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Development of the Joint Stand Off Weapon (JSOW) Moving Target Capability: AGM-154 Block Three program

Kyle Travis Turco
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Kyle Travis Turco entitled "Development of the Joint Stand Off Weapon (JSOW) Moving Target Capability: AGM-154 Block Three program." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Richard J. Ranaudo, Major Professor

We have read this thesis and recommend its acceptance:

U. P. Solies, Stephen Corda

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Accepted for the Council:

Anne Mayhew

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Vice Chancellor and Dean of
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Development of the Joint Stand Off Weapon (JSOW) Moving Target Capability: AGM-154 Block Three program

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Kyle Travis Turco

May, 2006

DEDICATION

This thesis is dedicated to

all who fight for freedom.

"War is an ugly thing, but not the ugliest of things. The decayed and degraded state of moral and patriotic feeling which thinks that nothing is worth war is much worse. The person who has nothing for which he is willing to fight, nothing which is more important than his own personal safety, is a miserable creature and has no chance of being free unless made and kept so by the exertions of better men than himself."

John Stuart Mill (1806 - 1873)

"In the truest sense, freedom cannot be bestowed; it must be achieved."

Franklin D. Roosevelt (1882 - 1945), *Speech, September 22, 1936*

ACKNOWLEDGMENTS

My sincere appreciation goes to the JSOW Team, Raytheon Missile Systems, and The Boeing Company for their tireless dedication to building and improving the products that support the greatest Navy the world has ever known. It has been an honor to work with such a dedicated team for the past two and half years, and I have ultimate confidence that they and JSOW will succeed. Without their help, this thesis would not have been possible, and more importantly, neither would JSOW Block Three.

I would like to convey my special thanks to Tim Hancock of Raytheon and Jeff Lueddecke of Boeing for their input, patience, and guidance while writing this paper. They went above and beyond all my expectations.

Most importantly, I wish to thank my wife and daughter for their endless love and patience as I researched and wrote this paper during "their" time. Thank you.

JSOW (AGM-154) on the wing of an F/A-18C

ABSTRACT

U. S. Naval Tactical Aviation capabilities are continually analyzed for capability gaps. This analysis has identified the need for a medium range standoff weapon with moving target capability. Technology advancements in Global Positioning System guided weapons, data link systems, and aircraft sensors can make time critical targeting of moving targets during interdiction operations possible with aircraft like the F/A-18 E/F Super Hornet. The Joint Stand Off Weapon "C" (JSOW C) variant met the criterion as an established system that could be evolved to enable this capability. The F/A-18 E/F has been identified as the threshold platform for JSOW Block Three program.

A systems engineering approach was used to analyze subsystem alternatives for their contribution to mission accomplishment, and their impact on program cost, risk, and schedule. Each alternative was given an overall assessment, and the most desirable solutions were combined to form the recommended design. Information was drawn from preliminary data made available by ongoing industry trade studies that are evaluating viable technologies. Critical insight was also gained during preparation live weapon demonstrations that are being planned to investigate design concepts. It is anticipated that the results and analysis of these demonstrations will provide significant support for the JSOW Block Three design recommended by this thesis.

The JSOW Block Three program has begun to develop a data link capable weapon system with a seeker for terminal guidance. The seeker is needed to overcome the relatively large target location error of current tactical targeting systems to accomplish the mission. It is also desired that the seeker enable autonomous aimpoint

selection and target recognition. The JSOW Block Three weapon must integrate a data link system that will employ the newly defined Weapon Data Link Network (WDLN) architecture, which is being specifically designed to support data link weapons.

Preliminary analysis indicates that Tactical Data Link 16 and an Ultra High Frequency (UHF) variable message format data link are the viable alternatives and both systems are compatible with the F/A-18 E/F. This thesis recommends and supports a Link 16 solution. The variable message format is less suitable for the task. However, the results of the planned ASuW demonstration's use of the Variable Message Format (VMF) may justify reconsideration. Initially the current seeker appears only capable of the very minimum requirements. The Block Three JSOW may require a complex software solution to enable land moving targets and autonomous target recognition. The suggested alternative is an improved or dual mode seeker that will enable these capabilities while minimizing overly complex algorithms.

The F/A-18 E/F Cockpit Vehicle Interfaces (CVI) for the weapon are being designed ahead of the weapon, and interface control design decisions must be front loaded so the threshold platform will support initial deployment of the weapon without costly software revisions. A timely and rigorous flight test program of what may be the first deployed network weapon will ensure a successful integration program.

The JSOW Block Three program has a well-defined mission and must choose a design that enables that mission. Fully funding the development and testing of the JSOW Block Three program is a must for the continued success of the United States Navy's Naval Aviation Enterprise.

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LIST OF ABBREVIATIONS

ACTD	Advanced Concept Technology Demonstration
AGR	Air-To-Ground-Ranging
APC	Armored Personnel Carrier
ASuW	Anti-Surface Warfare
ATR	Autonomous Target Recognition
BAAT	Best Altitude Above Target
BDA	Bomb Damage Assessment
BHA	Bomb Hit Assessment
C2	Command and Control
C4I	Command, Control, Communication, Computers, and Intelligence
CAINS	Carrier Aircraft Inertial Navigation System
CAS	Close Air Support
CATM	Captive Air Training Missile
CEP	Circular Error Probability
CJCS	Chairman of the Joint Chiefs of Staff
COTS	Commercial Off The Shelf
CPD	Capabilities Production Document
CUPC	Common Unique Planning Component
CVI	Cockpit Vehicle Interface

DCS	Digital Communications System
DD	Destroyer
DTED	Digital Terrain Elevation Data
DT/OT	Development and Operational Testing
DOD	Department of Defense
EGI	Enhanced GPS INS
EO/IR	Electro-Optical/Infrared
FF	Fast Frigate
FLIR	Forward Looking Infrared
FOM	Figure Of Merit
FOR	Field-Of-Regard
FOUO	For Official Use Only
FOV	Field-Of-View
FT MSL	Feet Mean Sea Level
GEU	Guidance Electronics Unit
GIG	Global Information Grid
GPS	Global Positioning System
HAE	Height Above Ellipsoid
HAT	Height Above Target
HERR	Horizontal Error
HOL	Higher Order Language
HMMWV	Highly Mobile Multi-Wheeled Vehicle

HSI	Horizontal Situation Indicator
HUD	Heads-Up-Display
ID	Identify or Identification
IFTU	In Flight Target Update
IOC	Initial Operational Capability
INS	Inertial Navigation System
ISR	Intelligence, Surveillance, Reconnaissance
JDAM	Joint Direct Attack Munition
JHMCS	Joint Helmet Mounted Cueing System
JITC	Joint Interoperability Test Command
JORD	Joint Operational Requirements Document
JMPS	Joint Mission Planning System
JSOW	Joint Stand Off Weapon
JTAC	Joint Tactical Air Controller
JTIDS	Joint Tactical Information Distribution System
JTRS	Joint Tactical Radio System
LAR	Launch Acceptability Region
LGB	Laser Guided Bomb (Paveway II)
LCM	Landing Craft, Mechanized
LST	Land Ship, Tank
MAGR	Miniaturized Airborne GPS Receiver
MIDS-LVT	Multi-Function Information Distribution System –

	Low Volume Terminal
MIL-STD	Military Standard
MPCD	Multi-Purpose Color Display
NOSEC	Non Secure
NSA	National Security Agency
NSAWC	Naval Strike and Air Warfare Center
NM	Nautical Mile
PDOP	Position Dilution of Precision
PMA	Program Manager, Air
PTT	Part Task Trainer
RCS	Radar Cross Section
SA	Situation Awareness
SAR	Synthetic Aperture Radar
SDB	Small Diameter Bomb
SLAM-ER	Standoff Land Attack Missile-Extended Range
SNF	Secret No Foreign
TADIL	Tactical Digital Information Link
TBD	To Be Determined
TCT	Time Critical Targeting
TDMA	Time Division Multiple Access
TEL	Transporter-Erector-Launcher
TGT	Target

TLE	Target Location Error
TN	Track Number
TPO	Technical Program Office
TTNT	Tactical Targeting Network Technology
TUMA	Target Under Missile Attack
U	Unclassified
VERR	Vertical Error
VFA	Fighter Attack Squadron
VX	Fixed Wing Air Test and Evaluation Squadron
WDL	Weapon Data Link
WDLN	Weapon Data Link Network
WGS	World Geodetic System
WIFT	Weapon In-flight Tracking

CHAPTER I: Introduction

The United States Naval Doctrine Publication One [1] states, "The basic roles of our Naval Forces are to promote and defend our national interests by maintaining maritime superiority, contributing to regional stability, conducting operations on and from the sea, seizing or defending advanced naval bases, and conducting such land operations as may be essential to the prosecution of naval campaigns." This is a broad definition, but gives one an understanding of the large scope of activities assigned to naval forces. The U.S. Navy of tomorrow must not only maintain maritime superiority, but also project that superiority ashore. Superiority is defined by the Department of Defense (DOD) [2] as, "That degree of dominance of one force over another that permits the conduct of operations by the former and its related land, sea, and air forces at a given time and place without prohibitive interference by the opposing force." It is the large scope of activities and need for battlefield superiority that drive the requirements discussed in this paper. To reach such a superior position in a shooting conflict, one must possess overwhelming capabilities to execute time critical interdiction missions. The DOD [2] defines interdiction as, "An action to divert, disrupt, delay, or destroy the enemy's surface military potential before it can be used effectively against friendly forces." This paper focuses on developing a weapon system to destroy enemies' mobile and relocateable targets.

Today and in the future, dominating the battlespace not only requires naval forces to target and engage enemy resources, but that they find, fix (precisely locate), track, identify, target, engage, and provide a report of results (assess) in near real-time from a

tactical strike fighter aircraft that typically has one or two operators. Additionally, the American public demands that they do it with little or no loss of life. All of the above factors place a complex set of requirements on current and developmental delivery platforms and weapon systems. The goal of the Joint Standoff Weapon (JSOW) Block Three program is to develop a combat deployable weapon system to meet these requirements by the end of the decade. The author, as an active member of the Integrated Product Teams developing this weapon, uses a systems engineering approach to examine the subsystem alternatives available to the JSOW development team to provide a recommended design that meets the needs of the U.S. Navy's leadership and warfighters.

JSOW Block Three Target Set

One of the first steps in weapon systems design is defining the intended target set. This is an ongoing process for many departments within the United States government. It is beyond the scope of this paper to examine and assess the expanse of threat resources that exist today. Using the established knowledge base, the JSOW Block Three development team formed a preliminary set of notional land and sea target groups for the JSOW Block Three weapon. The two sets are listed below, and represent possible target types. The list is being briefed to various organizations to ensure it encompasses all expectations at this point. As development progresses, certain target types will be designated as threshold targets and others will become objective targets. Threshold targets will drive requirements and will eventually be the primary test objectives for the program. Objective targets are a desired capability but not required. Because this process will not be complete until nearing the end of the weapon's developmental testing,

only recommendations for objective targets can be made at this time. The entire list will be considered throughout the paper. In the end, Chapter VI will address the objective versus threshold target sets considering both the recommended weapon design and the needs of the warfighter.

- Five notional land target groups
  - Large (>38 ft, transporter type vehicles)
    - Missile Transporter, Erector, Launcher (TEL), tank transporter, tractor-trailer
  - Armored fighting vehicles
    - Tank, Armored Personnel Carrier (APC), etc
  - Medium / Small (soft targets)
    - Mobile Surface-to-Air Missile Systems (SAMS), truck, support vehicles, etc
  - Scout (high speed)
    - Scout vehicles, cars, light trucks, etc
  - Train
    - Various length / composition
- Five notional sea target groups
  - Large warship (standard hull, >250 ft)
    - Destroyer (DD), Fast Frigate (FF), Landing Ship, Tank (LST), etc
  - Small warship (standard hull, >100 ft)
    - Corvette, patrol boats, etc
  - Landing craft (barge hull)
    - Landing Craft Mechanized (LCM), etc
  - Fast attack craft (10 to 30 ft)
    - Boghammer, Zodiac, hydro-foil, "pleasure craft", etc
  - Air cushion
    - Hovercraft, etc

Time Critical Targeting and Kill Chain Considerations

Before defining the "Problem", which the DOD calls the mission need, associated with destroying moving targets, one of the immerging aspects of warfare needs to be discussed. That aspect is Time Critical Targeting (TCT), which has evolved as an essential element of modern warfare. Figure 1 shows a simplified kill chain from a briefing [3] given by Program Manager, Air-201 (PMA-201) to the Program

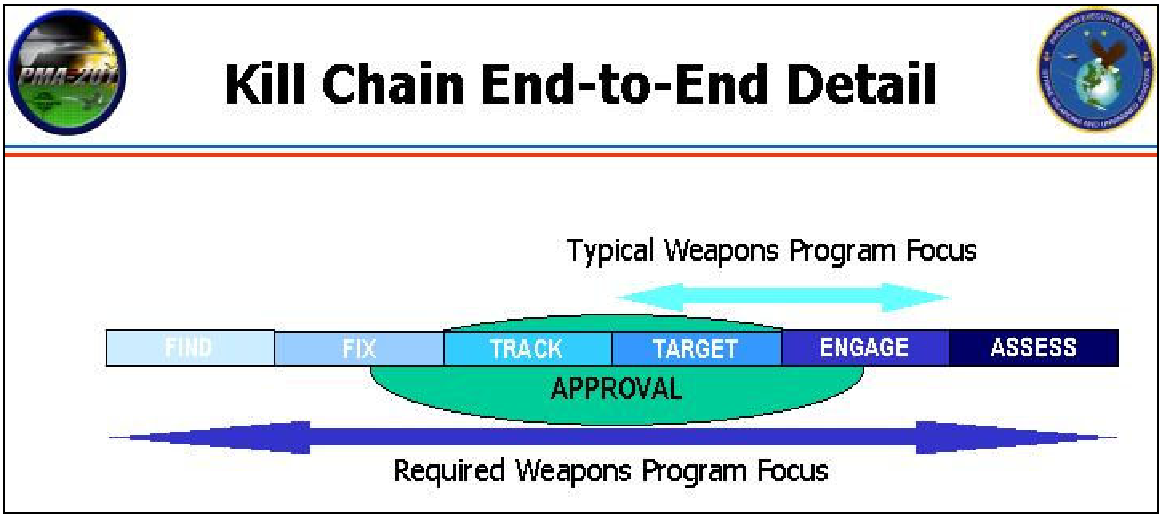

Figure 1 PMA-201 Generic Kill Chain Detail. [3]

Executive Office, Strike Weapons to explain the typical and newly required weapons program focus. A kill chain defines the events, their relationships, and the resources that are needed to execute a strike. Each of the six basic events is listed in Figure 1, which shows their relationship to one another. In order to attack a target, one must *find* or detect it, then *fix* its precise location, and begin to build a *track* or track file of information. As the track file is being built, the approval process begins, which is external to the kill chain, but provides permission to execute the attack. While approval is being requested, the item being tracked may be *targeted* with a platform and weapon capable of executing the attack. Once approval is granted, the target can be engaged. Finally, the results of the attack are determined and relayed during the *assess* event. Figure 1 provides insight with the "focus" arrows into the culture change needed in weapon system development to broaden a weapon design effort so it encompasses the entire kill chain. Part of this culture change requiring consideration of the entire kill

chain is needed to truly enable TCT.

There has always been the need to execute the kill chain in the minimum amount of time, but not always the capability. Fast moving vehicles used by asymmetric (terrorist) forces that can hide in civilian populations are the pinnacle objective of TCT. Part of the *assess* block in the kill chain requires higher headquarters to decide how to proceed before the process can start over. For headquarters to make command decisions, they must have decision quality information, and traditionally, weapon systems were not designed to be a part of the information chain. In the past, if a situation required time critical actions, the decisions and kill chain execution were delegated to the lower level commanders in the field. However, in today's political environment that option is only used in very extreme situations. Consequently, the DOD has the need to engage time critical targets, but lacks complete weapon systems designed to pass the required information so they may accomplish the entire kill chain in minimum time. Currently, an attempt is made to accomplish this goal with a complex maze of systems, which has unavoidable time latency. This is a recognized issue and there is extensive literature on the need for a shift to network centric warfare. One of the most relevant documents is the *United States Naval Tactical Data Links Roadmap* [4] prepared by the Naval Network Warfare Command. This document outlines current impediments to network centric warfare and the path forward to solve them.

JSOW Block Three Mission Need Defined

The mission need statement defines the "problem" for the JSOW Block Three development team. The mission need is derived and defined from a variety of sources,

all of which are classified because they identify specific capability gaps. However, Figure 2 was obtained and declassified to show the results of analysis regarding specific U.S. Naval capabilities [5]. The briefing was derived from theater commanders' needs throughout the world and used to brief the DOD and other agencies on the needs of the Naval Warfighter.

Figure 2 shows the results for Naval Strike Capabilities. The column labels and some of the details have been removed to make this an unclassified figure. Regardless, one can see the large red block associated with hard and soft moving targets, which identifies a major capability gap. In Figure 2,"JSOW WDL C" is the JSOW Weapon Data Link "C" variant, which shows that development of a data link capable JSOW could fill this gap.

