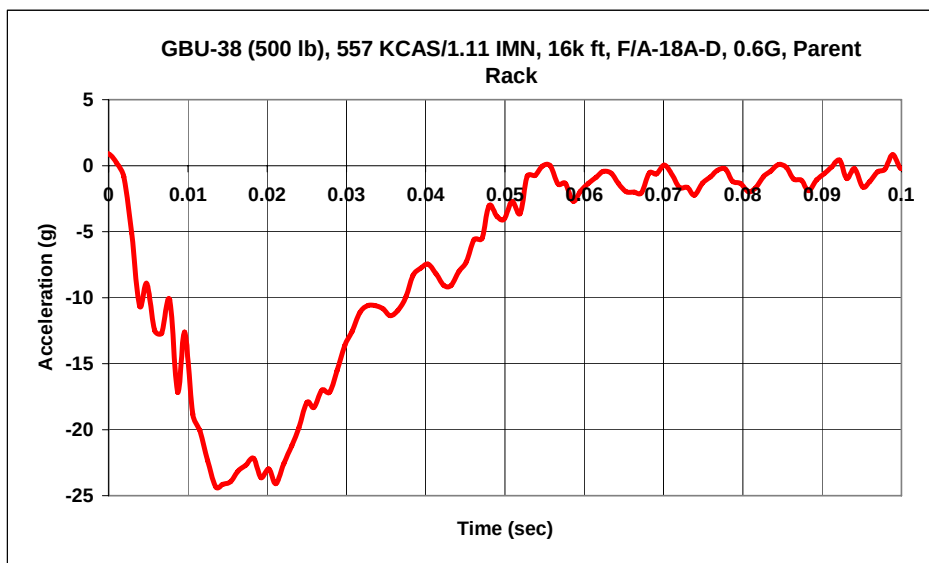


Figure 17
500 lbs JDAM Ejection Acceleration Profile
Source: JDAM Program Office

As the weapon is guiding to the target, the fuzing system will then determine if it is in actual flight with data supplied by the weapon thus completing the second arming environment. For the fuze to retain the critical capability of safety, the fuze must determine that the data supplied are valid and the arming conditions have been met allowing the firing capacitor to be charged, putting the ESAD in an armed status. To do this, the weapon's mission computer could do one of two things. The mission computer in the Guidance Control Unit (GCU) would periodically pass, via the serial data interface, time-to-impact and the fuzing system validates that the time is decreasing as well as compares the timing against internal timers to ensure the time-to-impact characteristics are correct. This requires a certain level of dependency of the fuzing system on the weapon's mission computer which might not be looked upon favorably by the safety community. The other option is to have the fuzing system receive the weapon's raw data of position and allow the fuzing system to independently calculate the time-to-impact which would reduce the dependency on the weapon's mission computer. Also, a combination of the two whereby the fuzing system receives time-to-impact and positioning to calculate time-to-impact would be ideal for the safety community for redundancy, independence, and verification but this approach might not be achievable because of the computing power and complexity required by the fuzing system.

Finally, once the fuzing system has sensed the umbilical disconnect, proper weapon ejection acceleration profile, and determines the weapon is approaching the target, the second arming environment is achieved. Unlike the legacy fuzing systems though, the HiRel Fuzing System should not use arm times counted from a notional Time zero (T_0) that is usually associated with the arming environments but rather count backwards a prescribed minimum time from a notional Time of impact (T_i). Since the HiRel Fuzing System would be utilized only with smart weapons with a long time of fall and not high drag weapons, there is no foreseeable reason to count a prescribed arm time from release. An arm time from release complicates safe separation modeling when it is less than 20 seconds where most of the legacy systems operate. But, if most PGM's time of fall is greater than 60 seconds and the fuzing system did not arm until 2 seconds before impact as determined by the fuze, then this would minimize the safety concern associated with safe separation. However, the fuzing system should have a check to require it to not arm any less than a prescribed time limit from release. This no-earlier-than arm time should be cockpit selectable and passed via the serial data interface to allow the aircrew the greatest amount of flexibility.

COST CONSIDERATIONS

The HiRel Fuzing System would be designed and manufactured more like current guided missile fuze systems rather than legacy bomb fuze practices. Therefore,

the system would be produced in smaller quantities and would increase the unit production cost. But a weapon system production procurement strategy directed at matching the JDAM and LGB inventory requirements will bring the unit production cost down. Also, the unquantifiable return on investment for total system increase in reliability would lower total ownership cost as well. The following is a rough order of magnitude engineering estimate of the design and procurement cost of the HiRel Fuzing System. The non-recurring costs are broken into four areas consisting of development, test, qualification, and software changes. Development cost is estimated to be \$10M based on past experience for developing and preparing weapon unique fuzes. The test and fuze test hardware costs are estimated at \$3M providing 30 fuzes costing \$100K each. The government qualification cost is estimated at \$3M to support free flight drops, HERO qualification testing, and penetration sled testing. The software changes for both the aircraft Operational Flight Program (OFP) and weapon OFP are estimated to cost \$8M and \$2M respectively. This is based on similar aircraft and fuze integration costs. The estimated total development cost is \$26M as summarized in table 2. For procurement costs, the HiRel Fuzing System is comparable in complexity to existing weapon unique serial interfaced fuzes, therefore assuming a 90% learning curve, an initial procurement of 10,000 fuzes would have an average cost of approximately \$5.6K per fuze (Clessas, 2005). For subsequent procurements the average cost should be less than \$5K.

Table 2
Estimated HiRel Fuzing System Non-recurring Costs

Non-recurring Component	Cost (\$M)
Development	10.0
Test Fuze Hardware	3.0
Qualification Tests	3.0
Aircraft OFP Change	8.0
Weapon OFP Change	2.0
Total	26.0

Chapter 4

FINDINGS AND DISCUSSION

BALANCING RELIABILITY AND SAFETY

This study's intent was to evaluate the potential use of a more reliable fuze system for General Purpose (GP) bomb family of weapons. The first question that needed to be answered was if there is an underlying requirement for increased reliability with the current inventory of fuzes. Here are some words from Lt Gen Walter Buchanan the Commander of 9th Air Force speaking about Operations Iraqi Freedom and Enduring Freedom revealing the expected or implied current weapons' reliability requirement of 100% (JDAM Program Office, 2005).

"My concern is that this war has reached a point where a tactical error can have strategic implications so everything in our arsenal needs to work first time, every time. We have also become the victim of our own success in that the ground troops 'know' we can shack the target every time and pretty much control collateral damage. As such, we only drop one at a time so when one doesn't work as advertised it becomes obvious."

The FMU-139 Electro-mechanical Fuze alone has a very high demonstrated reliability and yet it receives most of the flak when weapons do not function properly. The incorporation of the ancillary components imposed by safety requirements produces variability in reliability. Also, these components ultimately

reduce reliability because of the increase chance of improper assembly and mechanical failure. The bottom-line is a failure is unknown until the aircrew and aircraft have been put in harm's way and see from the cockpit a dust cloud on the ground where a high order detonation should have been. So, the balancing act of safety and reliability of the current inventory of fuzes should be addressed because there is an underlying requirement for increased reliability with the current inventory of fuzes. There is an expectation that GP bombs with current fuzes work 100% of the time and unfortunately they are employed with that mindset. The operational users are setting themselves up for failure because the current fuzing system does not work 100% of the time.

TECHNICAL RISKS

The second question that needed to be answered to evaluate the potential use of a more reliable fuzing system was whether increased reliability is feasible. The proposed concept of the HiRel Fuzing System does not require new technology development with the MIL-STD-1760 connector because of their use today and also because the MIL-STD-1553 messages are mature and proven. However, the risk rests on the experience of existing fuze production contractors, which have limited experience working with or designing products that interact with these interfaces. Currently, the fuze to weapon/aircraft interface is assessed to be a medium risk. There is an ongoing effort to mitigate that risk by incremental steps. The first effort is called the FMU-139 Product Improvement Program

(PIP) whereby ESAD technology is evaluated in a FMU-139 type fuze, which will continue to utilize the ancillary components for power and meeting the safety requirements. The PIP will also have the addition of serial data interface to receive fuze data from the weapon. This first step will be a one way communication for the fuze to receive arm and detonation delay times. The next effort will progress to a complete removal of the components leading to the fuzing system completely interfacing with the weapon/aircraft system. The removal of these components has a two-fold effect on increased reliability because the removal of the components and the steps in the process of building that system will inherently increase the reliability of the system. Also, a complete interface will allow for status monitoring and testing of the fuzing system to report any failures which will subsequently prohibit the employment of a known failed weapon system. The PIP effort will not be the complete answer, but the knowledge and experience from the PIP effort will be building blocks for the HiRel Fuzing System. The differences between mechanical and electrical fuzes are summarized in table 3 revealing how ESAD technology promotes a more reliable fuze system.

Table 3
Comparison of Mechanical and Electrical Fuzing Systems

	Mechanical Fuze	Electrical Fuze
History	50+ years	5 + Years
Interface & Control	Most use electronics	All use electronics
S&A Description	Electro-mechanical S&A	Electronic S&A
S&A Type	Primary Mechanical with some Electronics	Electronics & Logic
Explosive Initiator	Easy to Initiate, Sensitive EED	Hard to Initiate, Insensitive LEEFI
Explosive Barrier	Separates EEDs & explosive	None Required
Stored Energy	Piston Actuators, Bellows Motors.	None
Power Consumption	Low	LEEFI requires more
Testability	One-shot devices	Facilitates testing over life cycle
Manufacturing	Special/Hand Assembly Operations	Standard/Highly Automated
High-G Survivability	Harder	Easier
Long Term Storage	Generally gasket tight	Can be hermetic

Source: Mr. Wayne Steege, Alliant Techsystems

Another area of reliability that has to be vetted out for the HiRel Fuzing System is the penetration requirement. Although modern electronics can provide the required reliability for the weapon's time of fall, it is uncertain if it can survive the high shock and vibration levels associated with weapon impact. The survivability of the fuzing system within a penetrating bomb is assessed to be a medium risk, but can be mitigated to a low risk. The reduction in size of the components required for the initiation module of a fuzing system allows that module to be hardened to survive these environments. Several sled tests during the PIP effort will reveal the robustness of these components and confirm their survivability.

The area with the greatest risk is approval of the HiRel Fuzing System design by the safety community. As stated earlier, the HiRel would not be the first ESAD, but a complete overhaul of GP bomb fuzing that has been used for the past two decades will create discomfort. The approval of the HiRel Fuzing System by the FISTRP is assessed to be a medium risk. There are several things that can help mitigate this risk. First, the knowledge from other programs that utilize ESAD technology for their warheads like AIM-9X and JSOW should be sought after to ensure lessons learned from their approval process can be implemented. Next, safety reviews should be conducted early in the program because of its revolutionary nature to minimize safety approval risk. Lastly, safety architecture that is kept as simple as possible has the greatest ability to gain safety approval. Every effort should be made to design a simple safety architecture for the HiRel Fuzing System.

One of the main concerns of the safety community will be the two arming environments as defined in MIL-STD-1316. The proposed HiRel Fuzing System design contains some areas that have some technical risks associated with them. As discussed earlier, one of them is the fuze to weapon/aircraft interface, which will provide pre-mission fuze data as well as time to go and position information for the fuze to determine free flight for the second arming environment. The weapon and aircraft OFP integration effort is assessed to be a medium risk primarily because this fuzing system is one of many systems trying to integrate

with the weapon and aircraft. Software verification and validation takes time and the fuzing system might not be considered a priority, which may lead to a suboptimum integration schedule. The other area that contains a technical risk associated with an arming environment is the sensing of the proper weapon ejection acceleration profile. The sensing of the acceleration profile might be difficult to assess because of its uniqueness and is assessed to be a medium risk. The profile must be unique so that the fuzing system will be able to discriminate the profile from aircraft flight vibration and correlate to a genuine ejection of a weapon from the rack. Currently, there is an insufficient data set for all GP bombs' acceleration profiles from all the different racks and aircraft stations. To mitigate this risk there is an ongoing effort to characterize weapon rack ejection acceleration profiles combined with umbilical disconnects to determine disconnect time relative to the acceleration of the weapon to see the usefulness of these events for an arming environment. If the acceleration profile is not unique, it should not be used as a contributor for the safety arming environment.

Through the mitigation efforts addressed above, increased reliability is feasible with the removal of unreliable components or mechanical elements, the simplification of buildup of the fuzing system to eliminate or reduce human error, and the use of an interface between the weapon and the fuzing system to allow fuze level status reports.

ENHANCEMENT OF MISSION ACCOMPLISHMENT

The third question that needed to be answered for this study to evaluate the potential use of a more reliable fuzing system was whether a new fuzing system would enhance mission accomplishment. Any increase in reliability for a fuzing system is beneficial because all duds are counterproductive. The number one reason that duds are counterproductive is that the target is not destroyed. If the target is not destroyed and it is critical enough, then a re-attack is required. Another reason a dud is bad is if friendly troops are in contact with the enemy, they will remain in contact because the threat was not destroyed. Also, duds become Unexpended Ordnance (UXO) on the battlefield requiring EOD to render the duds safe or remove them before permitting troop movement or, worse yet, to prevent the enemy acquiring the UXO to use for their purposes as an Improvised Explosive Device (IED). None of these results is favorable and therefore an increase in fuzing reliability will enhance mission accomplishment by reducing sorties for re-attacks, avoiding risks during those re-attacks, ensuring first strike success, and reducing UXO.