To better understand the true magnitude of filling the identified gap, PMA-201 has begun a process termed "kill chain scoring". As stated in CDR Holberg's (JSOW Deputy Program Manager) briefing:

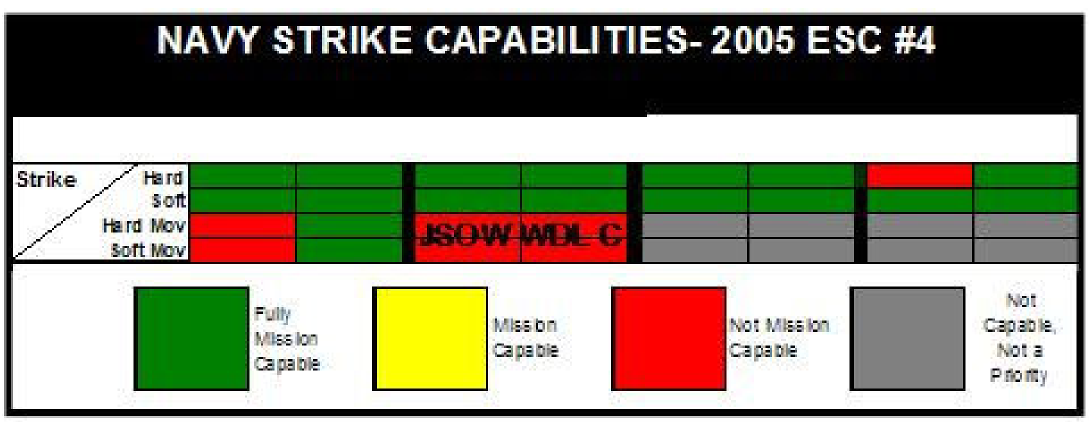

Figure 2 CFFC 2005 Executive Steering Committee #4 Capabilities Example. [5]

"The purpose is to provide a framework for capability analysis using systems engineering to score kill chains based on technical data. It does not address combat identification or engagement approval processes." [3]

Figure 3 is an example diagram from the kill chain analysis in the same briefing. The example only shows the desired end state to avoid exposing current gaps in the kill chain. The blue arrows were added to show the threshold kill chain for JSOW Block Three. Note that the F/A-18E/F was considered the threshold launch platform. Threshold platform means the F/A-18E/F will be the first aircraft to integrate this new capability and deploy it.

As one can see from this analysis, the development of the JSOW Block Three weapon must consider the entire kill chain and all of its components. To develop a weapon system that merely puts a warhead on the desired target is no longer sufficient.

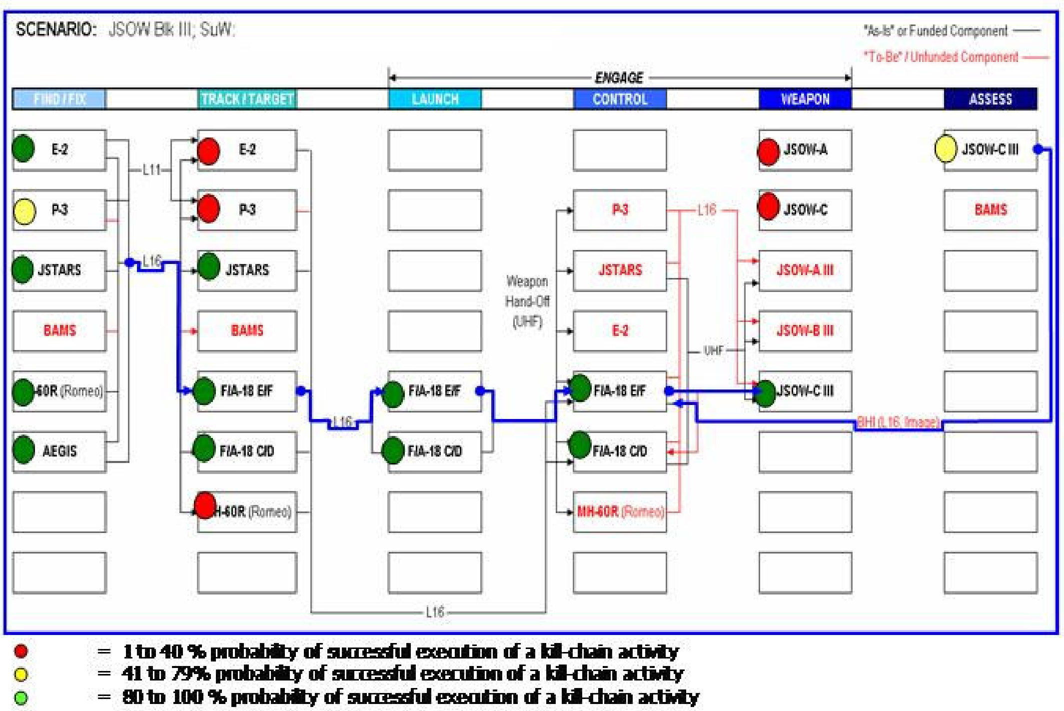

Figure 3 JSOW Block Three Notional ASuW Kill Chain. [3]

One of the goals for JSOW is to develop a weapon that "drops into" this kill chain to make it a reality. This kill chain example is specific to anti-surface warfare (ASuW), which means engaging ships on open water. However, analysis exists for many other kill chains where JSOW Block Three fills the requirement. It is not by accident that the initial design for JSOW Block Three will meet the requirements for the weapon in the ASuW Kill Chain. This is one capability gap that the Navy recognizes it must fill quickly.

With all factors in hand, PMA-201 and its operational sponsors have established the following mission need: **Develop a cost-effective solution to engage moving targets ashore and afloat with the flexibility to adapt to emerging network architecture [6].** This statement does not specify a solution; a little explanation will show why the JSOW Program was given the go ahead to develop a solution. C*ost effective* means two things in the above statement. First, the solution needs to cost as little as possible to develop and test. Second, the total cost per kill ratio needs to be favorable. Each of these was seen as an advantage for JSOW as it is a mature system that could evolve to the need and capitalize on the production quantity to reduce delivered cost. A system built from the ground up would have a difficult time accomplishing this aspect of the mission need. Next, the solution must *adapt to emerging networks*, which is another advantage for JSOW as it is starting with fresh data link hardware that will be designed with this capability. Other systems, like the Standoff Land Attack Missile-Extended Range SLAM-ER are currently tied to legacy data link systems that have reached their serviceable life. Finally, the JSOW design allows for standoff employment

ranges, which is not mentioned in the mission need, but is necessary to fill the identified capability gap. Further explanation of the JSOW selection is discussed in Chapter II, which outlines the assumptions made before beginning the JSOW Block Three program.

Scope and Limitations of Analysis

The purpose of this paper is to employ a systems engineering approach to analyze various subsystem alternatives for their contribution to mission accomplishment, and their impact on program cost, risk, and schedule. Each alternative was assigned a rating for the above metrics and given an overall assessment. The most desirable subsystem solutions were combined to form the recommended design. The paper will discuss the program assumptions, requirements, and then analyze the various hardware and software alternatives to arrive at a recommended design. Finally, implementation issues will be discussed to close the gap between the weapon system and its initial launch platform, the F/A-18 E/F Super Hornet.

The scope of this paper is limited to discussion regarding the planned development of a JSOW variant capable of engaging moving targets. It intentionally does not address the advantages or disadvantages of the JSOW system over other fielded or developmental systems. There are limited references to other system's designs and capabilities in this paper, but they are only to give the reader a broader insight into current and future strike weapon systems.

The discussions and recommendations found in the paper are from an F/A-18 Hornet pilot and warfighter's perspective. This perspective and the opinions contained in this paper do not intend to represent the opinion of the Department of Defense, the

Department of the Navy, or the JSOW Program. Therefore, the primary concern is the development of an operator friendly, strike-fighter cockpit compatible and effective weapon. Program risk, technology, schedule, and cost concerns were considered secondary. Cost analysis is only factored into the discussions and recommendations in this paper when available from industry trade studies. It is beyond the scope of this paper to conduct independent cost trade studies. However, engineering sense is applied to avoid a "gold plated" design that would be unachievable. Political concerns associated with the development of a JSOW data link variant are considered tertiary, if at all.

CHAPTER II: JSOW Block Three Assumptions

Background

The JSOW Team made a number of assumptions before beginning the JSOW Block Three program. The sources varied from cost considerations to DOD interoperability mandates. Each will affect the final product and are outlined here to help the reader understand some of design decisions or recommendations made in the remainder of this paper. It is worth noting that the word *limitation* was avoided because it implies something that cannot be changed. This program began early in 2005 and was on going at the completion of this thesis, which means the only clear assumption is *change*.

The first assumption made was that JSOW Block Three would be an evolution of the JSOW weapon family and would build upon its current components and capabilities wherever possible. A complete redesign of the JSOW system would be cost prohibitive and adversely effect program risk. The inherent flexibility in the JSOW design was one of the reasons for choosing to develop the JSOW Block Three. Therefore, a brief introduction to the JSOW weapon family is in order. Figure 4 shows the current family of JSOW weapons that have been developed jointly by the U.S. Navy and the U.S. Air Force in conjunction with Raytheon's Missile Systems Division. The weapon is a 1000-pound class store that is integrated on multiple fighter and bomber platforms across the Navy and Air Force. The weapon uses the MIL-STD-1760 [7] interface to communicate to the launch platform. Each variant uses a common missile body called the "truck", a common guidance electronic unit (GEU), and common control section in the tail. All

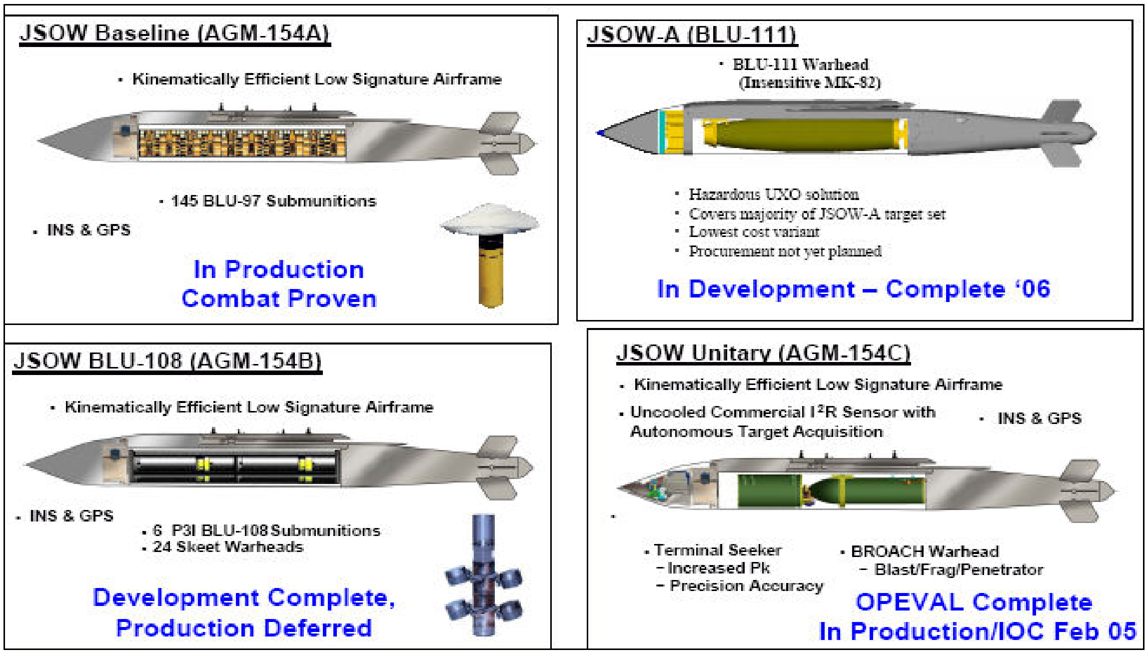

Figure 4 JSOW Weapon Family. (Source: JSOW Technical Project Office)

except the JSOW C (AGM-154C) use GPS for midcourse and terminal guidance. The JSOW C uses an imaging infrared (IIR) seeker for precision terminal guidance against land fixed targets. The design and use of common components has allowed the JSOW Team to develop the multiple payloads seen above because platform integration costs are greatly reduced by eliminating the need to test store aerodynamics and separation characteristics for each variant.

Considering the available variants above, the JSOW C was chosen as the starting point for the Block Three program because of its two-part penetrating warhead and its IIR seeker. The reasons for choosing a weapon with a seeker are discussed later in this chapter. The current JSOW C warhead was developed to have capability against a broad spectrum of land stationary targets. It utilizes an initial augmenting shape charge to

punch a hole in the target's surface, and then a second charge (follow through bomb) passes through that hole and detonates after a cockpit selected delay. The delay can be set from zero to 240 milliseconds. In an effectiveness study conducted by the JSOW Project Office [8], analysis and testing deemed the warhead suitable for use against surface combatant vessels and has already demonstrated excellent effectiveness against hard and soft land vehicles [9].

The JSOW C achieved initial operational capability in 2005. It is the newest variant in the JSOW family. Further information on the JSOW C is available to the public on PMA-201's website: http://www.strikenet.js.mil/201/jsow/jsow-index.asp. Information and links to other sources are listed on the website. An additional benefit to the JSOW Block Three program is the recent completion of the JSOW C development. This means the JSOW C government and contractor team is still in place and has the resident knowledge to evolve the weapon to meet the moving target mission need. Therefore, with the JSOW C as a baseline, the development team set off to understand what was necessary to evolve the current weapon.

Target Location Error and Circular Error Probable (CEP) Discussion

Discussions in following paragraphs outline the assumptions made by the PMA-201 and the JSOW Team before beginning the development of the Block Three weapon. Most have a common theme between them, which is their affect on target location error (TLE) and/or Circular Error Probable (CEP). Therefore, a brief discussion of these topics is presented in the following paragraphs.

Target location error is simply the difference between the actual three-

dimensional position of the target and the position determined by the system charged with "fixing" the target. In the case of a moving target, the target must be "tracked", which implies continuous "fixing" of the target. Figure 5 shows a simple diagram where the platform and sensor have presumed to locate a target where the difference between the actual and presumed locations is the TLE.

Therefore, one can conclude that TLE is associated with the sensor and platform that generates the target coordinates. Each sensor and platform has a number of errors associated with the ability to locate itself, then locate the target, and finally transform that location into a three-dimensional set of coordinates. For GPS weapons, this typically equates to a latitude, a longitude, and an elevation. The details of the sensor and platform errors are discussed in later paragraphs. One can see from Figure 5 that there is a vertical

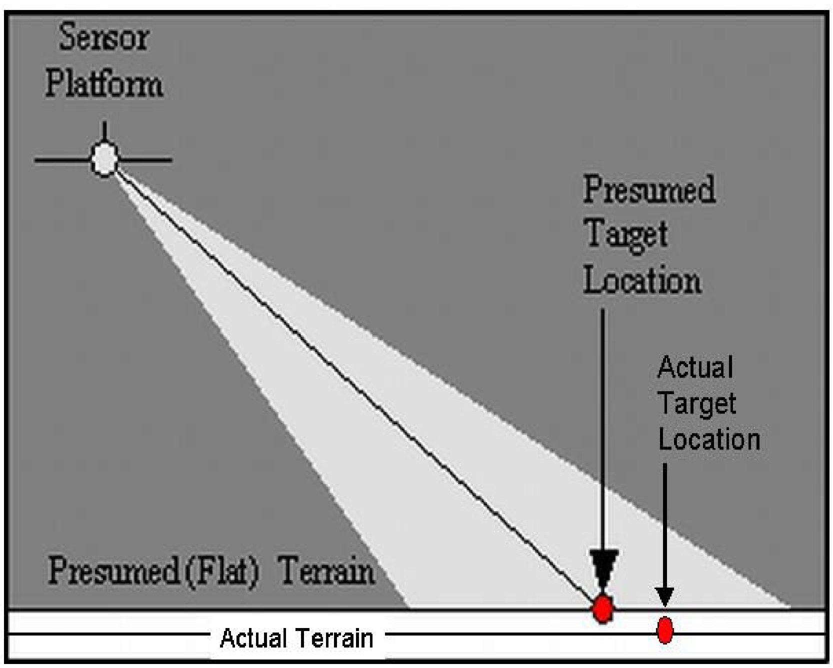

Figure 5 Target Location Error Diagram.

and horizontal component to the TLE. The vertical component of the error has become increasingly important as GPS guided weapons have become the weapon of choice. For further information, Beekman and Dupont's paper, Methodology for Evaluating Platform/Sensor Coordinate Generation Accuracy [10], provides good insight into current topics regarding TLE.

For this paper, TLE will be referred to in two components: Circular error (CE) for horizontal radial error and Linear Error (LE) for vertical or height errors. Currently, DOD agencies are trying to standardize the terminology used to describe target location errors. However, traditional CE and LE values are generated for the 50th percentile, indicated by CE50 and LE50. A set of target coordinates with a CE50 and LE50 value are interpreted to mean the target will be located within the cylinder created by these values 50% of the time. The values are typically sited separately because LE or vertical error can be minimized by employing a steep impact angle approaching 90 degrees, and because the circular error is easily plotted on an image or map. Spherical error (SE) can also be calculated from the LE and CE values to give a sphere that statistically will encompasses the actual target. Target coordinates typically have some errors associated with them, which are directly introduced to the GPS weapon when they are input as the target location. Without some form of terminal guidance, one must plan for the possibility that the weapon may miss by the TLE's magnitude plus any weapon generated errors.