A purely cost savings approach reveals a return on investment for the Precision Guided Munitions (PGM) saved from duding when an increase in reliability of just 4%. If the average cost of the perspective PGMs that will use the HiRel Fuzing System is approximately \$30K per unit, then \$120K would be saved on the basis of a fuzing system reliability improvement of 4% for every 100 PGMs

expended (Riggs, 2005). The cost savings associated with reducing sorties for re-attacks, avoiding risks during those re-attacks, ensuring first strike success, and reducing UXO are all not quantifiable but all would enhance overall mission accomplishment.

The cause for a weapon failure that results in a dud has been very elusive and even more so with an early burst because the evidence is destroyed. Engineering investigations turn to speculation because root causes can not be determined. The primary reason a weapon is released with a failure is because there is no failure feedback in the current inventory of fuzes. An all electronic fuze can be tested throughout its life cycle without being expended unlike its predecessor, the electro-mechanical fuze. From factory testability to testing after assembly, an electronic fuze can give feedback that it is connected and functioning properly. Also, fuzing system tests prior to a mission reveal if a failed weapon exists on an aircraft to allow the ready spare aircraft to fill-in so as not to jeopardize the strike. Finally, a fuze self check right before weapon release can prevent a non-functioning weapon from being released and leading to the UXO concerns expressed earlier. Failure feedback from the HiRel Fuzing System will improve overall mission accomplishment by reducing UXO and IEDs because failures will be known before dropping ordnance.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The purpose of this study was to evaluate the concept of a more reliable fuze system, the High Reliability (HiRel) Fuzing System, which attempts to achieve a higher reliability for General Purpose (GP) bomb bodies as utilized in Precision Guided Munitions (PGMs). The author's analysis was based on information attained during a U. S. Navy developmental test program, however all conclusions and recommendations are independent of the test program. The author's role in this program was as chief engineer for U.S. Navy in-service fuze programs. The study revealed that there is a definite need for increased reliability with the current inventory of fuzes. Operational users employing Precision Guided Munitions have the expectation that GP bombs work with a degree of reliability in excess of the design requirement of the current fuze inventory. As a result of the precision revolution, a requirement for a highly reliable fuzing system is realized.

However, any new fuze design must answer the question of how it can ensure it is at a safe distance from the aircraft before arming and at the same time increase reliability. The proposed HiRel Fuzing System concept attempts to do that. The goal of the HiRel Fuzing System is to integrate into a weapon system and

ultimately provide a higher reliability to the weapon system as a whole. The proposed concept for the HiRel Fuzing System intends to increase reliability through several actions. HiRel will provide higher reliability by eliminating points of failure through the removal of external components that degrade reliability. Current fuzing performance is dependent on the level of attention given by the ordnance crew assembling the weapon. The MK-122 Safety Arming Switch, FZU-48 Bomb Fuze Initiator, cabling, and connections only increase the chances of failures and any one part's functionality can not be verified before or after installation. But because of safety constraints, these components are required for the determination of arming environments and if they are removed, then a new design will require the determination of brand new arming environments acceptable to the safety community.

Also, the HiRel Fuzing System concept minimizes reliability issues associated with human factors by greatly simplifying buildup through the reduction of the number of connections significantly. The ordnance crews are not expected to buildup a JSOW or AIM-9X in the field, because those weapons come as all-up-rounds, but the operational forces expect the same reliability as those systems from the GP bomb fuzing systems. With computers talking to computers, the HiRel Fuzing System will have simple connections, be able to execute system checks and report the fuze status to the weapon to prevent a dud from occurring. The all-electronic fuzing system will also allow factory testability to weed out

failures in production compared to the electro-mechanical fuze that is analogous to a mouse trap where the only way to know if it works is to set it off. Additionally, a fully integrated fuzing system will also receive fuze settings via a serial data interface eliminating the need for external switches that are unreliable and that can mistakenly be put in the wrong position. Eliminating the switches in the HiRel Fuzing System removes one more thing that can fail, which will increase reliability.

All of these attributes of the HiRel Fuzing System will permit the operational user to employ the one bomb, one target mindset, but the concept represents a substantial change from current bomb fuzing, which relies on mechanical elements and lanyards. The developmental effort requires incremental steps to evaluate functionality as well as provide confidence to the safety community that the HiRel Fuzing System is truly safe. The FMU-139 PIP effort will mitigate the technical and safety risks associated with ESAD technology and integrating a fuze/weapon/aircraft system paving the way for the HiRel Fuzing System. The PIP improves reliability inherent in an ESAD but still relies on external components and there is still the unknown if it will work until it hits the ground. Since in the mind of the operational user that reliability is measured at the target, the failure feedback from the HiRel Fuzing System will be the main contributor to increasing reliability for the system and improving overall mission accomplishment by nearly eliminating UXOs.

RECOMMENDATIONS

A fuzing system as an electronic safe and arm device, with status monitoring, and simplistic buildup would be highly reliable, but there is a lot that needs to be done before it can become reality. Specific recommendations pertaining to the sensing of the proper weapon ejection acceleration profile for the determination of the second arming environment are summarized below:

1. Conduct drop tests with perspective HiRel weapons to characterize acceleration profiles while incorporating the umbilical connector to define the time sequence of events.
2. Employ the weapon environmental group to make a comparison of data from drop tests with an Energy Spectral or Shock Response Spectrum to reveal if drops are unique enough to be utilized for an arming environment.
3. Conduct hung store drop tests to characterize acceleration profiles for the contingency of a hung store and use that profile within the fuzing system to initiate a dud for safety.

Specific recommendations pertaining to the interface and the integration of the fuzing system with the weapon/aircraft system are summarized below:

1. Proactively coordinate integration efforts with weapon and aircraft representatives for required hardware and software changes.
2. Determine uniqueness and format of the data for time to go and position from the weapon mission computer for use with free flight determination of the second arming environment.

Specific recommendations to gain approval by the safety community of the HiRel Fuzing System design are summarized below:

1. Research lessons learned about safety approval from other programs that utilize ESAD technology for their warheads like AIM-9X and JSOW.
2. Conduct safety reviews early in the HiRel program because of its revolutionary nature to minimize safety approval risk.
3. Keep the safety architecture as simple as possible.

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APPENDICES

Appendix A

STRIKE MISSION BRIEF EXAMPLES

DESERT STORM STRIKE MISSION BRIEF EXAMPLE

The following are slides for an example mission brief during Desert Storm. Approximately 100,000 weapons were delivered by Tactical Aircraft with 93% of the ordnance being unguided bombs and the other 7% of the weapons were precision guided (Hole, 2006). The strike composition slide in figure A-1 depicts an example strike package to prosecute 16 target points with 16 strike aircraft carrying 128 General Purpose (GP) bombs. Those strike aircraft required 20 support aircraft which provided protection against surface to air missiles and enemy aircraft, supported with communication links, and utilized jamming to suppress enemy radars. The formation snapshot in figure A-2 shows the aircraft in relation to each other and how complicated a strike would be with that many aircraft. Finally, the aimpoints in figure A-3 reveal the requirement of 16 aircraft to flow through the target area increasing the risk to aircrew and aircraft on a strike.

STRIKE COMPOSITION				
(Desert Storm)				
CALL SIGN		AIRCRAFT	MISSION	ORDNANCE
HAMMER	01	FA-18	STK/FTR	8xMK83
"	02	FA-18	"	"
"	03	FA-18	"	"
"	04	FA-18	"	"
"	05	FA-18	"	"
"	06	FA-18	"	"
"	07	FA-18	"	"
"	08	FA-18	"	"
NAIL	41	FA-18	STK/FTR	"
"	42	FA-18	"	"
"	43	FA-18	"	"
"	44	FA-18	"	"
"	45	FA-18	"	"
"	46	FA-18	"	"
"	47	FA-18	"	"
"	48	FA-18	"	"
SWEEP	11	FA-18	CL. ESCORT	1/2/3
"	12	FA-18	"	"
"	13	F-14	"	2/2/2
"	14	F-14	"	"
"	15	FA-18	"	1/2/3
"	16	FA-18	"	"
"	17	FA-18	"	"
"	18	FA-18	"	"
TRON	07	EA-6B	JAM	1xAGM88
"	17	EA-6B	"	"
TRON	20	FA-18	HVAAP	1/2/3
"	21	FA-18	"	1/2/3
ZAP	22	FA-18	HARM	3xAGM88
"	23	FA-18	"	"
"	24	FA-18	"	"
"	25	FA-18	"	"
SNOOP	26	S-3	ES	"
RAVEN	27	ES-3	ES	"
DOME	01	E-2	C2	"
DOME	02	E-2	C2	"

To prosecute 16 DMPIs requires:

128 GP weapons

16 Strike Aircraft
20 Support Aircraft
36 Total Aircraft

Figure A-1

Strike Composition for Desert Storm Example
Source: CDR Tom Hole, USN

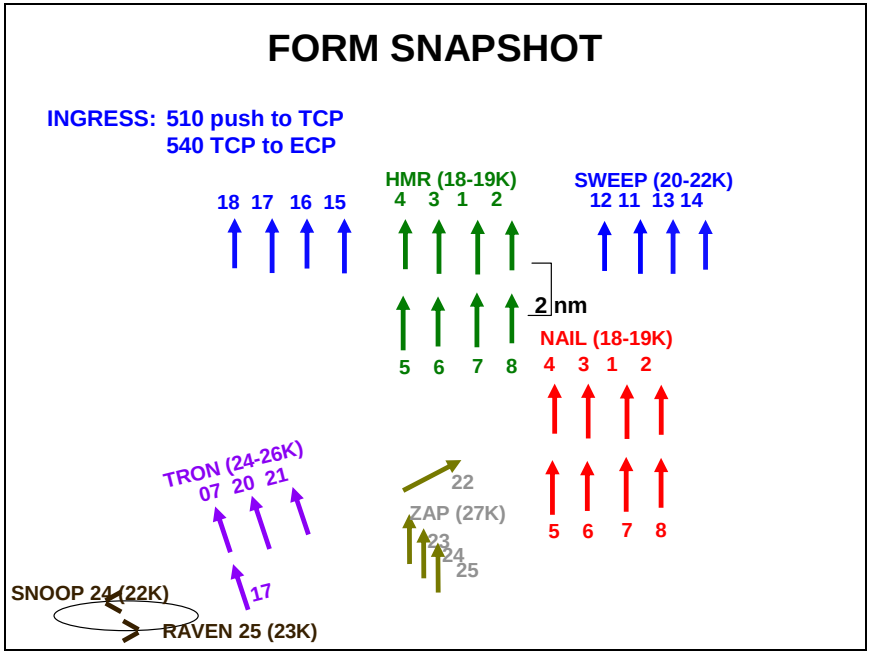


Figure A-2

Formation Snapshot for Desert Storm Example
Source: CDR Tom Hole, USN

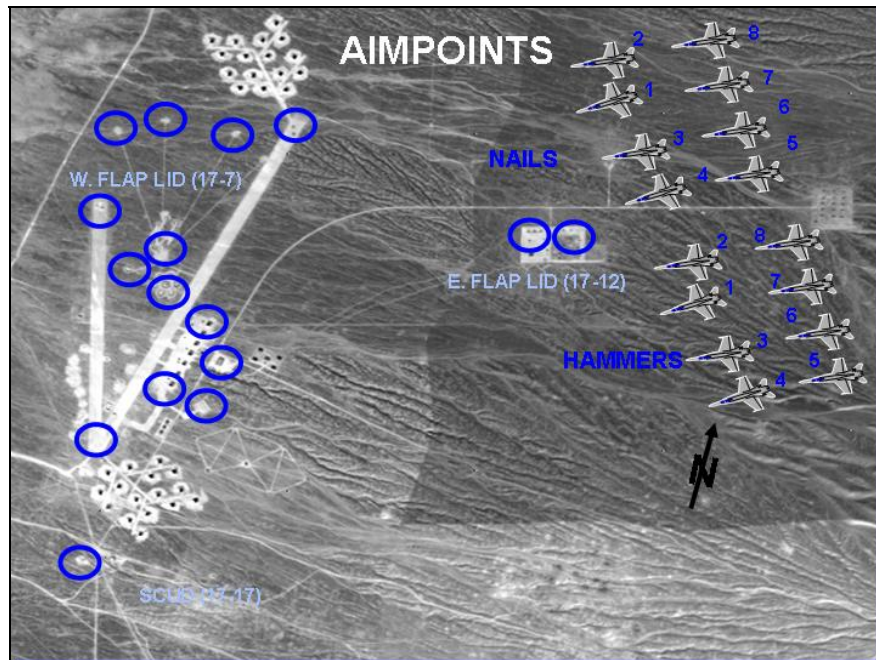


Figure A-3
Aimpoints for Desert Storm Example
Source: CDR Tom Hole, USN

OPERATION ENDURING FREEDOM AND IRAQI FREEDOM STRIKE MISSION BRIEF EXAMPLE

The following are slides for an example mission brief during Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). Approximately 25,000 weapons were delivered by Tactical Aircraft to date with 85% of the ordnance being precision guided bombs and the other 15% of the weapons were unguided (Hole, 2006). The strike composition slide in figure A-4 depicts an example strike package to notional prosecute the same 16 target points with only 4 strike aircraft carrying 16 Precision Guided Munitions (PGM). The strike aircraft still require support aircraft with the same roles as described above but less aircraft required. A formation snapshot would reveal a less complicated evolution with only 15

STRIKE COMPOSITION			
CALL SIGN	AIRCRAFT	MISSION	ORDNANCE
HAMMER	01	FA-18	STK/FTR
"	02	FA-18	"
"	03	FA-18	"
"	04	FA-18	"
SWEEP	11	FA-18	CL. ESCORT
"	12	FA-18	"
"	13	F-14	"
"	14	F-14	"
TRON	07	EA-6B	JAM
TRON	20	FA-18	HVAAP
"	21	FA-18	"
ZAP	22	FA-18	HARM
"	23	FA-18	"
RAVEN	27	ES-3	ES
DOME	01	E-2	C2
			8xMK82
			"
			"
			"
			1/2/3
			"
			2/2/2
			"
			1xAGM88
			1/2/3
			1/2/3
			3xAGM88
			"

To prosecute 16 DMPIs requires:

16 PGMs

4 Strike Aircraft

11 Support Aircraft

15 Total Aircraft

Figure A-4
Strike Composition for OEF/OIF Example
Source: CDR Tom Hole, USN

aircraft to orchestrate compared to 36. Finally, the aimpoints in figure A-5 reveal the requirement of only 4 aircraft to flow through the target area minimizing the risk to aircrew and aircraft on a strike.