Circular Error Probable is the other term of great interest to weapon developers and warfighters. When dealing with weapons, the term CEP is typically associated with the weapon's performance with respect to statistical miss distance. It is used as a

prediction tool for mission planning, and to write performance specifications for weapon developers. However, it is actually a rolled-up value resulting from the errors generated by the entire system of systems. Figure 6 is an example of a CEP plot that shows the measured impact distances plotted on a grid using, in this case, a bearing from the target and radial miss distance[11]. . Cross range miss distance and down range miss distance can also be used. To calculate CEP or $CEP_{50\%,}$ one simply draws a circle centered on the target that contains one-half of the impacts. If there are an odd number of impacts, the circle is drawn with a radius equal to the median miss distance, which in Figure 6 is 4.0 feet. If there is an even number, the radius of the circle encompasses one-half of the impacts. For example, if there were ten scored hits, the CEP circle would be drawn to

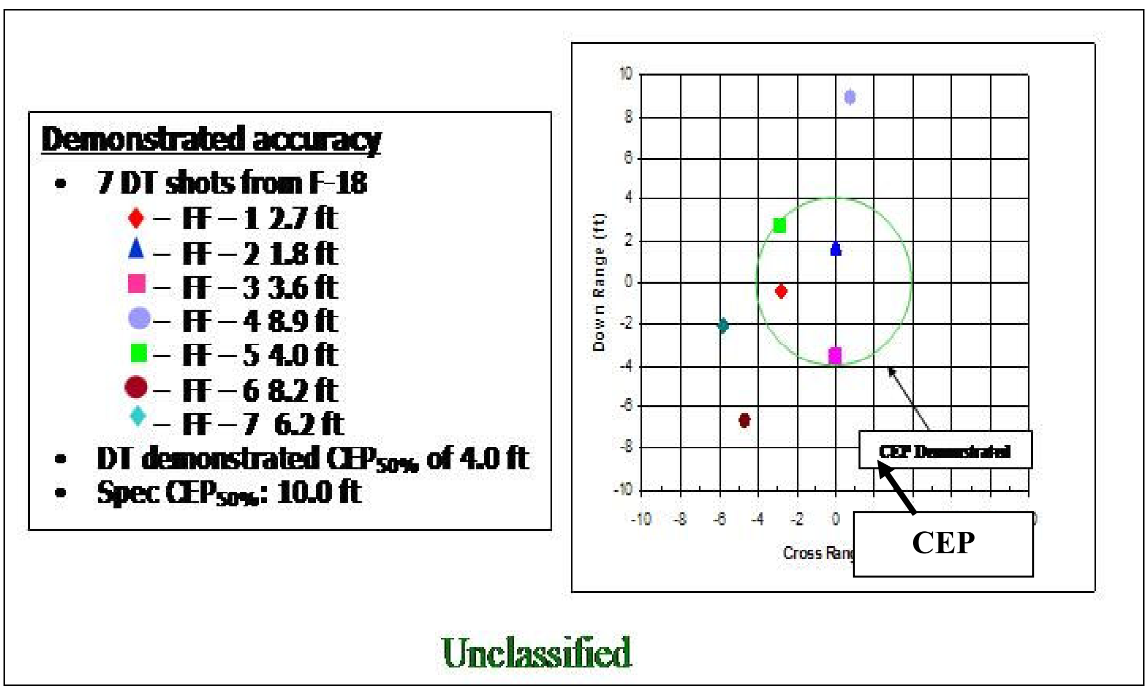

Figure 6 Example Weapon Circular Error Probable (CEP) Plot. [11]

fall on the impact fifth farthest from the target. No complex statistical equations are required, just a simple method to represent where any given single bomb will fall half of the time. There are some immediately obvious shortcomings to this method, which are expertly explained in Beekman and Dupont's paper [10]. The term has endured however, because it is a simple relative method of comparing complete system performance as the subsystems vary. For example, one could compare the F/A-18's CEP for dropping and self-guiding laser guided bombs (LGB) with dropping Joint Direct Attack Munitions (JDAM) using self-generated coordinates. The F/A-18/LGB combination would have a smaller CEP.

The more pertinent issue, regardless of statistical method, is the errors and their sources that generate miss distance, which result in the need for CEP figures. The sources of error that primarily concern the JSOW Block Three design are discussed below. One should keep in mind that these errors are what the weapon must overcome to hit the target, in addition to self-generated navigation and guidance errors. The sensor and aircraft errors are discussed below as assumptions because there is little the JSOW team can do about them before they are introduced to the weapon, and they depend on a large number of variables. The design team must understand their contribution to TLE and minimize their affect on the weapon's CEP. One may ask why CEP is so important, and James Irvine's extensive report [12] on the subject succinctly answers:

> *"In reality, this means that a modern missile warhead is approaching the one-shot-kill dream of World War II air planners. A modern missile with a CEP of 3 m in effect obliterates any target at which it is aimed. A modern missile with a CEP of 13 m (the publicly stated CEP of a GPS* [only] *Guided System) will probably produce Level "B" Damage on its target and stands an 85% chance of obliterating it, and 2 or 3 weapons will certainly do the job of obliterating it."*[12]

Sensor Assumptions

The two sensor types currently available to tactical aircraft for direct target coordinate generation are Forward Looking Infrared (FLIR) pods and radars , which generate coordinates via target tracking modes or synthetic aperture radar (SAR) maps. In the case of SAR maps, the image must be mapped to a coordinate system and then coordinates can be generated for each pixel. For the purposes of JSOW Block Three, the sensors will need to provide target coordinates for a moving target, which will require them to be in a tracking mode. The sensor must continually update the target position and pass that information to the aircraft so it may be loaded in the weapon while onboard, and after launch via a data link. For the threshold platform, which is the F/A-18 Super Hornet, it was assumed that these sensors would be the Advanced Targeting FLIR (ATFLIR) and the APG-73 or -79 radars. The Raytheon Corporation manufactures all three of these systems for the F/A-18. The APG-73 uses a mechanically scanned antennae array and the APG-79 uses an active electronically scanned array radar.

By choosing to use the ATFLIR as a possible source of coordinates, further assumptions were made. The first is the TLE associated with this particular pod. Currently, FLIR sensors generate the smallest TLE between the two types mentioned above, but have very limited range capability when compared to radar systems. Figure 7 shows the recent results of an F/A-18 ATFLIR TLE study conducted by Lieutenant Commander Patrick Modlin and Dan Risch at the F/A-18 Advanced Weapons Laboratory in China Lake, CA [13]. The vertical axis represents a normalized TLE.. The horizontal green reference line depicts a typically satisfactory TLE value for weapons terminally

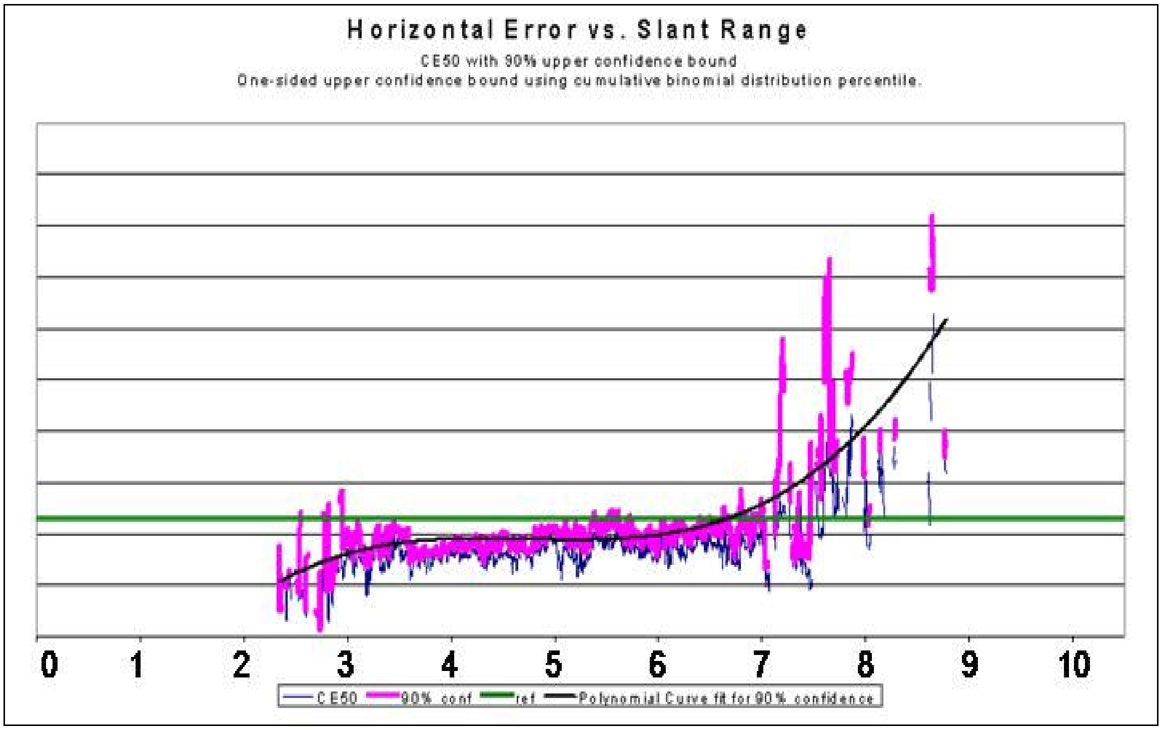

Figure 7 Normalized Forward Quarter TLE for ATFLIR on an F/A-18E/F. [13]

guided by GPS. The horizontal axis represents normalized range from the target. Figure 7 shows that an ATFLIR can satisfactorily produce coordinates of this quality, but only at relatively short range. It also shows that past seven, the quality rapidly begins to degrade. However, for the ATFLIR, this represents nearly the maximum range at which this system is capable of finding and tracking a moving target of nominal size. With this data in hand, the JSOW team assumed the ATFLIR would only provide coordinates at relatively short range for the JSOW, but with relatively low TLE. One must keep in mind that data latency and moving target tracking errors, which have not been factored into the TLE data in Figure 7 will further degrade accuracy. Additionally, no FLIR system provides an adverse weather (ground obscuring clouds) capability against ground or sea

targets. For standoff employment, a second coordinate source had to be considered if the full range of the JSOW was to be available to the crews that employ it.

The use of radar becomes an obvious choice for targeting a medium range, adverse weather capable weapon, but the APG-73 and APG-79 radars come with their own set of limitations when attempting to track a moving target and provide weapon quality coordinates. Typically, the ground (or sea) moving target tracking (GMTT) modes of these radars have been used at long range to detect a target and then cue other sensors, like the FLIR, to the target position. This is generally done because the TLE associated with these radar modes is large relative to the FLIR. They are certainly too large to terminally guide a GPS only weapon that requires precision coordinates to engage a target. Figure 8 shows the relative relationship between the JSOW seeker field-of-view (FOV), the radar track uncertainty, and the FLIR uncertainty. The diagram was taken from research provided by JSOW team members at Raytheon Missile Systems 14]. The FOV of the seeker depends on the search altitude and range from the target of the weapon. The current seeker starts processing at 2000 meters slant range. The FOV in Figure 8 is shown for the current maximum search altitude of the JSOW C, which generates the given FOV dimensions. The three red triangles simply represent possible target locations the FLIR or radar could return for a target actually located at the boresight. One can also see the radar's TLE or cross-range and down-range errors could allow the target location to fall outside the current JSOW FOV. This issue is further exacerbated by errors within the weapon and the data latency associated with the data link system.

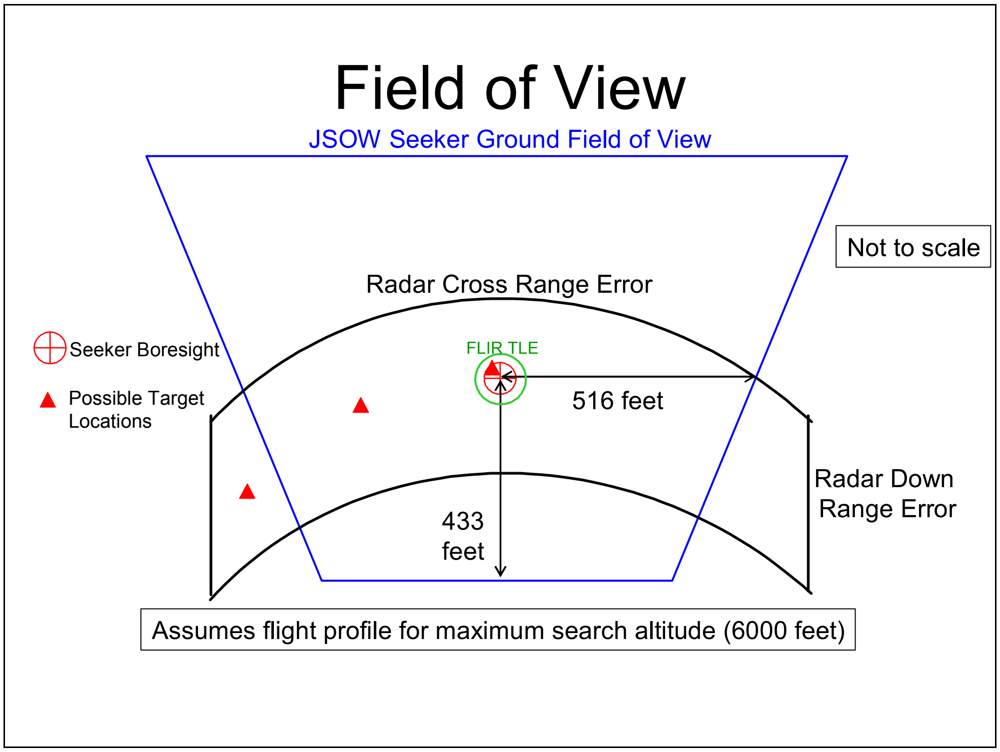

Figure 8 JSOW Seeker Relative Field of View. [14]

Figure 9 illustrates how each error effectively reduces the seeker FOV, which requires the targeting sensor and platform to further reduce TLE or for the seeker to scan its field of regard. However, the use of a terminal guidance seeker is necessary to give the weapon even a chance for a successful engagement. A GPS guided weapon simply requires a TLE unobtainable by tactical radars at medium standoff ranges. The actual radial values associated with Figure 8 and Figure 9 have been removed and the figures are not to scale for classification reasons.

Aircraft Assumptions

Currently the U.S. Navy has two models of the F/A-18: the F/A-18 C/D Hornet and the F/A-18 E/F Super Hornet. The later is an evolution of the C/D model and

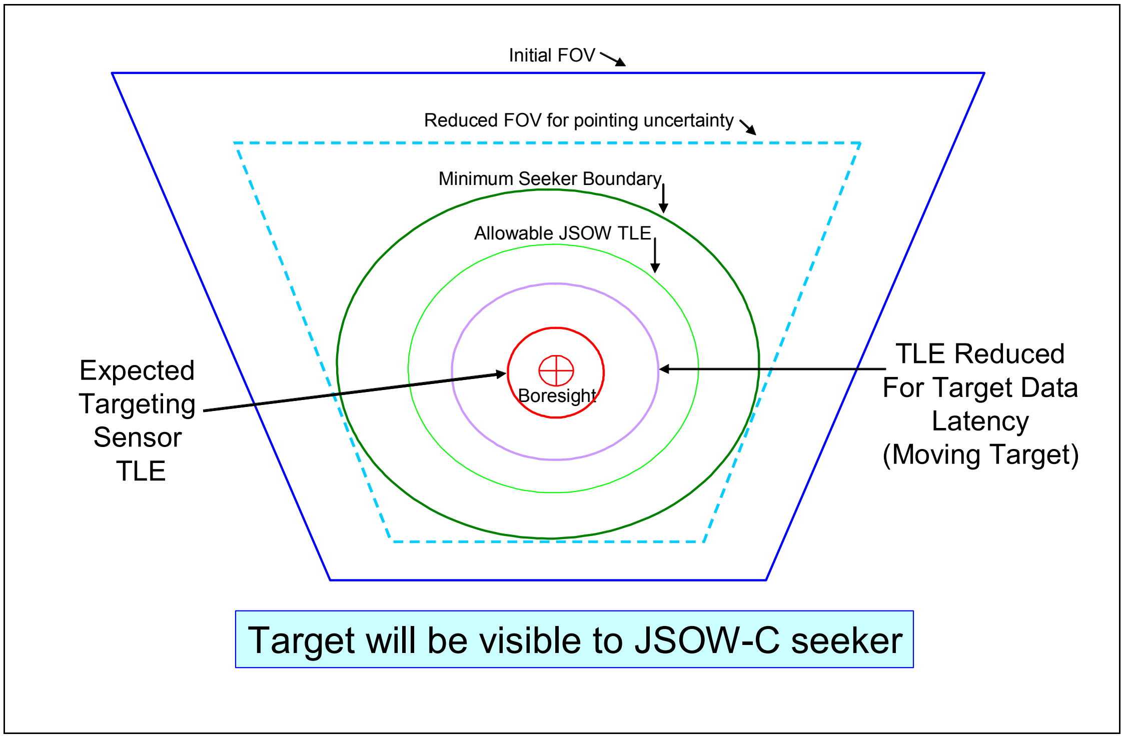

Figure 9 Effective Seeker Footprint for the JSOW C. [14]

primarily a replacement for the F-14 Tomcat. Both models can employ all JSOW variants. However, early in the JSOW Block Three program it was assumed, for various programmatic reasons, that the Super Hornet would be the threshold or first platform to carry the Block Three weapon. Having selected the F/A-18E/F as the threshold platform for JSOW Block Three integration, certain characteristics about that platform must be understood. The first is its contribution to TLE due to its own navigation solution errors. Basically, the aircraft must know its own location before it can use a sensor mounted on it to locate a target. The target coordinates will only be as good as the platform's position and velocity errors because all of the sensors are aligned to the aircraft. Scott Quackenbush, of the F/A-18 Advanced Weapons Laboratory at China Lake, CA, has

written a paper that discusses the specifics of the F/A-18 navigation system with regard to TLE [15]. An excerpt from the paper is contained in Appendix 1.