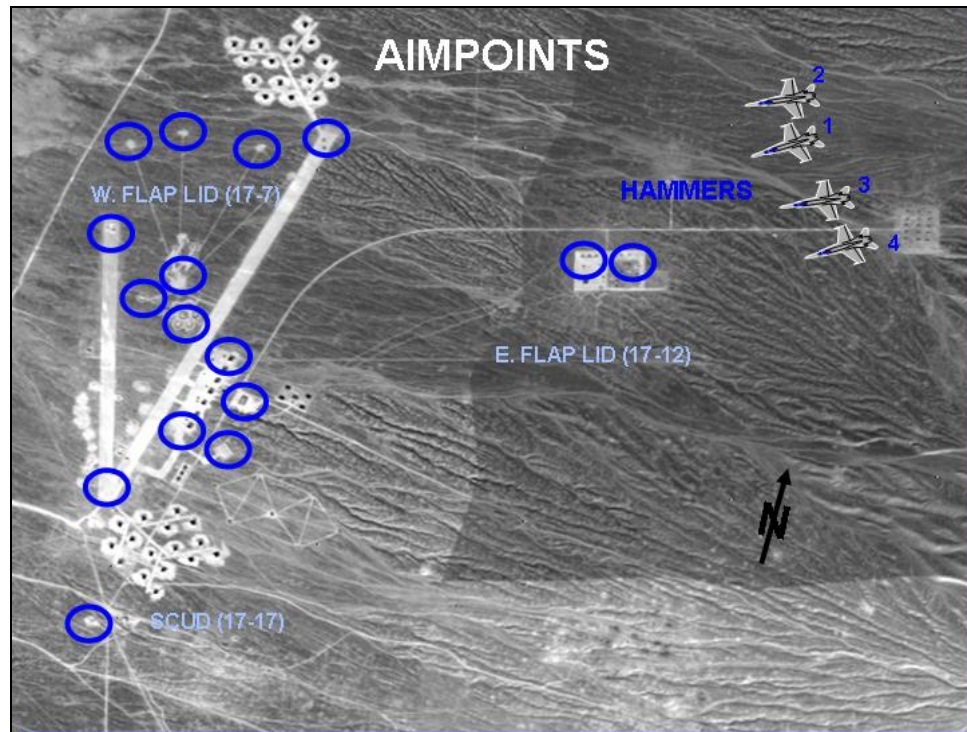


Figure A-5
Aimpoints for OEF/OIF Example
Source: CDR Tom Hole, USN

A p p e n d i x B

CURRENT WEAPON SYSTEM BUILDUP

The following appendix is an abbreviated checklist from the Airborne Weapons Assembly Manual, NAVAIR 11-140-10-1, for Laser Guided Bombs.

WEAPON COMPONENT PREPARATION/INSPECTION

MK 80 SERIES BOMB

A. PREPARATION

1. Cut and remove banding material from pallet
2. Remove shipping caps/plugs from nose and tail of bomb
3. Ensure suspension lugs are properly installed
4. Place bomb body on platform stand

B. INSPECTION

1. Nose/tail fuze well threads NOT damaged; well cavity clean and free of moisture; electrical connector NOT corroded or deformed
2. Ensure electrical connector firmly seated
3. Remove charging receptacle well plug and verify that charging receptacle diaphragm/connector is NOT corroded or deformed
4. Inspect bomb body for chipped or loose thermal coating

WARNING

Bombs with more than 56 square inches or one area greater than 15 square inches of thermal coating missing shall not be used afloat.

5. If FZU-48/B is to be used, prepare bomb as follows:

NOTE

The non-destructive method is the preferred method of M70 Series Cable removal.

- a. (Non Destructive) Remove M70 series cable (figure B-1) from charging well as follows:
 - (1) Using lock ring tool (figure B-2), remove lock ring from charging well
 - (2) Using cable knockout (figure B-2), knock fuze plugs out of retaining clips

(3) Using retaining clip removal tool (figure B-2), remove retaining clips and discard

(4) Remove and retain M70 series cable

b. (Destructive) Remove M70 Series cable (figure B-1) as follows:

(1) Using lock ring tool (figure B-2), remove lock ring from charging well

(2) Pull charging well plug outward and cut both legs of the cable

(3) Using retaining clip removal tool (figure B-2), remove retaining clips and fuze plug/cables from fuze cavities

(4) Dispose of all items removed

c. Mark bomb body "FUZE CONTROL CABLE REMOVED"

FMU-139 SERIES FUZE AND COMPONENTS (Figure B-3)

1. Container NOT damaged

2. Remove fuze and closure ring from shipping container

3. Safing pin installed in gag rod/housing; fuze free of moisture/corrosion

WARNING

If safing pin is removed from FMU-139 fuzes and no red and black striping is visible on gag rod sleeve (sleeve not extended), fuze is safe. If safing pin cannot be reinserted, notify proper authority for disposition. If red and black striping is visible on extended gag rod sleeve, fuze may be unsafe. Notify proper authority.

4. Verify red and black striping NOT visible on gag rod sleeve

5. Ensure that LOW DRAG ARM TIME switch is set to the "X" position

6. Remove plastic shipping plug and flag from connector

7. Set fuze switches as required

8. (If Applicable) Prepare FZU-48/B as follows:

a. Remove FZU-48/B and power cable from container

b. FZU-48/B lanyard present and NOT damaged

c. Embossed arrow present; initiator clean and NOT damaged

d. Bottom of FZU-48 properly crimped

e. Remove dust caps from connectors at bottom of FZU-48/B

f. Power cable clean and NOT damaged

WARNING

Power cable assembly P/N 9042203 (identified by white backshell) will be used.

P/N 835308 is no longer authorized and shall be destroyed.

g. Connectors clean and NOT damaged

h. Puller clip present and NOT damaged

- i. Allen head screws and serrated teeth present and NOT damaged
- 9. (If Applicable) Prepare FZU-61/B as follows:
 - a. (If Applicable) Remove FZU-61/B from container
 - b. Pull ring and swaging sleeves present and NOT damaged
 - c. Cable NOT frayed; Break link NOT damaged

NOTE

If FZU-61 is already attached to FZU-48/B, verify correct length for bomb body being used. For MK 84 MODS 4/5, the lanyard length should be 27 inches. For all other bomb bodies, the length should be 24 inches.

MK 122 ARMING SAFETY SWITCH (Figure B-4)

WARNING

Do not pull MK 122 switch lanyard during handling. If the lanyard pin breaks away from switch, discard entire MK 122 switch so it will not be used on a bomb.
Do not attempt to replace lanyard pin.

- 1. Remove MK 122 from package; remove rubber shipping cap
- 2. Inspect coaxial cable for cracks or breaks in the insulation
- 3. Verify electrical contact is clean
- 4. Verify magnet wire properly routed and NOT broken

NOTE

Do not install MK 122 until weapons assembly is completed.

WEAPON SPECIFIC COMPONENT PREPARATION/INSPECTION

There are two components that make up a Laser Guided Bomb (LGB) and they are the Tail Kit and the Computer Control Group (CCG). The preparation and inspection for the Tail Kit consists of 12 very detailed steps with 1 Warning. The preparation and inspection for the CCG consists of 17 very detailed steps with 1 warning, 3 Cautions, and 1 Note.

WEAPON ASSEMBLY

FMU-139 ELECTRONIC FUZE INSTALLATION FOR USE WITH FZU-48/B (Figure B-5)

A. Fuze Installation

NOTE

If Dual Fuzing is used, repeat steps 1 through 7 for nose fuze. Both fuzes must be set to the same settings.

1. Back off setscrew in bomb nose fuze well
2. Place O-ring on retainer bolt; install retainer bolt and tighten to 600 + 50 foot-pounds of torque; tighten bomb nose fuze well setscrew to 150 + 20 inch-pounds of torque

CAUTION

Torque value shall not be exceeded; breakage of screws is highly possible.

3. Ensure fuze settings as follows:

NOTE

The low drag arm time rotary switch is positioned at the "X" position for all FFCS use. However, when FMU-139 is utilized with the FZU-48/B vice the MK 122 Safety Switch, the low drag rotary switch must be set at other than "X" position. If the low drag rotary switch is set to the "X" position when FZU-48/B is utilized the weapon will dud.

- a. Set LOW DRAG ARM TIME switch as directed
- b. Set HIGH DRAG ARM/DELAY switch as directed
4. Attach cable connector to fuze and lock into place

WARNING

When installing or removing power cable on FMU-139 fuze, do NOT use pliers or any other tools on the shell. The use of tools could damage internal parts and cause fuzing malfunction.

5. Thread a standard piece of arming wire through bomb conduit from arming well until it appears at fuze well
6. Attach puller clip of fuze power cable to arming wire and pull power cable through conduit beyond arming well; tape power cable to bomb body and remove arming wire

NOTE

When nose fuze is used, the fuze retainer nut from the guidance kit is used to secure the fuze vice the fuze closure ring.

7. Insert fuze into fuze well; secure fuze into fuze well with closure ring/fuze retainer nut

CAUTION

If closure ring wrench is not available, use spanner wrench and exercise care to prevent damage to closure ring and fuze.

8. Remove fuze power cable(s) taped to bomb body; remove puller clip(s) from power cable(s); with initiators embossed arrow pointing forward, connect power cable(s) to appropriate connector(s) of initiators

CAUTION

Do not twist cable connector during installation on removal from FZU.

9. With embossed arrow pointing forward, insert initiator into charging well and evenly tighten two Allen head screws on top cover until initiator is secure
10. (Nose Fuze) Remove safety pin from fuze; install fuze seal nut into retainer bolt and tighten against the fuze retainer nut. Tighten fuze seal nut setscrew
11. (If applicable) Install FZU-61/B firing lanyard as follows:
 - a. Cut existing FZU-48/B lanyard off just above the lower swaging sleeve
 - b. If bomb body is to be used is a MK 84 MOD 4/5, cut off short leg of FZU-61/B. For all other bomb bodies cut off long leg of FZU-61/B
 - c. Install FZU-61/B onto FZU-48/B and tape bomb body

B. Post Installation Inspection

NOTE

Since the nose fuze cannot be seen, steps 1 through 4 apply to tail fuze only.

1. Safing pin installed in gag rod/housing
2. Closure ring tight in fuze well
3. Fuze SAFE; red and black NOT visible on gag rod sleeve
4. Fuze switches set as required
5. Inspect FZU-48/B as follows:
 - a. Embossed arrow points to nose of weapon
 - b. Air intake NOT open and NOT blocked by upper aerosurface
 - c. Lanyard present and NOT damaged
 - d. Properly installed and secure
6. If applicable, FZU-61/B properly installed and NOT damaged

FMU-139 ELECTRONIC FUZE INSTALLATION FOR USE WITH MK 122 SAFETY SWITCH (Figure B-6)

A. Fuze Installation

NOTE

If dual fuzing is to be used, both fuzes must be set to the same fuze settings.

1. Safety pin installed gag rod

WARNING

If safing pin is removed from FMU-139 fuzes and no red and black striping is visible on gag rod sleeve (sleeve not extended), fuze is safe. If safing pin cannot be reinserted, notify proper authority for disposition. If red and black striping is visible on extended gag rod sleeve, fuze may be unsafe. Notify proper authority.

2. (Tail Fuze) Insert fuze; install threaded closure ring; tighten with closure ring wrench

CAUTION

If closure ring wrench is not available, use spanner wrench and exercise care to prevent damage to closure ring and fuze.

NOTE

When nose fuze is used, the fuze retainer nut from the guidance kit is used to secure the fuze vice the fuze closure ring.

3. If dual fuzing is to be used, proceed as follows:
 - a. Back off setscrew in bomb nose fuze well
 - b. Place O-ring on retainer bolt; install retainer bolt and tighten to 600 ± 50 foot-pounds of torque; tighten bomb nose fuze well setscrew to 150 ± 20 in-pounds of torque

CAUTION

Torque value shall not be exceeded; breakage of screws is highly possible.

- c. Install fuze into nose fuze well
- d. Screw fuze retainer nut into retainer bolt and tighten against the fuze. Remove fuze safety pin from nose fuze
- e. Install fuze seal nut into retainer bolt and tighten against the fuze retainer nut. Tighten fuze seal nut set screw

B. Post Installation Inspection

NOTE

Since the nose fuze cannot be seen, the following steps apply to tail fuze only.

1. Safing pin installed in gag rod/housing
2. Closure ring tight in fuze well
3. Fuze SAFE; red and black NOT visible on gag rod sleeve
4. Fuze switches set as required

MK 122 ARMING SAFETY SWITCH INSTALLATION (Figure B-6)

WARNING

Do not pull MK 122 switch lanyard during handling. If the lanyard pin breaks away from switch, discard entire MK 122 switch so it will not be used on a bomb.

Do not attempt to replace lanyard pin.