Target location error is further compounded in the F/A-18 by the method the system uses to calculate Best Altitude Above Target (BAAT). The algorithm is simply trying to find any two sides of the triangle formed by the target's position, aircraft's position projected on the ground, and the aircraft's position in the sky. Figure 10 shows an example of this triangle, where the value A1 is the desired product. This value is the target's height above the reference plane, which is mean sea level (MSL) or height above the ellipsoid (HAE). Side B is a given using the aircrafts GPS/INS system, which includes aircraft position uncertainty error. It is more difficult to find one of the other sides. If a FLIR is onboard, the laser range finder of the FLIR is the most accurate method and allows the calculation of A1. If it is not onboard, then the radar can be used if the aircraft is close enough to the target located on the island, but this range is well inside anything usable for standoff weapons. Lastly, the sum of side A and A1 can be found using the Barometric or Radar Altimeter, or the GPS. All three methods are relatively inaccurate and do not allow for the calculation of A1, and the target elevation is assumed to be the same as the terrain elevation below the aircraft. With this method, the magnitude of A1 will contribute directly to the vertical position error of the perceived target location. Nominally, the altitude calculated by the BAAT algorithm is the largest source of error for target coordinates generated by the F/A-18 and presumably most other tactical aircraft. One other solution currently being investigated by the F/A-18 Advanced Weapons Laboratory is the use of Digital Terrain Elevation Data (DTED) to find the

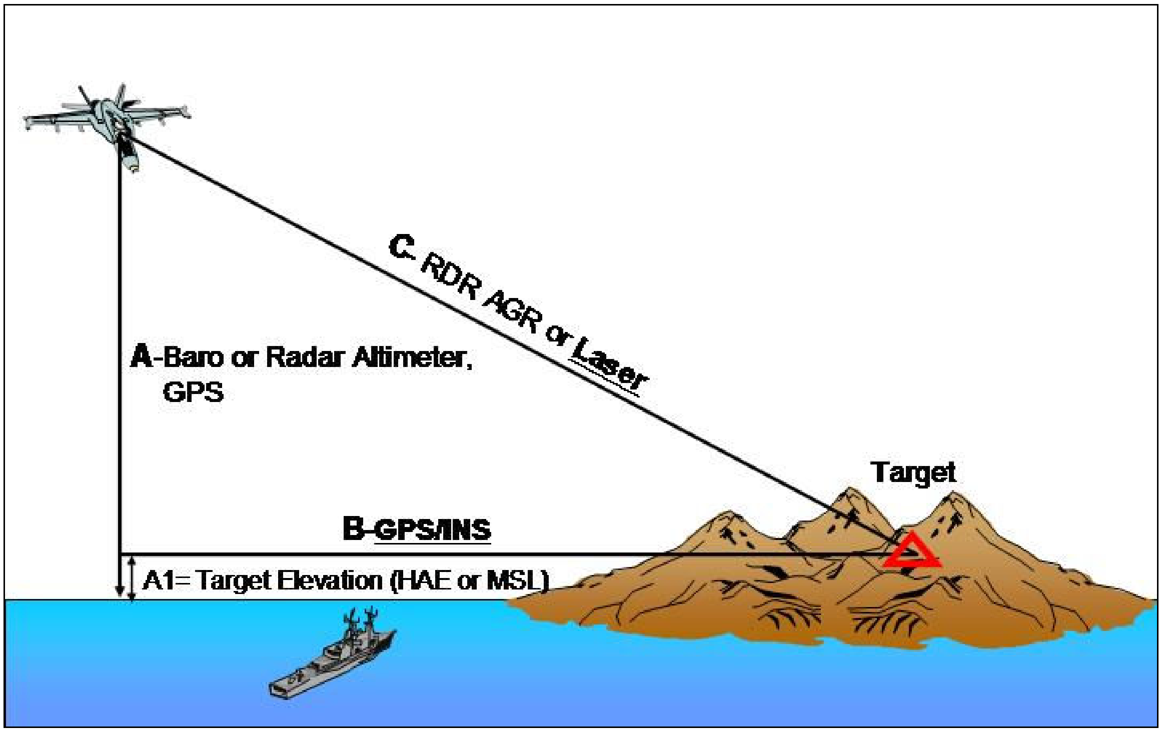

Figure 10 Best Altitude Above Target Example.

target elevation. DTED is a geo-registered database of elevations that can be used to find an elevation if the latitude and longitude of a position is known. This method offers potential improvement over current methods except when the laser is available. However, current DTED databases can still introduce vertical errors approaching 100 feet due to their low resolution or granularity.

The JSOW Block Three team must accept the fact that the aircraft will be a major contributor to the total target location error. This error may be of such magnitude for moving targets tracked at medium standoff ranges that it will preclude the targeting platform from reliably guiding a weapon in the terminal phase.

Finally, by choosing the F/A-18 E/F as the threshold launch platform for the

Block Three JSOW, there are numerous interface and integration assumptions that must be part of the design. Fortunately, these assumptions are well documented and understood by the JSOW team, which has been integrating the JSOW family of weapons on the F/A-18 since its inception. The details of the JSOW/F/A-18 Interface Control Document (ICD) are beyond the scope of this paper, but are available in reference [16].

Data Link Assumptions

The desired target set for JSOW Block Three contains primarily moving targets, which are vehicles or vessels that can change their position and/or course rapidly during a weapon's time of flight. The very concept of attacking such targets requires the ability to update a weapons intended aimpoint during its flyout from the launch platform to the target. Currently, weapons such as the laser guided bomb or Maverick missile possess a moving target capability because they use a seeker to respectively track a laser spot or directly track the moving vehicle. However, either method requires the launch platform to be in close proximity to the target pre- and post-launch, which classifies these weapons as direct attack weapons. This approach does not allow for the desired standoff range available from JSOW. The launch range and associated time of flight for standoff weapons necessitates a different approach to providing In-Flight Target Updates (IFTUs) to the weapon's guidance and control subsystem. The available solution is the use of a weapon data link that enables the launch platform to communicate to the weapon after it has been launched. The implementation of a data link system into the JSOW Block Three was as much a requirement as an assumption.

The current environment of military data links, networks, and the concept of the

Global Information Grid is a complex and costly tangle of software, hardware, encryption and interoperability issues. The Block Three program is currently conducting an industry trade study to examine the possible solutions that meet JSOW's mission needs, cost requirements and program schedule desires. Chapter IV provides an in-depth look at this topic and preliminary discoveries from the trade study. However, one major assumption was made early on. The JSOW data link would use the recently developed Weapon Data Link Network (WDLN) message architecture, which establishes a DOD standardized message set to communicate with weapons. The message details are further discussed in Chapter IV, but it is worth noting here because they directly influenced the development of the Concept of Operations presented in the next chapter.

Summary

To encapsulate the above assumptions, there is currently fielded or near term tactical system that can generate target coordinates with sufficient precision and accuracy to launch and terminally guide a standoff weapon. Even with the implementation of a data link system that theoretically does not introduce further error, some method of terminal guidance, other than GPS alone, will be required for the foreseeable future to effectively engage moving targets. This has led the JSOW Block Three development team to assume that it will have to design an evolution of the JSOW C variant with a data link system for mid-course guidance updates and a seeker for terminal guidance. They surmised that even with a seeker for terminal guidance, the current JSOW C's direct to the target flyout, allowable search altitudes, and staring seeker may not be sufficient to allow radar targeting.

CHAPTER III: Development of JSOW Block Three Requirements

Introduction

DOD acquisition programs establish requirements or specifications to provide contractors with guidelines and performance criteria to shape their system design and eventually establish the desired system performance. The requirement documents are developed during the science and technology demonstration phase and are finalized in the Joint Operational Requirements Document (JORD), which is now referred to as a Capabilities Production Document (CPD). As the JSOW Block Three Program is currently in the demonstration phase, PMA-201, the JSOW Technical Program Office (TPO), and their operational sponsors are still developing the CPD. The Chairman of the Joint Chiefs Of Staff Manual 3170.01A [17] states:

> *The…Capability Production Document (CPD) states the operational and support-related performance attributes of a system(s) that provide the capabilities required by the warfighter – attributes so significant they must be verified by testing or analysis*.

Therefore, this chapter summarizes the work done to lay the foundation of the JSOW Block Three CPD and provides input regarding those capabilities from an operators' perspective. The core of a capabilities discussion is the development of the Concept of Operations (CONOPS) and the implementation of that concept, which is discussed below using the kill chain analysis performed by PMA-201. Additionally, recall the target set discussion from Chapter 1; this will directly contribute to the development of the

CONOPS and is a major factor in the kill chain development process.

Concept of Operations Development

PMA-201, the JSOW Project Officer (the author), Raytheon Missile Systems, and the Boeing Integrated Defense Systems Team jointly developed the Concept of Operations for the JSOW Block Three program. They are a series of graphical depictions that show various scenarios of weapon employment. Appendix 2 contains a briefing that was used to present the CONOPS to the Naval Strike Air Warfare Center in Fallon, NV [18]. The CONOPS development was guided by the needs and tactics of the warfighter, JSOW capabilities, and the WDLN message set, but consideration was also given to the fact that JSOW will not be the only weapon with data link in the future, nor the only weapon the F/A-18 will employ with data link. Therefore, they were not developed to be JSOW specific. The CONOPS do not imply the required functionality at Initial Operational Capability (IOC), but a desired end state after a yet to be determined number of spiral developments. The briefing also contains additional programmatic information that may not necessarily represent the opinion of this author.

To understand the CONOPS, it is important to review a few terms associated with their development. Slide 6 of Appendix 2 defines three roles used throughout the CONOPS. They are:

- Shooter: the launch platform, which is responsible for putting the weapon into the network and eventually launching the weapon in the Launch Acceptability Region (LAR).
- Targeteer: the platform responsible for providing IFTUs to the weapon via data

linked WDLN messages. If this platform is other than the shooter, it is referred to as the Off Board Target Source (OBTS). This should not be confused with a 3rd Party Target Source, which provides target information (via means other than the WDLN) to the controller and not directly to the weapon.

- Controller: the platform in control of the weapon's functions. The Shooter is always the Controller by default until the responsibility is handed over to another platform. While the weapon is on the platform, the shooter can take control back, but once it is launched, the controller "owns" the weapon.

These three primary roles can be a single platform or three independent platforms as the CONOPS slides show. There are also five basic scenarios in the CONOPS that will drive weapon functionality and the Cockpit Vehicle Interface (CVI), the later of which is discuss in Chapter V. The scenarios are described below, and Figure 11 provides an example of the CONOPS scenario slides. It should be noted that the CONOPS continue to evolve and minor differences between the discussion here and the scenarios in Appendix 2 may exist.

- Single Ship Control (Slide 9): A single platform plays all three roles.
- Engage on Third Party Target (Slide 10): All three roles are maintained on a single platform, but the origin of the target coordinates is from a third party, which must be passed to the shooter using existing means (Link 16 data link, voice, ect.).
- Cooperative Control (Slides 12-19): This scenario has three subsets where the shooter may designate an OBTS, a third party controller, or a secondary

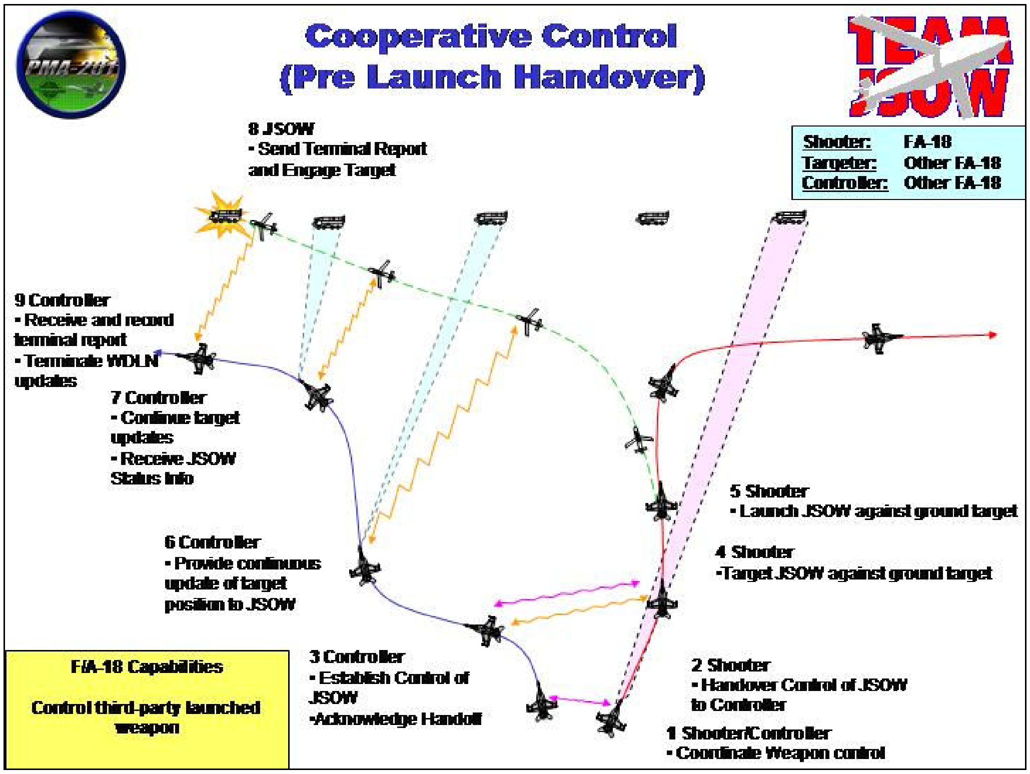

Figure 11 JSOW Block Three CONOPS Example Slide. [18]

controller.

- OBTS: Designated by the controller and can only pass IFTUs to the weapon. The Shooter remains the controller.
- Third Party Control: Control of the weapon is passed to a third party pre- or post-launch. Recall, post-launch that the shooter is unable to take control back. The Third Party Controller may designate an OBTS.
- Secondary Controller: Pre-launch, a Third Party Controller is setup in the system, but control is not passed. This is primarily an administrative function in the CVI to allow a cooperative

controller to be established in the weapon and monitor its status while waiting handoff. The term is not used in the CONOPS slides, but is discussed in the CVI design.

- Re-task (Slides 20-23): This scenario takes place after one of the above scenarios has begun and enables the controller to retarget the weapon in-flight. This is different than providing moving target updates, because the controller will have to allow it after some determination has been made as to whether or not the weapon can in fact execute the re-task request. The action of re-tasking the weapon is a way to zero the Kalman filter and effect an immediate change in the weapon's course.
- Abort (Slides 24-26): This scenario comes into play when the controller has determined a need to abort the mission due to any number of reasons. The WDLN message set allows for three abort options, but actual implementation is to be determined for JSOW, and a topic of discussion for Chapters IV and V.
- Lost Communication (Slide 27): This is an undesirable scenario, but one that requires forethought because it may occur, and the weapon must have a plan.

Currently the CONOP has the weapon continuing to the expected target position. Figure 11 provides an example of the CONOP slides, but review of Appendix 2 is highly recommended before continuing. There are many aspects of the scenarios that are impractical to discuss and pictures do an excellent job of explaining each scenario.

With a solid understanding of the desired CONOPS, one can begin to see how they will ultimately drive many major phases of the JSOW Block Three program.

Weapon design and functionality will have to support them, while platform integration and the CVI will have to enable the aircrew to employ in each scenario. In addition, the test and evaluation phase will be driven by evaluating the system's performance in the various scenarios. With the desired operations in mind, the next section discusses the requirements of the weapon to operate within a system of systems.

Capability and Kill Chain Implementation

JSOW Block Three also has a requirement to enable the kill chain developed in Figure 3. As previously discussed, weapon systems can no longer afford to be developed in a vacuum and only focus on the *Engage* portion of the kill chain in Figure 12. Figure 12 is a slightly expanded and modified version of Figure 3 that has critical areas labeled 1 through 7 for discussion. The numbered areas, discussed below, will directly affect some of the system requirements for the JSOW Block Three. One will see how aspects of the

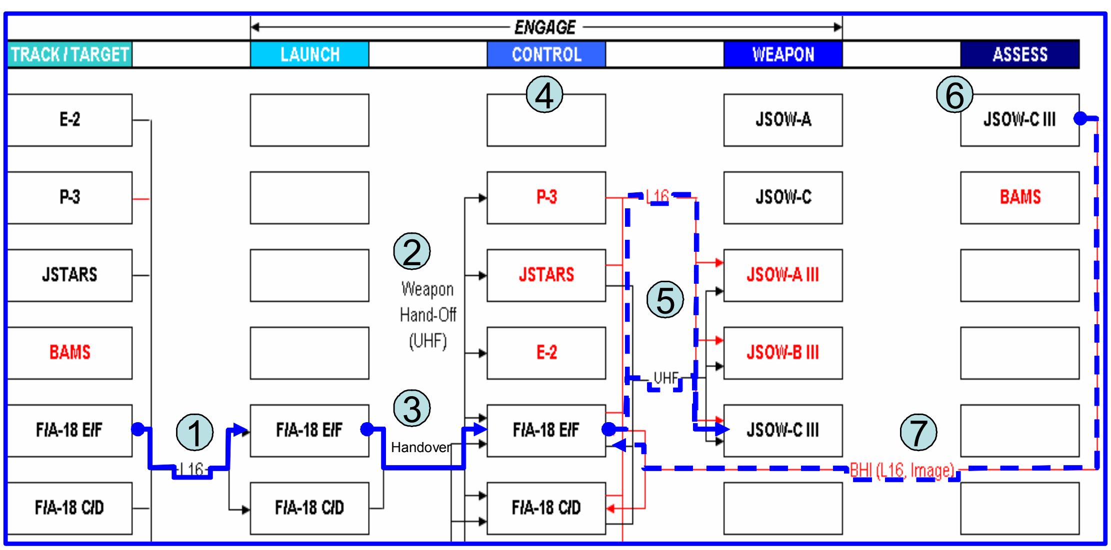

Figure 12 JSOW Block Three Kill Chain Example. [3]

CONOPS were influenced by the flows in this kill chain. It may be noted that the Block Three A, B, and C variants are shown in the figure; this paper only addresses the C variant. The A and B variant are area weapons and will be employed against a different target set.

At point ① in the kill chain, there is a requirement for various platforms to communicate the coordinates of their target to the launch platform (shooter). Here, a Link 16 data link network is used to pass the target information from the tracking platform to the launch platform. This path in the kill chain exists today, but will require the JSOW team to anticipate errors and data latency associated with this method of targeting. Not only does this function affect the weapon design, but it must be taken into account during weapon integration to the F/A-18. The target information must be passed to the weapon via an umbilical while captive and then via the data link once in free flight.

Next in the chain, point ②, the weapon must be able to directly communicate with other platforms prior to launch to establish roles and ensure communication has been established with the desired weapon. Part of that process will involve some form of handover, point ③, communication between the shooter/controller and the new controller or OBTS. This communication can take place digitally over networks or by voice communication. Either way, there must be pathways for the platforms to coordinate and for the weapon to receive instructions from the controller and/or OBTS before launch. This will drive requirements for the weapon to be fully “up” in the network pre-launch and for the F/A-18 CVI handover process to be executed with minimal workload.