CAUTIONS

Do not pry tools or any other objects between the coaxial cable and the lanyard pin hold to the orientation of the safety switch while tightening the retaining nut.

Doing so may damage the safety switch causing the bomb to dud.

Take special care to prevent damage to coaxial cable and lanyard of MK 122 arming safety switch during bomb moving and loading operations.

A. MK 122 Installation

1. Plug male connector of switching unit into bomb body charging receptacle, piercing the diaphragm
2. Slide switching unit retaining nut, threads down, over cable and lanyard
3. Screw retaining nut into bomb body, tighten with spanner wrench provided, ensuring coaxial cable is aft of lanyard pin
4. Insert free end of cable through bomb suspension lug; tape cable and lanyard to weapon

B. Post Assembly Inspection

1. Magnet wire NOT broken
2. Coaxial cable aft of lanyard pin
3. Cable and lanyard taped to weapon

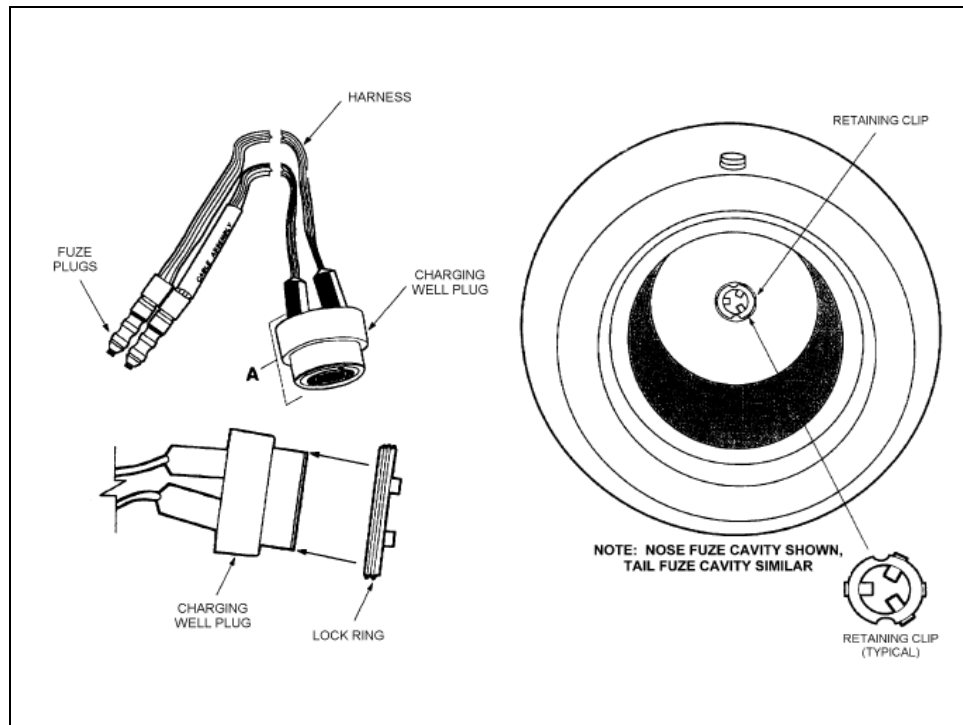


Figure B-1
M70 Series Cable Removal
Source: Airborne Weapons Assembly Manual

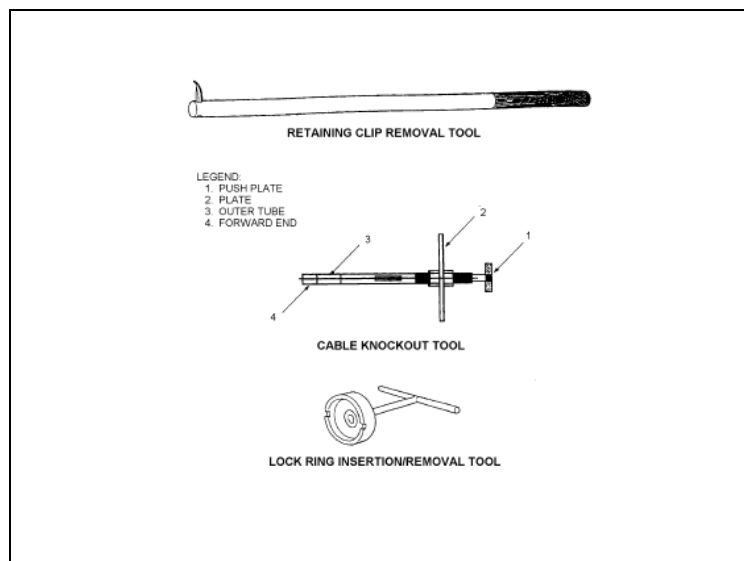


Figure B-2
Cable Removal Tools
Source: Airborne Weapons Assembly Manual

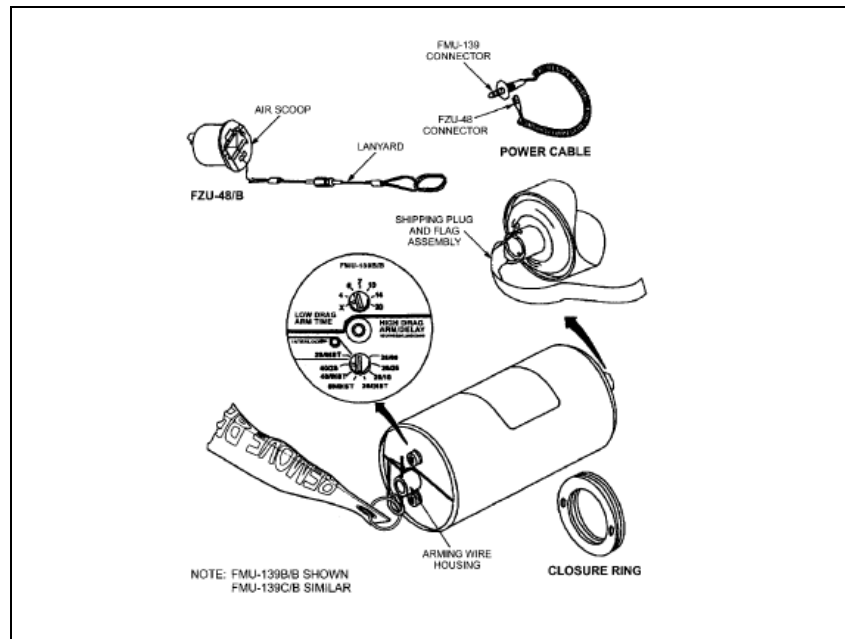


Figure B-3

FMU-139 Series Fuze and Component Preparation/Inspection

Source: Airborne Weapons Assembly Manual

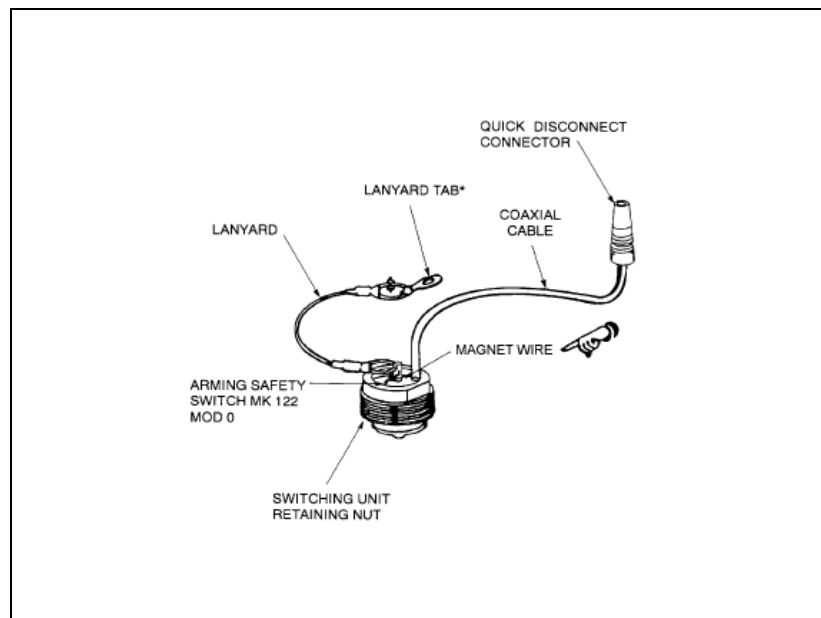


Figure B-4

MK 122 Arming Safety Switch Inspection

Source: Airborne Weapons Assembly Manual

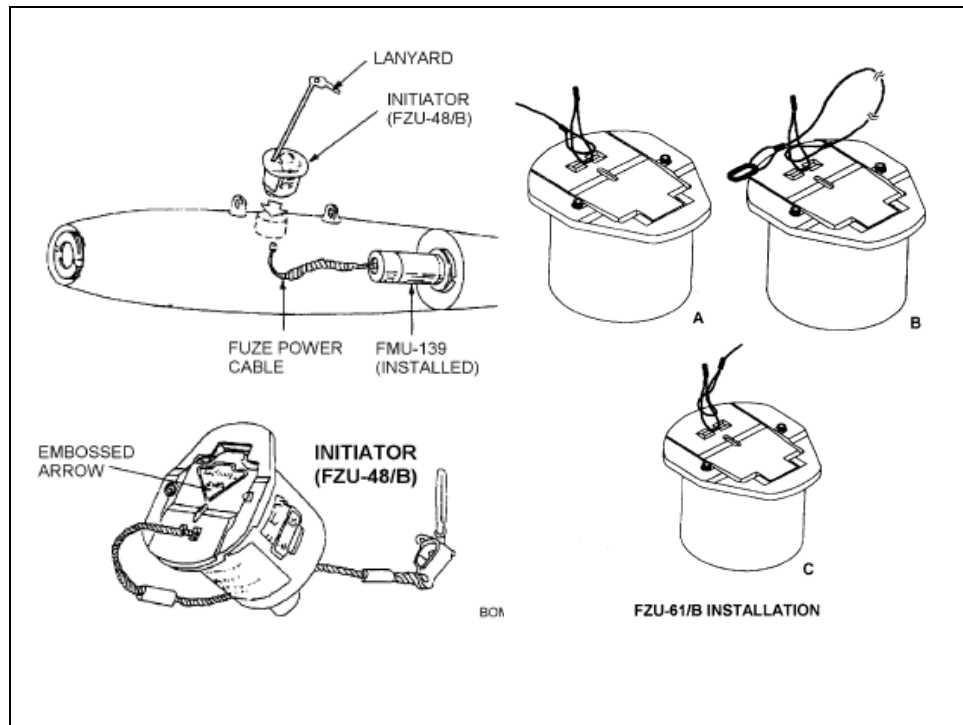


Figure B-5
FMU-139 Fuze Installation/Removal with FZU-48/B Initiator
Source: Airborne Weapons Assembly Manual

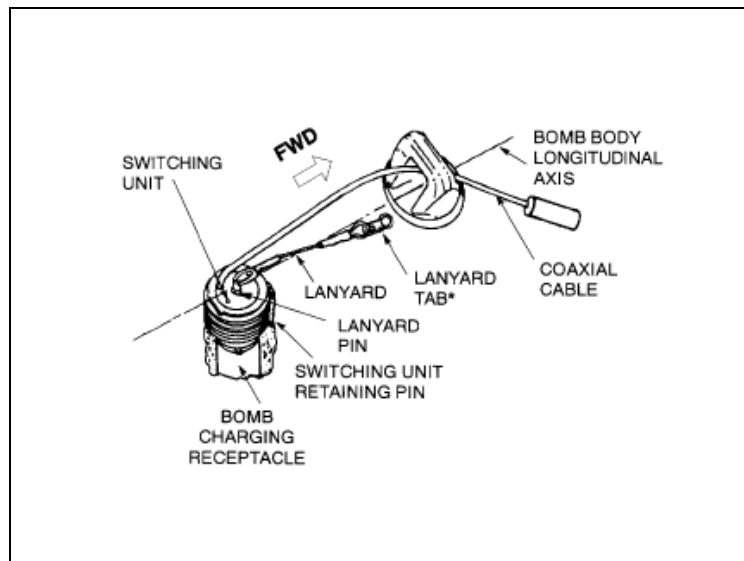


Figure B-6