Point ④ implies the requirement to enable a number of platforms to control the

weapon, which includes everything from the F/A-18 to Intelligence, Surveillance, and Reconnaissance (ISR) platforms. This requirement is actually heavily influence by point ⑤, which will define the waveform used to communicate directly with the weapon and subsequently control the weapon. The dotted line implies the waveform has not been selected. As mentioned, it was assumed that the weapon would implement the WDLN message set, which will be standard among these platforms. However, it will require the individual platforms to perform the necessary integration to support the WDLN messages. As currently planned, only the F/A-18E/F Super Hornet will support the WDLN message format at weapon IOC. As stated, the waveform (Link 16, UHF, or another) has not been determined, but once selected a platform desiring to directly control the weapon will have to integrate the associated hardware capability as well. Currently, the F/A-18 has the capability to communicate via Link 16 or Variable Message Format using a Digital Communication System UHF radio. Chapter IV will discuss this topic in detail.

Point ⑥ falls under the *Assess* column. There is always a desire to assess the outcome of the weapon's employment so commanders can plan the next course of action. This is traditionally not a weapon function, but a task for the launch platform or other ISR resources. The very nature of a standoff weapon makes it very difficult, or next to impossible, for the launch platform to perform this function and stay out of the target area. Additionally, the DOD does not possess the ISR resources to assess the affects of each weapon drop. Typically, the assessment is in the form of a Bomb or Battle Damage Assessment (BDA) report, which describes what was hit and the level of damage inflicted

by the munition. However, it is not possible for a weapon to accomplish this task because it is destroyed in the process of damaging the target. Therefore, the term Bomb Hit Assessment (BHA) or Bomb Hit Indication (BHI) is used to describe a report that only shows what was hit. The weapon can perform this function prior to impact by sending its final impact coordinates and/or an image from the weapon's sensor back to the launch platform or to anyone in the network. This is the pathway defined by point ⑦, which will be the same waveform used to communicate to the weapon. This describes a function that establishes a requirement for a two-way data link.

Other Requirements

The reader should keep in mind that the discussion here does not encompass all requirements associated with a weapon development program. This chapter only lays the foundation from which many documents will be developed. Each will specifically determine design, testing, performance, production, and logistical requirements. Requirements for mission planning software and aircrew training materials will also have to be developed. Some of these items are commented on in later sections, but are generally beyond the scope of this paper and not completely developed in the discussions. The JSOW Technical Project Office at the Naval Air Weapons Station China Lake, California may have further information on the Block Three requirements documents as they become available. Distribution may be limited to DOD and DOD Contractor personnel.

Generic Weapon Model

To summarize the assumption and requirement discussions outlined above, a generic weapon system model was developed for this paper. It was developed by the author and may not represent the opinions or view of the entire JSOW Block Three team. Figure 13 shows the model, which served as the baseline for development of the various subsystem alternatives presented in this paper. All of the items identified above the weapon represent subsystems intended to be common between the JSOW C and the Block Three JSOW, and were previously discussed as assumptions. The five subsystem areas, Seeker, GEU, Data Link, CVI and Mission Planning, are the topics of discussion for the alternatives analysis in Chapter IV. The bullets below each topic represent functionality or capability that must be retained from the JSOW C or implemented to meet the requirements discussed above. Each topic list is a top level summary and not all encompassing. Finally, the Cockpit Vehicle Interface topic is saved for the implementation discussion in Chapter V because the CVI is intended to enable the weapon, not drive its design. In addition, extensive work has been accomplished on the CVI to meet the F/A-18 H5E software build timeline, and its design is nearing completion.

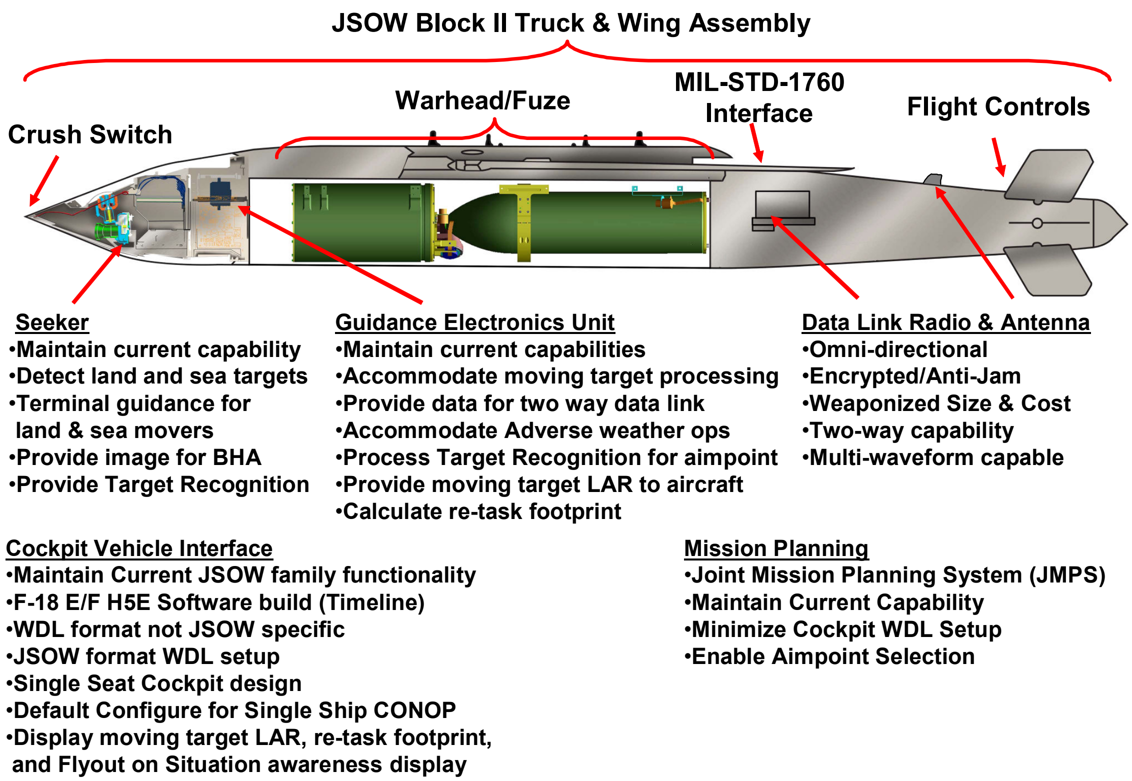

Figure 13 JSOW Block Three Project Generic System Model.

CHAPTER IV: Development and Analysis of Alternatives

Introduction

Now that the problem is defined, it is time to analyze in detail the available options for each subsystem that will enable JSOW to accomplish the mission. Three major subsystems were identified in Figure 13 that require modification or development to allow the JSOW C to meet the mission described above. Each of those subsystems is discussed below, initially, without regard for cost or program risk from immature technology or schedule. The primary concern of this chapter is to expose the available alternatives and understand which is best suited to the mission. The results of the analysis will be summarized in a chart at the end of the chapter comparing each alternatives level of contribution to the success of the program. In the summary of alternatives analysis, cost and risk will be factored in using a relative analysis and will be part of the considerations for the recommended design.

Seeker Alternatives

As emphasized in the preceding paragraphs, the seeker is one of the most critical subsystems for the Block Three JSOW, if not the most important. The seeker will enable the weapon to overcome the errors generated by the targeting platform sensor and all of the systems between it and the weapon. To do this, it must be able to detect and track a moving target in a variety of conditions, and provide accurate location information to terminally guide the weapon to impact. Additionally, the seeker must integrate with the

GEU and data link so that it may pass a BHA image through the weapon and onto the network.

First, consider the current seeker, which has demonstrated outstanding results in testing against a variety of ground fixed targets [9]. This seeker is a Commercial-Off-The-Shelf (COTS) product, which is also used by the auto industry for night vision head-up displays. It uses an un-cooled imaging infrared detector to create video of the target area, and is optimized to highlight contrast in the scene so the weapon's algorithm can detect edges in the images. These edges are then matched to a line template, which was created during mission planning from an overhead image of the target area. Figure 14 shows a post-flight processed picture depicting this procedure. The image was taken from a training briefing [11] for JSOW C, but was originally supplied by Raytheon Missile System's JSOW Team. One can see that the line template is simply matched to the weapons real-time generated line template, which allows any TLE in the target coordinates to be zeroed out. This method allows the process to take place autonomously so the launch platform may return to base after the weapon is launched. It does not require the actual target or impact point to be visible. It has been demonstrated that the target may be completely buried. This is a desirable design characteristic and one that should be retained in the Block Three design for fixed targets.

The previous paragraph leads to an alternative discussion that must also be considered for JSOW Block Three, and that is whether the Block Three design should allow Man-in-the-Loop operation of the weapon. This refers the ability of the operator to real-time "fly" or guide the weapon during its flyout based on seeker video sent back to

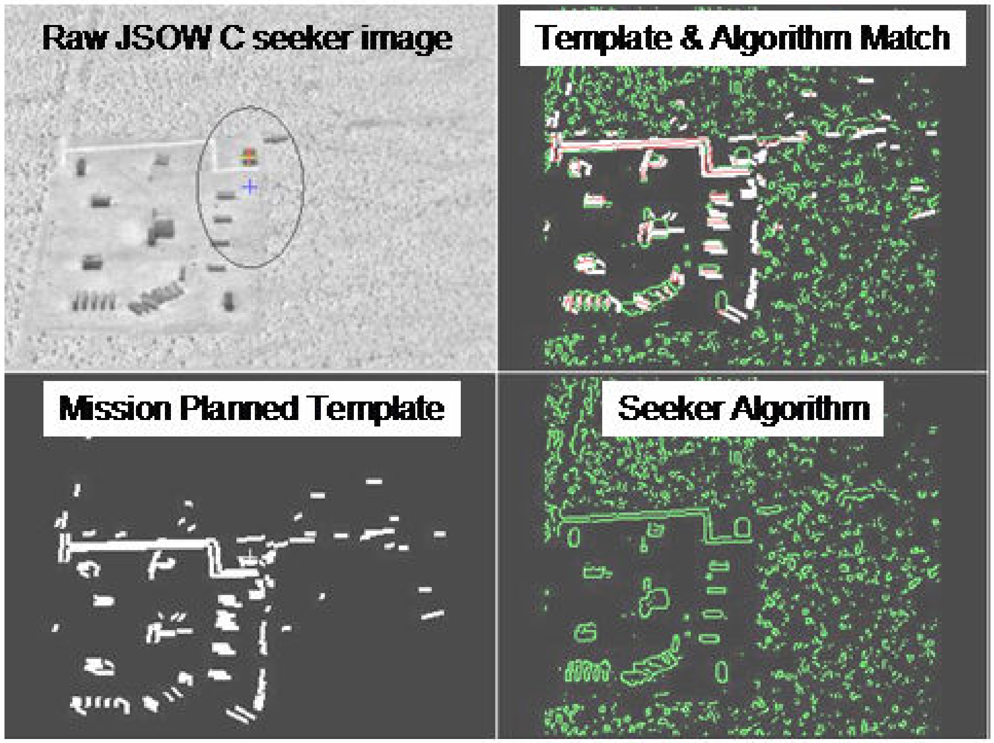

Figure 14 JSOW C Seeker Guidance Example. [11]

the controlling platform. This implementation has been used successfully in other weapon systems like the Walleye and SLAM-ER air-to-ground weapons. However, this design is not without its limitations and inherent flaws. One of the major issues with this type of guidance is the bandwidth required to continuously stream weapon video back to the controlling platform. Currently fielded data link networks, such as Link 16, do not have the resources to support such an implementation. They were designed for wide area situation awareness and have many participants with numerous data requirements of their own; this will be discussed in further detail in the next section. Therefore, man-in-the-loop weapons implemented their own dedicated data link systems, which required the controlling platform to carry an external pod to enable the data link. This created an

inherently “stovepipe” solution where only members with the unique pod can participate. The pod also requires the use of one of the few weapons stations on the aircraft. An additional consideration is the human factors associated with a man-in-the-loop design, where human factor implies error. It is because of this host of factors that a man-in-the-loop system is not considered a desirable solution for JSOW Block Three.

Without human guidance, the alternative becomes an autonomous system capable of detecting and tracking a target within its field of regard (FOR) without controller input. This design is similar to that mentioned above for the current JSOW C; however, the nature of the target set requires that alternative methods of tracking the target are developed. Additionally, moving targets are targets of opportunity by nature and developing mission planned line templates does not lend itself to this mission. Figure 15 is a JSOW C seeker image taken from a video clip during a captive flight test to determine the suitability of the current JSOW seeker against sea surface targets in an open ocean environment. One can see there are no contrast edges to be found on the ocean other than the outline of the ship and the nearby tugboat. Unfortunately, an image from the seeker of a land moving target is not available, but one can gather from Figure 14 that there will be no shortage of edges, and a highly cluttered environment will be present when attempting to autonomously detect and track a ground moving target. Each environment with its unique challenges may require a robust detection and tracking algorithm, which will take time to run its process and eventually lead to a target track. Each of these considerations lends it self to a sensitive and high resolution detector. Sensitivity allows the seeker to see more details or smaller temperature differentials at

Figure 15 JSOW C Seeker Image of a Ship at Sea, ASuW Demo Flight, May 2005.

further range, which will allow longer image processing times. Higher resolution allows for better discrimination among the details of the scene, which will be desired for cluttered environments and Autonomous Target Recognition (ATR) processing. Together, sensitivity and better resolution in some cases may allow the seeker to detect and track the target sooner. This will be beneficial against possible high value targets that may be able to jam certain aspects of the weapons guidance like GPS and/or the data link. The higher fidelity seeker may also allow the seeker to come on earlier and still be effective, which will increase the seeker's ground plane footprint and possibly help overcome the radar TLE issues discussed in Chapter II.

As a first alternative, the current seeker would be considered a leading contender because it is already integrated into the JSOW C, and has proven its sensitivity and

resolution is at least capable of tracking a seaborne target. However, the current seeker has already become an obsolete part, and a lifetime buy for the remaining production of JSOW Block Two weapons has been made. This required the JSOW team to research a replacement seeker for production cut-in at Block Three. This is obviously beneficial to the Block Three program, as the timing allows them to influence the choice based on the needs of the Block Three Mission.

The two primary seeker alternatives presented by the Raytheon JSOW Team are IIR replacements for the current seeker. The first is a 320 x 240 pixel detector that is a form, fit, and function replacement with obvious programmatic advantages of reduced risk and cost. However, limited flight test data has indicated that the current seeker or a form, fit, and function replacement will take an extensive software solution to track land moving targets [19]. There is the possibility that it may never be able to accomplish the land moving target mission. The selection of a seeker based on dollar and risk costs alone, at the expense of performance, may limit the capability of the JSOW Block Three. Additionally, the cost to develop a software solution may dwarf the increased hardware cost of the second alternative, which is a higher resolution 640 x 480 detector. Images taken from the two seekers are compared below in Figure 16.

The resolution advantage of the 640x480 seeker may allow the detection and tracking algorithms to function sooner with the higher level a detail and contrast between objects. This higher level of detail may also enable the weapon to classify targets through Autonomous Target Recognition (ATR) algorithms. Once targets can be classified, other capabilities become possible that directly affect the weapons combat

Figure 16 JSOW C Seeker Replacement Images Side-by-Side. [19]

effectiveness. One of the most critical is the constant need for combat ID, which is identifying targets as friend or foe. Standoff weapons shooting at targets of opportunity present a unique challenge to combat ID. A seeker that could classify a target based on visual information could present that data to the pilot for action or the weapon could automatically take action to avoid hitting a non-combatant. Even a simple but reliable capability will offer enormous advantages over current, specifically ASuW, weapons that lock-on to the first thing they detect. An additional benefit of target classification will be aimpoint selection. This capability allows the mission planner to associate preplanned aimpoints with target types. Depending on the type of target, this could greatly increase the effectiveness of the weapon's warhead by allowing it to strike at a vulnerable point

and inflict maximum damage.

There are other seeker options available to JSOW that should be considered as well. One of the first solutions that present itself is the AIM-9X program, which uses an IIR seeker to track very fast moving targets. That program uses a cooled 128x128 focal plane array and missile body built by Raytheon Missile Systems. A cooled seeker offers many advantages in sensitivity and therefore detection range. The AIM-9X program is currently developing the capability to engage ground moving targets in addition to their current air-to-air target set. A cooled seeker brings many challenges for the JSOW, which has long shelf life requirements and must maintain the proper weapon cost-to-target value ratio. A cooled seeker could approach ten times the cost of an un-cooled solution [20]. However, different divisions of Raytheon Missile Systems are developing algorithms to track ground moving targets with, at least at this point, IIR seekers. There certainly is the potential for the two programs to benefit from sharing ideas and data.

Additional seeker hardware options include dual band two element IR detectors that use two color comparisons to detect targets. The Norwegian developed Penguin anti-ship missile has employed this type of seeker [21]. There are also seekers that employ millimeter wave imaging technology to produce high resolution radar images of the target area. Millimeter wave technology has the added benefit of offering an all weather capability that can "see" through clouds, fog, and smoke. A millimeter wave seeker alone is not necessarily the perfect solution either. This type of seeker uses radar and comes with the same inherent low angular resolution that hampers targeting radars. This limitation makes it less suitable for precision terminal guidance than electro-optical or

infrared EO/IR seekers. [22] The U. S. Army and Northrop Grumman Corporation recently demonstrated success with a dual-mode infrared/millimeter-wave seeker, which detected, tracked, and struck a land moving target during a flight test [23]. Emmitt Gibson, vice president of Precision Munitions at Northrop Grumman, said, "Integrated with either a loitering weapon or a missile, the [Eagle Eyes] seeker will improve substantially the…ability to strike discrete, high-value targets, both moving and stationary" [23]. The Eagle Eyes seeker combines advanced millimeter-wave radar with an imaging infrared sensor, providing a co-boresighted, dual-mode seeker in a 5.5-inch-diameter, 8-inch-long compartment [23]. The point is; there are other options.

It is the author's belief that the seeker of the Block Three JSOW will play such a critical role in the combat success of this weapon that the primary requirements for its selection must be tied to the target set and mission accomplishment. The dual-mode option offered above provides added capability, flexibility, and could possibly be acquired at an overall reduced cost and risk compared to a software or system level solution. This type of seeker may be more costly than its predecessor, but within the system of systems that will employ JSOW it may be a cost wise place to pay for this capability. Less capable seekers may never fully accomplish the mission and will require the aircrew to compensate for the seeker. This will increase their workload and decrease situation awareness. A seeker capable of fully accomplishing the mission must be selected.

Data Link Alternatives

The data link subsystem is the newest and least defined hardware to be added to the JSOW Family of weapons. As the following paragraphs will discuss, the data link implementation will be the most hotly contested aspect of the entire development process. This is primarily because the specifics of weapons data link implementation are not standardized, and the weapon is only a small node in what is rapidly become a global network among military assets. The data link section will discuss the various components critical to the JSOW Block Three design, which includes the F/A-18 capabilities, various waveforms and their hardware, the WDLN message set implementation, and unique aspects of data link for weapons.

F/A-18 Super Hornet Data Link Capabilities

Discussion of the F/A-18 E/F Super Hornet data link capabilities is key to the JSOW Block Three program because the aircraft is the threshold platform, and its available data link waveforms will bound the initial alternatives for the weapon. Currently, there are two viable data link capabilities in the F/A-18: Link 16 using the Multi-Function Information Distribution System Low Volume Terminal (MIDS-LVT), and a Digital Communication System (DCS) that uses the ARC-210 RT-1824 DCS radio and variable message format (VMF) to send digital information over the Hornet’s number two radio. Both systems are fully integrated and deployed on the Super Hornet, but are also in various stages of product improvement. The complete details of their implementation and functionality are beyond the scope of this paper, but they are available in any F/A-18 Super Hornet Gold Book [24]. The Gold Book is the software

users manual for the F/A-18 E/F.

Since both data link types, or “waveforms”, are available on the platform, it may be possible to integrate the weapon using either one. It is also fortunate that the WDLN message set has been designed to accommodate J-series messages for Link 16 use and K-series messages for UHF VMF use. The *Weapons Data Link Network (WDLN) Advanced Concept Technology Demonstration (ACTD) Interface Control Document (ICD)* provides a very detailed explanation of the message sets and their utility [25]. However, there are some unique differences between the two systems and consequently their CVI and information display capability in the F/A-18. Their differences will be discussed in the WDL Waveform Alternatives section, here the focus will be on the F/A-18 CVI for each of the systems and how it relates to enhancing mission accomplishment for the JSOW Block Three.

The MIDS system was primarily designed for Air-to-Air Command and Control (C2) and to enhance crew’s situation awareness with regard to the air warfare picture. With that goal in mind, the F/A-18 uses the MIDS information to provide the majority of the content provided on the aircraft’s Situation Awareness (SA) display. An example of the display is show in Figure 17. On this display, track files (each symbol is associated with a track number) can be selected and further information is presented on the target data format. Track files can take the form of your wingman’s precise position, air targets and ground targets, to name a few. The targets can come from onboard or offboard sensors, which allows the aircrew to see targets detected by all available sensors on the network. Currently, the F/A-18 design displays air-to-air weapon flyouts when network

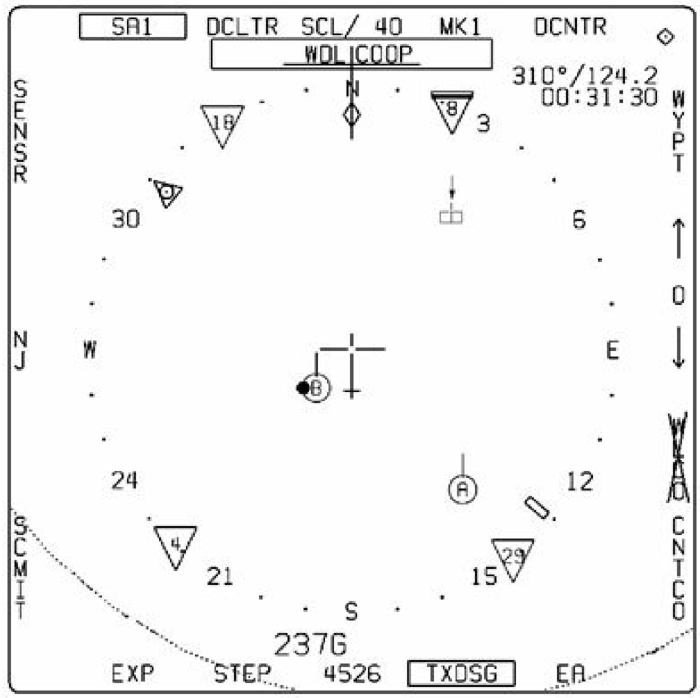

Figure 17 F/A-18 Situation Awareness (SA) Display Format. [27]

members shoot at enemy air targets. This same information can also be displayed on C2 platforms. This capability is an enormous advantage to all network members. It could be modified to support air-to-ground weapon flyouts with minimal effort because a JSOW Block Three weapon using Link 16 would be a networked solution providing its own position and status data directly to the network. This continuous information exchange is only available among Link 16 network members. As will be discussed with VMF, only discrete point-to-point messages are sent via VMF. One could compare Link16 to the internet (graphical real-time updates) and VMF to cell phone text messaging (textual discreet messages).

There are some drawbacks to the Link 16 solution, most of which will be discussed below in the WDL Waveform Alternatives and WDL Hardware sections. As

for the F/A-18, the major draw back to a Link 16 solution, from personal experience, would be the system's display limitations on the SA format. These are related to the F/A-18's hardware and may similarly affect the VMF solutions offered below. In addition, Link 16 networks have displayed a level of instability that could be cause for concern when controlling air-to-ground weapons. This issue would certainly require further investigation and characterization before proceeding with Link 16. Overall, the F/A-18 MIDS system appears well suited to the task of bringing air-to-ground weapons to network centric warfare.

The DCS system in the F/A-18 was designed for air-to-ground communication with friendly ground troops. Specifically, it enables digital or voice-out Close Air Support (CAS) missions. Troops on the ground using a digital terminal can input a CAS mission using a standard text format and then relay that message to an aircraft that is established in the VMF network. This replaces the need for extended voice transmissions, and reduces the potential for errors since the target coordinates are transferred machine-to-machine. Once the aircraft receives the mission, the aircrew can digitally acknowledge it. All of the transmissions are sent over the F/A-18's secondary or "Comm 2" radio, which is also used extensively for intra-flight coordination. Digital and voice communication cannot take place simultaneously, and there is no inhibit to keep others from talking over the digital transmissions. One's own aircraft will attempt to sequence digital and voice communication to limit dropouts. The DCS system was also upgraded to allow it to transmit the aircrafts position back to the ground operators, so they may monitor the attack. This functionality can only take place between one aircraft and operator at a time.

This capability will be the first generation capability used to allow the F/A-18 to demonstrate control of a pre-production WDL JSOW, which is further discussed in Chapter V. It has previously been used in a WDL JDAM demonstration with success. [26] The system accomplishes the CAS mission well and has demonstrated success controlling weapons, but does not currently provide any capability to automatically broadcast information to other net participants. Additionally, current implementation in the F/A-18 does not allow any form of graphical feedback to the aircrew. Overall, the VMF solution provides little situation awareness to the shooter or controller, and none to other network participants. The only feedback in a VMF network would be from the weapon, which broadcasts a Weapon In Flight Tracking (WIFT) message. The message contains weapon position, received target data, and other vital system level information. Currently, the F/A-18 H5E integration effort will support display of some of this message's content. Figure 18 shows a mockup of the proposed Weapon Data Link format for the H5E software build. In this diagram, an area labeled "TGT" is circled, which is planned to be populated by data from the weapon's WIFT message. The field will display the weapon's intended point of impact, which may be the IFTU coordinates or the position the seeker is tracking in the endgame. This information will be displayed regardless of the selected waveform, but it will be the aircrew's only feedback on the weapon's target or position if VMF is used. A Link 16 solution will inherently display this information in a graphical manner on the SA format, along with the weapon's position, and possibly controller to weapon pairing lines. There would be some integration required to support this functionality, but it would be relatively minimal

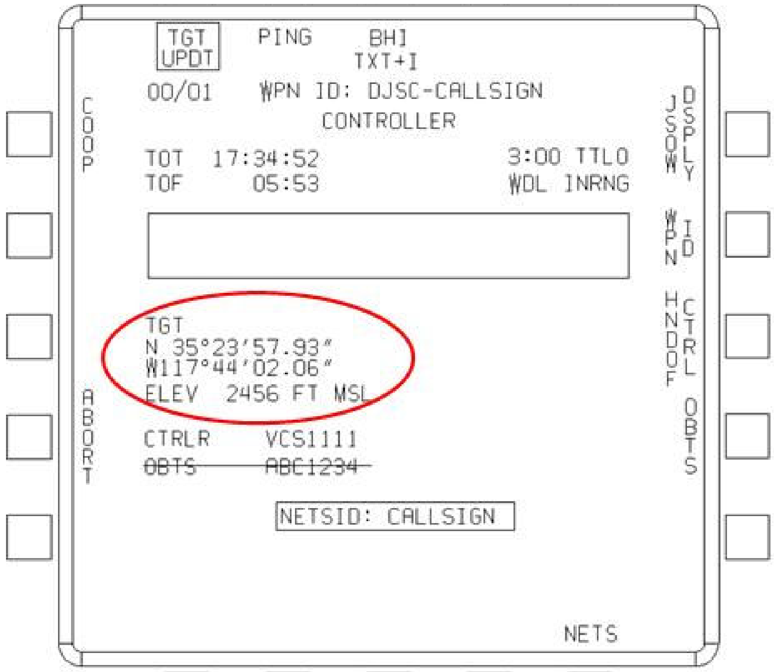

Figure 18 F/A-18 Multi-Function Display (MFD) H5E WDL Format. [27]

compared to the alternative for a VMF solution.

Regarding VMF, there is a possible solution to its situation awareness shortcomings. There is the ability to take the information coming in VMF format from the weapon and rebroadcast it via the controlling aircrafts Link 16 terminal. This would merely be the opposite of a Third Party target source sending a target via Link 16 to the controlling aircraft, which then translates it to VMF to be sent to the weapon. To do this, even on a limited basis, would greatly help the VMF data link solution move towards a network centric design. Operationally, it would enhance the warfighter's situation awareness like Link 16 displays do today. However, there would be a greater cost to the JSOW Block Three program to implement this capability in the F/A-18 and to test it. An additional drawback to VMF implementation is the information required to uniquely

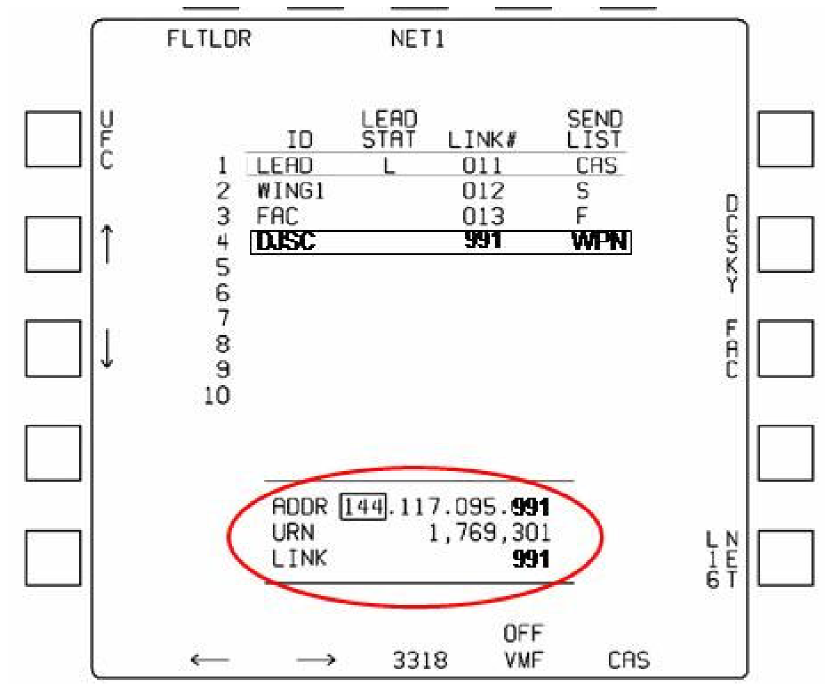

Figure 19 F/A-18 E/F VMF NETS Format. [27]

identify a platform or weapon in the network. Figure 19 circles what must be entered via mission planning or directly in the airplane to identify one's self or a weapon. This task is easily accomplished during mission planning. However, from the author's personal experience, it is not a simple task to pass this information over the radio in a timely fashion. This is typically not a requirement for network members, who usually preplan their networks.

When weapons become available on the network, it may be necessary to frequently pass weapon network IDs to controlling platforms during time sensitive strike missions. Requiring all of the above information to be passed over the radio will impede mission accomplishment. Conversely, Link 16 only requires a unique four to six digit track number (TN) for each network member. If the weapon is in the Link 16 network,

the TN can be passed via radio and a TN search can be performed to locate it on the SA format.

In summary, it appears that either solution is viable in the F/A-18, if design requirements focus on all aspects of mission accomplishment and not just on guiding the weapon. The deciding factors between Link 16 and VMF may have to come from other aspects of the program.

Weapon Data Link Waveform Alternatives

Background

Analyzing the waveform or data link alternatives for weapon data link is a complex maze of interoperability and standardization issues. It also requires consideration of forward and backward compatibility across hardware, network message architecture, and various waveforms. Figure 20 illustrates the scope of this problem. This figure was taken from a briefing prepared by the Weapon Data Link Network ACTD team [28]. Each of the three major services has developed and at least partially implemented a service unique network CONOPS, which are a broad mix of data link formats uniquely integrated onto various strike, fighter, reconnaissance, and C2 platforms. For example, even though Navy F/A-18s can form a Link 16 network, this does not mean that an Air Force F-15 can spontaneously join that network. It can be done, but a fairly large amount of coordination is required before flight, which involves determining which Link 16 net to employ, what encryption keys will be used, and which channels the flight will use

One may conclude that network joint interoperability is a thing of the future, not

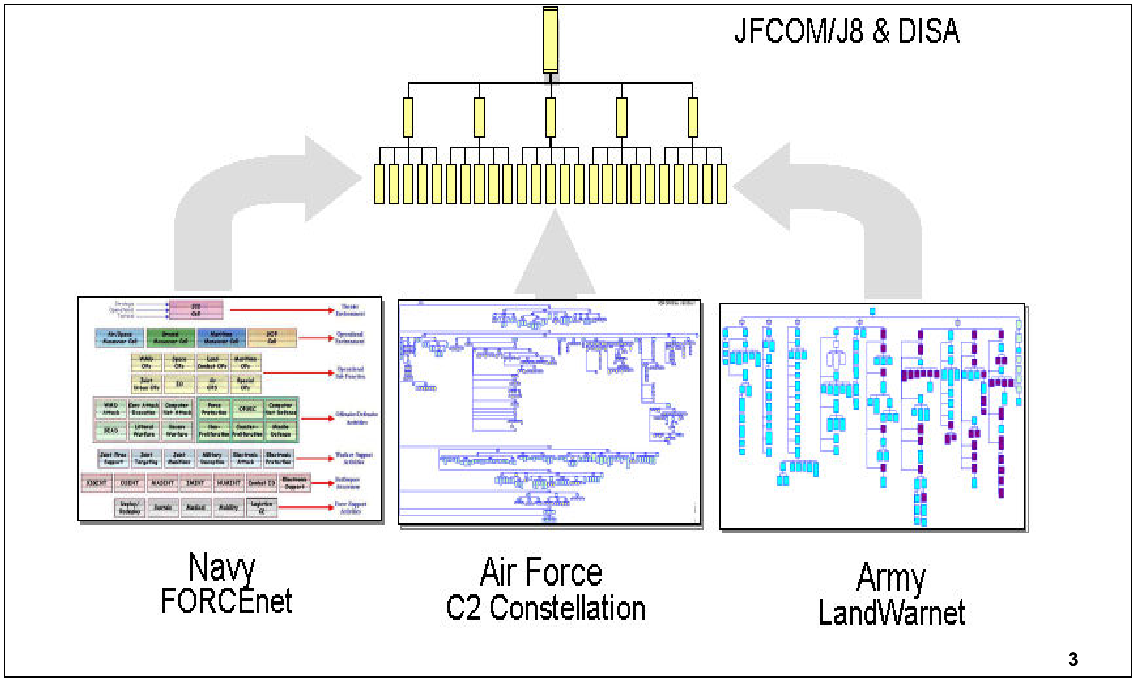

Figure 20 WDLN ACTD diagramming DOD Network Vision. [28]

of the present. The DOD has recognized this and has aggressively begun to implement policies to achieve the vision in Figure 20. Information regarding these policies is found in DOD Directive 8100.1, Global Information Grid (GIG) Overarching Policy and Chairman of the Joint Chiefs of Staff (CJCS) Instruction 6212.01D, Interoperability and Supportability of Information Technology and National Security Systems, which details the Net Ready Key Performance Parameter. These policies will, in large part, effect the development of network centric weapon systems. There is an outstanding article in the Defense Standardization Program Journal, September 2005, by Ron Taylor that further discusses the challenges to weapon data link standardization [29]. As the idea of networked weapons has begun to emerge, they are being seen as the first newcomer to the network environment where these policies can be implemented from the ground up on a

service wide basis. This presents many challenges to relatively small and minimally funded weapon development programs that do not have the resources or the timeline to develop the technologies required to comply with the newest directives. Therefore, JSOW Block Three has begun to evaluate established waveforms with the network vision in mind.