MK 122 Arming Safety Switch Installation/Removal
Source: Airborne Weapons Assembly Manual

V I T A

Mitchell R. Conover was born in Glendale, California on March 20, 1972. He grew up in La Crescenta, California and graduated from Crescenta Valley High School in June 1990. Upon graduation from the United States Naval Academy with a Bachelor of Science in Aerospace Engineering with distinction, he was commissioned as an Ensign in the United States Navy, May 1994. He reported to Pensacola, Florida to begin flight training as a Student Naval Aviator later that year. After receiving his Naval Aviator Wings in November 1996, he was selected to be a pilot in the FA-18 Hornet. After completing initial FA-18 training at Marine Corps Air Station El Toro, California, he served an operational tour in VFA-97 "Warhawks" based in Lemoore, California. During his tour with the Warhawks, he cruised aboard the U.S.S. Carl Vinson and participated in Operations Southern Watch and Desert Fox. In July of 2001, he reported to the United States Naval Test Pilot School at Naval Air Station Patuxent River, Maryland and graduated with class 121 in June 2002. Upon graduation, he reported to VX-31 Test Squadron, Naval Air Weapons Station China Lake, California where he served as the Anti-Radiation Missile Project Officer. After his tour in China Lake, he returned to VFA-97 for a training officer tour to participate in the first Navy Tactical Air Integration Unit Deployment Program to Marine Corps Air Station Iwakuni, Japan. He is currently serving as an Assistant Program Manager for Systems and Engineering within the Precision Strike Weapons Program Office at Naval Air Station Patuxent River, Maryland.