JSOW Block Three Data Link Alternatives

Initially, all viable data link alternatives were considered, from point-to-point legacy solutions to the high speed Internet Protocol capable Tactical Targeting Network Technology (TTNT). With an understanding of the programs requirements (capability, cost, timeline), it immediately became apparent that legacy systems would not be suitable, nor could the program afford to wait for technology such as TTNT to be fielded. To field a system by 2010, which already seems like forever to the operators and around the corner to developers, the network system has to be something available; a system that the weapon development team could design for, integrate with, and use for Developmental and Operational Testing (DT/OT). This led to the conclusion that the waveforms available on the threshold platform (F/A-18E/F) must be the starting point. However, it was also understood that the initially fielded waveform might not be the final solution. The design would have to evolve further throughout its life cycle

As eluded to in the previous section, the F/A-18E/F data link capabilities offered two viable alternatives for weapon data link implementation: MIDS Link 16 (J-series) and a UHF implementation of a VMF network (K-series). Each of their capabilities was briefly discussed with respect to implementation in the F/A-18 in the previous section.

Here their characteristics are specifically compared to each other to determine, which is the most suitable for the JSOW Block Three program objectives.

Link 16, Joint Tactical Information Distribution System (JTIDS), Tactical Data Information Link, J-series (TADIL-J), and MIDS are synonymous when referring the network type and one may hear them all used to describe:

> *"The DoD's primary tactical data link for command, control, and intelligence, providing critical joint interpretability and situation awareness information. Link 16 uses a Time Demand Multiple Access (TMDA) architecture and the "J" message format standard. The "J" series of message standards are designated as the Department of Defense's primary tactical data link, according to the Joint Tactical Data Link Management Plan (JTDLMP)."* [30]

Link 16 not only gives its users a network to pass data, but also provides voice communication, navigation, and identification capabilities because of its precise network timing and high security. Voice communication is not required for weapon data links, but provides added capability to anyone adding Link 16 to their platform. It also facilitates secure voice communication among platforms coordinating weapon control. Navigation is provided via precise timing required to participate in the network in a similar fashion to GPS. If GPS signals were jammed, a weapon could use the network as a position keeping aid. One of the greatest advantages to Link 16 is its security. The network architecture incorporates both message and transmission encryption, which is then passed into a network made jam resistant by frequency hopping. The system is non-nodal and incorporates a relay function so participants can come and go over a wide area without interrupting the network. All of these attributes are highly suitable for a signal controlling a weapon. A publicly available briefing, *Link 16 Aided Moving Target*

Engagement, from BAE systems provides these details: [31]

- Dependable Anti-Jam
  - 51 Frequencies switched at a rate > 76K/sec
- Fast access
  - No access request delays
- Low latency
  - < 50 ms possible
- Multiple missiles
  - Simultaneous operation using multi-nets
- Long Range
  - 300nm
  - Relay capability
  - Over-the-horizon operation
- Secure
  - Transmission Security & Message Security
  - Type 1 Encryption
- Non-Nodal
  - No Single Point Vulnerability

These network attributes build a solid case for the Link 16 waveform. The facts that it is a well established system and the primary tactical data link for the Navy are additional benefits.

There are some notable disadvantages to Link 16 implementation even though the design of the waveform seems well suited to the task. Although not unique to Link 16, integrating weapons into well established networks will be difficult. There are numerous stakeholders responsible for the design and implementation of Link 16's Time Division Multiple Access (TDMA) network structure. In the past, these entities have primarily been concerned with the air-to-air picture and command and control. In discussion with the F-18 Advanced Weapons Laboratory Link 16 engineers and project officer , their first words regarding weapons in the network were that the current networks are at full capacity. In addition, it is implied that something will have to be given up to

accommodate WDLN on Link 16. However, these cultural and technical issues will have to be overcome as network centric operations become the norm. There are ongoing investigations into these questions, which may show that sub-nets and/or stacked nets will enable WDLN to seamlessly participate in Link 16.

VMF, JVMF, TADIL-K all refer to a data link system that uses the K series of messages, henceforth referred to simply as VMF. The CJCS Instruction, Tactical Data Link Standardization Implementation Plan, defines VMF as:

> *Variable Message Format (VMF) -- VMF is a message format designed to support the exchange of digital data between combat units with diverse needs for volume and detail of information using various communications media. VMF is a bit-oriented message standard with limited character-oriented fields. Message length can vary with each use based on the information content of the message. VMF is intended to be the basis of the US Army's digitization transformation. [30]*

The VMF format eliminates the need to transmit placeholder data packets that would be required in a fixed-format, like Link 16. This reduces the transmission load on the hardware, and is the primary reason it was chosen for the military's bandwidth challenged hardware. Another "…advantage of VMF is that the messages can be easily carried over different media from the Single Channel Ground and Airborne Radio System (SINCGARS) to the Tactical Internet" [4]. They can also be carried over an F/A-18 UHF DCS radio. VMF was primarily implemented in the F/A-18 to enable digital communications with equipment integrated with Army and Marine ground troops.

With the above in mind, VMF appears to provide a plausible waveform alternative for weapon data link implementation. The message format can support weapon requirements and is well integrated with our ground force's network systems,

which will be an advantage when implementing the ground based control CONOPS shown in Appendix 2. However, the VMF format does not come without concerns. The primary one is a security issue. Unlike Link 16, there is little standardization among the various VMF users regarding encryption and anti-jam techniques. The F/A-18 DCS radio combined with encryption hardware already in the airplane does have the ability to secure the radio digital or voice transmissions. Additionally, the radio has a second frequency-hopping mode that can be entered to afford some anti-jam capability. In practice, both of the modes drastically reduce the range and reliability of the DCS radio when transmitting VMF information. The JDAM Moving Target Engagement demonstration also investigated the use of encrypted VMF messages and found a significant range reduction [26]. Although not conclusive, these two experiences suggest the current VMF encryption method may be unsuitable for weapon data link. The impact of encryption requirements on the weapon will be discussed later. It was previously pointed out that the current F/A-18 E/F VMF implementation uses the secondary radio for network transmission. This generates the potential for the weapon control messages to be jammed by one's own flight members if they attempt voice communications on the same UHF frequency. Extensive pre-flight coordination will be required to avoid such issues. Use of Link 16 voice capability does not conflict with VMF or Link 16 data transmission.

The last major area of concern for the VMF alternative is the message standards and their implementation. Chris Beattie of Aeronix, Inc. wrote an excellent discussion of the various standards associated with VMF [32]. Each revision of the standard has

included changes to make corrections or add needed capability, but the versions lack interoperability with one another. A program cannot simply plug in the new standard because the mission computers populate the content of the messages; upgrades require mission computer software upgrades. These upgrades for the F/A-18 E/F cost tens of millions of dollars to develop, test, and deploy. Mr. Beattie recommends:

> *"Any new development programs started on or after 1 January 2005 with an initial fielding date targeting January 2006 or later, should choose to implement MIL-STD-188-220D and MIL-STD-2045-47001D. This will not only incorporate all of the interoperability improvements introduced in the SCCs to Version C of the standards, but will also provide for incorporation of the IPv6 protocol and future backward compatibility*." [32]

This recommendation would be straightforward for JSOW Block Three to implement as the program is just starting WDL implementation. However, the F/A-18 E/F has already integrated a previous version of the VMF standard and now would have to possibly upgrade to be compatible with the JSOW WDL. The cost of the upgrade to the airplane may be beyond the scope of the JSOW Block Three program and unfunded by the F/A-18 E/F program. Prior to selecting a waveform for JSOW WDL, the cost associated with VMF standard implementation needs to be better understood. In addition, funding to implement the newest military standard in the F/A-18 E/F will have to be allocated. .

When comparing the two waveforms, Link 16 brings much more capability and flexibility to the design, which can support a fully networked solution. VMF only provides a simple data transmission capability that appears to be suffering from non-standardization issues. Each waveform appears capable of meeting the minimum requirements, but Link 16 can enable the network vision.

Weapon Data Link Network (WDLN) Implementation Alternatives

As previously stated, it was assumed the WDLN message standard would be implemented by the JSOW Block Three Program to maximize weapon data link standardization. However, it was briefly mentioned that the WDLN message sets are being defined for both K and J-series messages, which is one of the reasons any of the above waveform discussions was possible. The parallel development gave JSOW Block Three a choice between two obvious alternatives, which has driven much of the discussion in this chapter. Therefore, implementing both K and J-series message sets in the F/A-18 E/F mission computer is a third alternative worth mentioning. Two primary benefits arrive from this alternative. The first is the ability to employ either waveform for WDL. Regardless of the waveform JSOW chooses to employ, the F/A-18 E/F may have the need to support both waveforms as other data link weapons come online. Specifically, direct attack weapons like JDAM and Small Diameter Bomb (SDB) may find that only a DCS VMF solution is possible for many years due to hardware size and cost limitations of Link 16 terminals.

The second advantage of implementing both message sets is that it will allow JSOW to delay the waveform choice and/or field an interim solution. Currently, the F/A-18 E/F H5E software development program that is developing the WDL capability in the aircraft software is well ahead of the weapon development. To stay on schedule, the H5E program requires a waveform to be selected by the middle of FY 2006. The JSOW Block Three program may find it difficult to coordinate both hardware and software development programs, which could cause a delay in the ability to make this decision.

Additionally, to meet the desired IOC timeline, it may be necessary for JSOW and other weapons to field an interim data link solution while waiting for software compliant radio programs like Joint Tactical Radio System (JTRS) to produce hardware relevant for weapon integration. The interim solution may desire to use the K-series message. The ability of the aircraft to support both waveforms allows flexibility to accommodate discontinuities between the hardware and software programs. It also affords future capability that may allow the aircraft to serve as a gateway or translator between the two messages sets.

Obviously, there are many advantages to this approach. It is also inline with other capabilities in the airplane. One may have noted in Figure 19 that one of the push buttons was labeled "L16 NET". To support the airplane's CAS mission, both the Link 16 and VMF waveforms have been enabled on the CAS format to allow broader interoperability. The waveform selection for the CAS format is simply a pushbutton that toggles from one network to the other. This same design could be employed on the WDL format being developed in the H5E. The draw back, as always, is cost. More software code to enable the dual functionality, and with more functionality comes more testing. However, these costs will certainly have to be weighed against the cost of making a hasty decision regarding the WDL waveform.

Weapon Data Link Hardware Alternatives

The data link hardware alternatives discussion is all about power, size, cost, and until very recently, the DOD requirement to ensure radio hardware was compliant with the DOD Joint Tactical Radio System (JTRS) initiative. Refer to the Army's JTRS

website, http://jtrs.army.mil/, for details on the JTRS program and the recent memorandum waiving the JTRS compliance requirement. The intent of this discussion is to examine the general advantages and disadvantages associated with integrating data link hardware into a JSOW form factor that supports the J and K-series waveforms.

Until software reprogrammable radios are available for weapons, choice of a waveform dictates the hardware required to employ that data link system. Without the JTRS radio, the JSOW program must chose separate hardware that supports Link 16 or VMF, or can chose to delay development and wait for a weaponized JTRS radio. Based on the desired IOC date and the cost associated with a delay to the JSOW program, waiting for JTRS radio development does not appear to be a viable option. A white paper, *JTRS Role in Weapon System Acquisition*, prepared by Raytheon Missiles Systems provides a detailed cost analysis showing the consequences of delaying the JSOW program to wait for JTRS [33]. Therefore, the primary alternatives for initial operational capability are a Link 16 terminal or a UHF DCS radio to support VMF.

The DCS radio hardware alternative offers many near-term advantages to the JSOW Block Three Program. Not the least of which is existing hardware that has been demonstrated effective through various JDAM and JSOW moving target technology demonstrations. The form factor and power requirements also meet the needs of the JSOW Block Three program. Preliminary WDL and Antenna Trade Studies [34] by Raytheon Missile Systems indicate that 100 cubic inches of space is available for the integration of the data link hardware. This is ample space for UHF radio and modem integration, which are items commonly found in hand held equipment today. Link 16

hardware of the proper size is not in production today, and it would take sizable investment from JSOW to “productionize” the current experimental miniature terminals. The miniature terminals are from programs, like the Air Force Research Laboratory (AFRL) Weapon Data Link Architecture program, working on weaponizing a Link 16 terminal to meet the size, power consumption, and functionality needs of weapons.

JSOW Block Three trade studies have been based on a battery that would provide 30 amps, which results in a range capability with plenty of margin for the UHF radio. This is shown in Figure 21, which was taken from the trade study slides. The figure also shows a significant range disadvantage for Link 16. One must keep in mind that this was based on power output available from a notional battery providing 30 amps, and that the Link 16 system has a relay capability unlike VMF. The power available from the JSOW Block Two battery is not completely understood yet, and either solution may require Block Three to upgrade the battery. However, it certainly highlights that the Link 16 solution may have a power issue and consequently a transmission range issue to overcome.

The cost of the UHF equipment is also advantageous, as it is expected to be about 1/3 the cost of a weaponized Link 16 terminal. These figures have not solidified yet because neither hardware solution is in full-rate production. Overall, the UHF *hardware* makes a very solid alternative to current Link 16 terminals, which face hardware challenges that jeopardize the viability of Link 16 WDL in the near future.

The last topic of the section is the data link antenna design for the JSOW Block Three. Integration of the antenna is a critical hardware aspect due to the limited space,

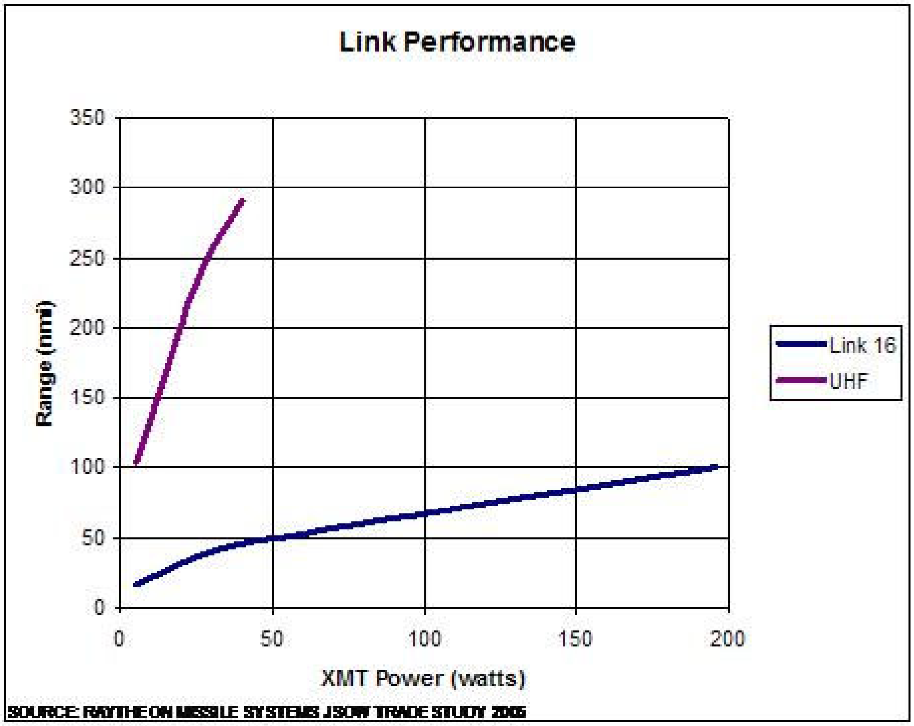

Figure 21 Raytheon Missile Systems Link Performance Analysis. [34]

radar cross section (RCS), and aerodynamic affects. The antenna will need to support the chosen waveform whether it is UHF (225 to 399 MHz) or L-band for Link 16 (960 to 1215 MHz) or possibly both. Additionally, the design must consider the characteristics of a directional or omni-directional antenna. Raytheon's preliminary trade study [34] produced four categories for consideration:

- Fixed Blades
- Deployable Blades
- Blade & Deployed Wire combined
- Conformal

The detailed analysis considering aerodynamic effects, cost, and RCS of the various

antenna options is still pending. However, general engineering observations are offered here, as well as considerations for each antenna's compatibility with the CONOPS. First and probably most importantly, based on CONOPS, the need for an omni-directional antenna is apparent. To enable the employment tactics proposed in Appendix 2, the weapon antenna will need to be able to receive and transmit in the forward and rear hemispheres. Additionally, to communicate with ground troops, which it may fly over enroute to the target, it will need to receive and transmit below the vehicle as well. This leaves little room for antenna nulls and may require a pair of antennas. The omni-direction capability certainly comes at the cost of power, which is already at a deficit in a battery-powered weapon. A directional antenna would offer signal amplification, but at too high of a cost to the employment flexibility.

The next major consideration for a JSOW antenna must be its affect on the weapon's RCS. The JSOW was specifically designed to be a low observable target for enemy systems that may attempt to shoot it down. The primary reason to employ a standoff weapon is typically to avoid entering an area where the threat can engage the launch platform. Meaning, the targets can shoot back or are protected by surface-to-air defensive systems. It is with this in mind that the JSOW truck was designed, and must be a consideration for the antenna selection.

These considerations and the engineering best practice of trying to keep it simple (no moving parts), quickly lead the design to a pair of conformal antennas. However, a conformal design requires use of precious internal space, were a blade can extend beyond the mold line of the original weapon. Deployable blades or wires, although more

complex, do offer the advantage of reduced RCS while the weapon is captive, and may not require costly separation testing because they do not alter the mold line of the weapon. This would also apply to the conformal antennas and may help recover some of the hardware integration cost. Ultimately, it may be necessary to neck down the choices with the above considerations and then conduct specific antenna evaluations to determine the best tradeoff.

Two-Way Data Link Considerations

Developing a two-way weapon data link is a viable assumption as the military transforms to network centric warfare. However, the power and design factors are affected so significantly by a two-way data link that the advantages and disadvantages must be considered. A one-way data link could pass IFTU information to the JSOW, updating the target position until such time the seeker took over in the terminal guidance phase. It is not necessary to have a two-way data link to successfully guide a weapon. This type of design would be similar to the AIM-120 design. The AIM-120 AMRAAM is an active air-to-air radar missile employed from the F/A-18 E/F that has proven combat success using a seeker and one way (launch platform to weapon) data link. The one-way design would reduce power requirements, the complexity of the system, and therefore the cost.

To achieve the DOD vision of network centric platforms and weapons, two-way communications is required. The weapon, as a member of the network, must be able to report its status, position, and intentions. This enables not only the shooter, but also all network members to monitor the progress of the strike and provide real-time feedback to

the command and control elements. In addition, a two-way data link enables many capabilities desired by the operators and commanders. It would allow the weapon to complete the kill chain requirement of assessing the effects of the strike in the form of a bomb hit assessment report and/or image. This in itself, for a standoff weapon, warrants the cost of a two-way design. Additionally, data link strike weapons will allow tactics like third party controllers as mentioned in the CONOPS discussion. The launch platform may never acquire the target in this scenario, and it will be vital for the weapon and third party controller to be able to communicate directly. This will minimize the opportunity for mistakes that could lead to fratricide or unacceptable collateral damage when a weapon impacts in the wrong area. The benefits gained from a two-way data link design are the capabilities that will make the JSOW Block Three a truly effective weapon on the future battlefield. These capabilities must be integral to the baseline design, and available at IOC.

Data Link Security Considerations

Data link security is of the utmost importance because vital command and control information is passed real-time over battlefield networks. Interception or denial of these lines of communication is unacceptable. In addition, any interference with weapon control signals by enemy or friendly forces will render the weapon unusable. One of the major design hurdles for the JSOW Block Three program will be the requirement to make the WDL encrypted and jam resistant. There is the added difficulty that current encryption standards desire hardware encryption components, but weapon developers are already discussing the desire to avoid hardware encryption modules in their data link

weapons to avoid the cost and anti-compromise requirements.

The alternative is software cryptographic systems. However, these systems and their National Security Agency (NSA) approval are complex. The JTRS programs have already begun to address this issue and it would be very advantageous for JSOW to adopt the method forged by the MIDS JTRS program, which will IOC on the F/A-18 E/F in 2007. Captain David Prater, program manager for the Navy's MIDS/Airborne Networking and Integration Program Office (PMW-780), explains the situation in an interview with Military Information Technology's Adam Baddeley:

> *"We have been working closely with the security policy apparatus all through this development. Last summer the NSA described the MIDS JTRS program as the 'policy icebreaker' for software cryptographic systems. The problem is that all of the old policy was based on hardware security systems. Software-based security systems require a new paradigm," Prater noted. "This is a whole new world and the old rules don't apply," he continued. "Understanding all of the implications and getting the policy right is a difficult process that will take time. There are two national policies in play here, on the one hand is the security policy, which we cannot afford to get wrong, and on the other hand the national military strategy, which is based on interoperability and coalition warfare. The proper balance between security and interoperability is essential."* [35]

The efforts of the MIDS JTRS program is something the JSOW program must align with and capitalize on to avoid having to fight a separate and costly "battle" with the NSA for a software encryption system. This technology may be applicable to both of the waveform alternatives discussed in this paper for WDL, but would certainly be a drop in solution for the Link 16 alternative. The cost savings of this issue alone may offset the added cost of implementing Link 16.

Jam resistance is another WDL program concern. Link 16 has built-in anti-jam capability with its use of spread spectrum technology that hops over 51 frequencies

77,000 times a second. This is an obvious advantage to the Link 16 waveform alternative. As previously mentioned, the VMF WDL has been demonstrated successfully, but only on a single UHF channel with no encryption or frequency hopping. Both capabilities exist in the F/A-18 E/F ARC-210 DCS radio, but involve additional hardware and software components that would have to be added to the weapon radio and modem equipment. WDL that resides on a single UHF channel is not an acceptable solution. This opinion was recently affirmed in discussions with subject matter experts at NSAWC when presenting the JSOW Block Three CONOPS. The JSOW data link alternative must address both of these issues with a robust design. Link 16 appears to have a working solution; VMF will require some investment by the JSOW Block Three program.

Guidance Electronics Unit Alternatives

A brief discussion of the JSOW GEU is warranted because alternatives are constantly being considered to in an attempt to reduce the entire life-cycle cost of the weapon. One potential area for cost cutting is a GPS weapon's inertial navigation unit (INU) because lower quality INUs are effective when the navigation solution is updated regularly by GPS. Lower quality INUs still provide a smoothing input to the overall navigation solution, but are much more susceptible to drift. The higher drift rate is overcome by GPS position and velocity updates. However, it is offered that the owner of that equipment, vessel, or vehicle that will make up a large percentage of the JSOW Block Three target set will be considered "high value". This will increase the chances of the target having some form of electromagnetic attack capability, which equates to the

ability to jam GPS and/or data link signals. During mid-course guidance, the JSOW may have the INU, GPS, and even Link 16 helping to update the navigation solution while data link is providing IFTUs. If effective jamming is present, the INU may be all that is available to guide the weapon to an extrapolated position where the seeker can acquire and track the target. It would be a serious oversight if a minor cost savings item became the weakest link in the JSOW Block Three's capability to engage a broad spectrum of targets. The GEU processing power and INU capability should be sufficient to allow an engagement even when the data link and GPS signals have been jammed out at a specified range to the target. This range will have to be determined through analysis and testing, and will certainly be a classified issue. Additionally, the GEU processor may have to support additional Block Three functions like ATR processing, moving target LAR calculations, and in-flight re-task queries. This added demand on the processor will require the development team to verify its capability prior to finalizing the design.

Mission Planning Alternatives

Mission Planning software has become an integral part the F/A-18 E/F and its weapon systems. With the recent deployment of the Joint Mission Planning System (JMPS) that encompasses all mission planning software for the F/A-18 E/F, integration with mission planning must start with the weapon design. The JMPS suite is a large and complex Microsoft Windows based program with a development infrastructure and release schedule similar to the F/A-18 Advanced Weapons Laboratory aircraft software release schedule. This means programs with mission planning needs, such as JSOW Block Three, must engage the JMPS team early to establish requirements and

development timelines that support the weapon development, aircraft integration, and testing.

For JSOW Block Three there are various levels or alternatives of mission planning that may be developed. The first alternative would involve no change to the current JSOW mission planning found in the JMPS Common Unique Planning Component (CUPC). This would require all data link setup to take place in the airplane. This may not be feasible as network participant requirements become defined. WDL networks may require some pre-defined network structure that must be downloaded to the airplane's mission computer. The second alternative would alter the JSOW CUPC to enable the network setup, and include the ability define network participant IDs, weapon or platforms, that would show up in the airplane. This would minimize the setup time required when the engines are running. In addition, the CUPC for Block Three should support any ATR functionality that the weapon is able to perform. This may include loading target libraries for the ATR algorithms and the ability to automatically or manually select an aimpoint on a particular target. The second capability will greatly improve the warhead's effectiveness when combined with the anticipated weapon CEP. Instead of merely hitting the target, it could allow the weapon to impact a particularly vulnerable location on the target, which could be modified during mission planning.

The third and last alternative builds on the previous two. In this case, the JSOW Part Task Trainer (PTT) would be upgraded in addition to the CUPC. The PTT is a software program that emulates the F/A-18 E/F cockpit environment on a personal computer. This item is traditionally used for training aircrew in regard to the operation of

the JSOW on the F/A-18. However, it could be upgraded to include the JSOW Block Three WDL functionality, which would allow aircrew to load their WDL networks, and then rehearse the handoff and weapon control capabilities over networked personal computers. They would also be able to simulate the mission planned employment profile to validate their data link tactics.

Each of the alternatives of mission planning capability discussed constitutes various levels of mission planning integration. Each successive level provides more capability to the operator. It has been the author's personal experience, from training fleet aircrew to employ the JSOW C, that upgraded and intuitive mission planning components will be vital to the success of the JSOW Block Three weapon. If the weapon cannot be easily planned, the aircrew will avoid using it, and it will become a niche weapon regardless of its capability. Inclusion of all the mission planning enhancements mentioned above will provide the most complete mission planning tools to the operators.

Summary of Alternatives Analysis

To summarize all of the previous alternatives discussion, a stop light chart consolidating the various subsystem alternatives was created. The chart provides relative feedback by rating alternatives with the six metrics listed below:

- Mission Accomplishment – alternative's relative contribution to meeting established mission or program requirements.
- Aircrew Situation Awareness – alternative's affect on overall aircrew awareness
- Aircrew workload – evaluation of alternative's affect on increased cockpit workload or anticipated level of compensation
- Technology Risk – how the alternative affects program technology risk
- Schedule Risk – how the alternative affects program schedule risk

- Cost – how the alternative affects the overall value of the weapon

Each alternative was rated in Figure 22 with one of three contributions to the program:

- Enhanced affect (green) – alternative has desirable effect plus enhanced utility.
- Acceptable affect (yellow) – alternative has desirable effect at minimum level.
- Undesired affect (red) – alternative has undesirable effect or does not meet minimum desired effect.

The ratings were derived from the previous alternative analysis and the author's experience as a member of the development team. Additionally, the following guidelines were applied when evaluating the overall rating. Any undesirable affect (red) in the first three columns prohibited an overall enhanced (green) rating. Any undesirable affect in the last three columns prohibited an overall enhanced rating unless mitigating circumstances exist, which are explained in a note. The following notes apply to Figure 22:

(1). Man-in-the-Loop seeker increases awareness with regard to the target, but decreases awareness to one's surrounds because of the attention required by the weapon.

(2). Autonomous seeker has the opposite affect of the MITL seeker because the aircrew does not have to focus on the weapon as much, but receives less feedback due to a lack of real-time seeker video.

(3). Weaponized Link 16 hardware is on the way, independent of the JSOW program, but currently unavailable. As it becomes available, its size, capability, and cost will be enhancements the program may be able employ.

(4). Cost of including both message sets is unknown at this time, and might be insignificant. This would elevate the alternative to an enhancement.

● (green) = Enhanced affect
● (yellow) = Acceptable affect
● (red) = Undesired affect

Subsystem	Mission Accomplishment	Aircrew Situation Awareness	Aircrew Workload	Technology Risk	Schedule Risk	Cost	Overall
Seeker							
MITL design	Enhanced	Enhanced/Acceptable (1)	Undesired	Acceptable	Undesired	Acceptable	Undesired
Autonomous	Enhanced	Enhanced/Acceptable (2)	Enhanced	Undesired	Undesired	Acceptable	Acceptable
1 for 1 replacement	Acceptable	Acceptable	N/A	Enhanced	Enhanced	Enhanced	Acceptable
Upgrade/Dual Mode seeker	Enhanced	Enhanced	N/A	Acceptable	Acceptable	Acceptable	Enhanced
Advanced AIM-9X type seeker	Enhanced	Enhanced	N/A	Undesired	Acceptable	Undesired	Acceptable
F-18 Implementation							
Link 16	Enhanced	Enhanced	Enhanced	Enhanced	Acceptable	Enhanced	Enhanced
UHF VMF	Acceptable	Undesired	Acceptable	Acceptable	Enhanced	Acceptable	Acceptable
Network Waveform							
Link 16	Enhanced	Enhanced	Enhanced	Enhanced	Enhanced	Enhanced	Enhanced
L16 Encryption	Enhanced	Enhanced	Enhanced	Acceptable	Acceptable	Enhanced	Enhanced
UHF VMF	Acceptable	Undesired	Acceptable	Acceptable	Acceptable	Enhanced	Acceptable
VMF Encryption	Undesired	Acceptable	Acceptable	Undesired	Undesired	Undesired	Undesired
JSOW Link Hardware							
Wpn L16	Enhanced	Enhanced	N/A	Acceptable	Undesired	Undesired	Enhanced/Acceptable (3)
UHF DL	Acceptable	Acceptable	N/A	Enhanced	Acceptable	Enhanced	Acceptable
Two-way	Enhanced	Enhanced	Enhanced	Acceptable	Acceptable	Acceptable	Enhanced
One-way	Undesired	Undesired	Acceptable	Enhanced	Enhanced	Enhanced	Acceptable
Omni-Directional Antenna	Enhanced	Enhanced	Enhanced	Acceptable	Acceptable	Acceptable	Enhanced
Directional Antenna	Undesired	Acceptable	Undesired	Acceptable	Acceptable	Acceptable	Undesired
Conformal	Enhanced	N/A	N/A	Acceptable	Acceptable	Undesired	Acceptable
External Blade or Wire	Acceptable	N/A	N/A	Acceptable	Acceptable	Acceptable	Acceptable
WDLN Implementation							
Single Message Set	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Include Both Message Sets	Enhanced	Enhanced	Enhanced	Enhanced	Acceptable	Undesired	Enhanced/Acceptable (4)
GEU							
Legacy GEU/IMU	Acceptable	N/A	Acceptable	Enhanced	Enhanced	Enhanced	Acceptable
Replace GEU/IMU	Enhanced	N/A	Enhanced	Acceptable	Undesired	Undesired	Acceptable
Current Battery	Acceptable	Undesired	Acceptable	Enhanced	Enhanced	Enhanced	Acceptable
Replace Battery	Enhanced	Enhanced	Enhanced	Acceptable	Undesired	Undesired	Acceptable
Mission Planning							
No Change	Undesired	Undesired	Enhanced	Enhanced	Enhanced	Enhanced	Undesired
WDL integration	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
WDLN sim tool	Enhanced	Enhanced	Acceptable	Acceptable	Acceptable	Undesired	Enhanced

Figure 22 Alternatives Analysis Summary.

Summary of Recommended Design

Figure 23 is a modification of Figure 13 that includes specific recommendations for each subsystem based on the analysis above. Each of the lists associated with the five subsystems below the weapon contain design requirements that will enable the Block Three weapon to accomplish its mission. Each of them is considered vital to the overall success of the weapon, and must not be discarded based purely on cost or risk. Again, it is important to point out that this design recommendation is based on both objective analysis and experience. It represents the recommendation of the author, not the JSOW Block Three leadership or development team.

One critical aspect of the recommended design is the selection of Link 16 as the

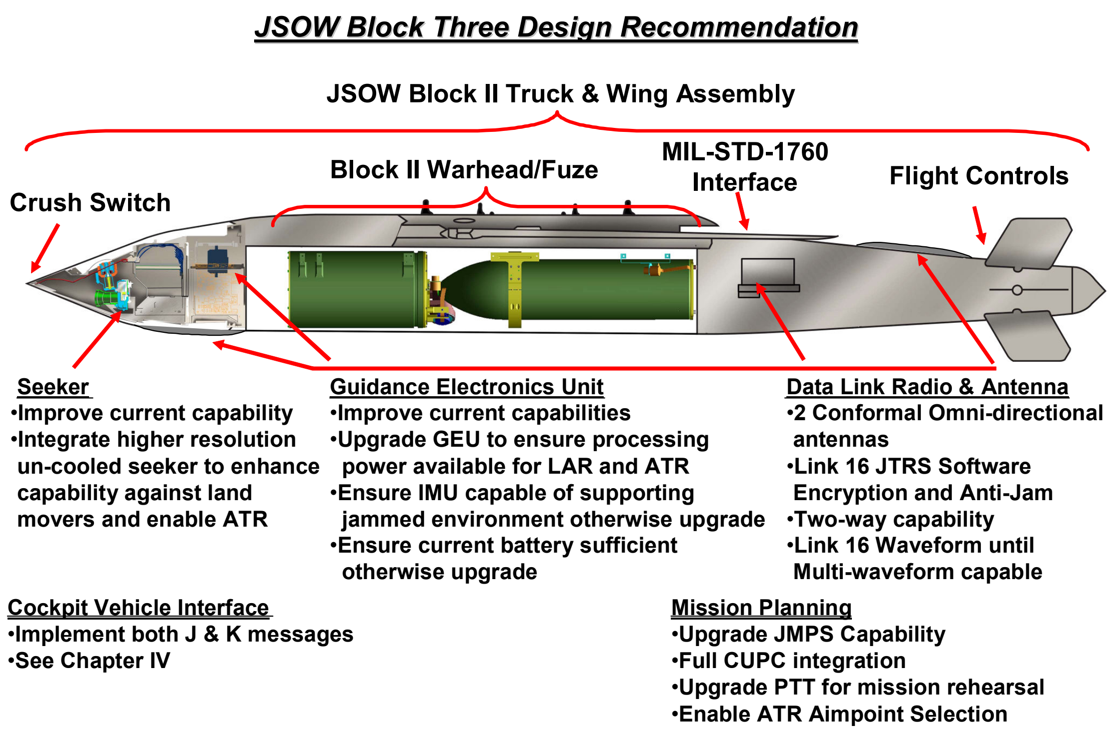

Figure 23 JSOW Block Three Sub-System Design Recommendations.

data link subsystem. Current hardware availability and its cost add risk to the program's success as previously discussed. However, the overwhelming enhancements to the mission accomplishment and aircrew SA warrant its selection as the primary alternative. Should the JSOW Block Three program agree with this recommendation, an aggressive initiative must begin immediately to pursue suitable weaponized Link 16 hardware. There are programs developing such a capability, but they appear to lack specific purpose and have marginal funding. If JSOW can demonstrate the need and advantages of Link 16 networked weapons, it may be possible to accelerate these programs to meet the timeline of the JSOW Block Three program.

Critical Technology Programs

This section is included to very briefly highlight previously unmentioned development programs that may have a substantial affect on the JSOW Block Three program. There may be other programs that fit this category, but these were found during the author's research for this thesis and as the project officer for JSOW and JDAM.

The Quint Networking Technology (QNT) program is attempting to produce weaponized or small form factor communication devices capable of handling multiple tactical waveforms. It is envisioned that a software reprogrammable radio may be able to handle multiple waveforms just by selecting one from the cockpit. Figure 24 provides an overview of the program. More information can be found at the following DARPA and Harris Corporation websites:

http://dtsn.darpa.mil/ixo/ixo_FeatureDetail.asp?id=110

http://www.harris.com/view_pressrelease.asp?act=lookup&pr_id=1649

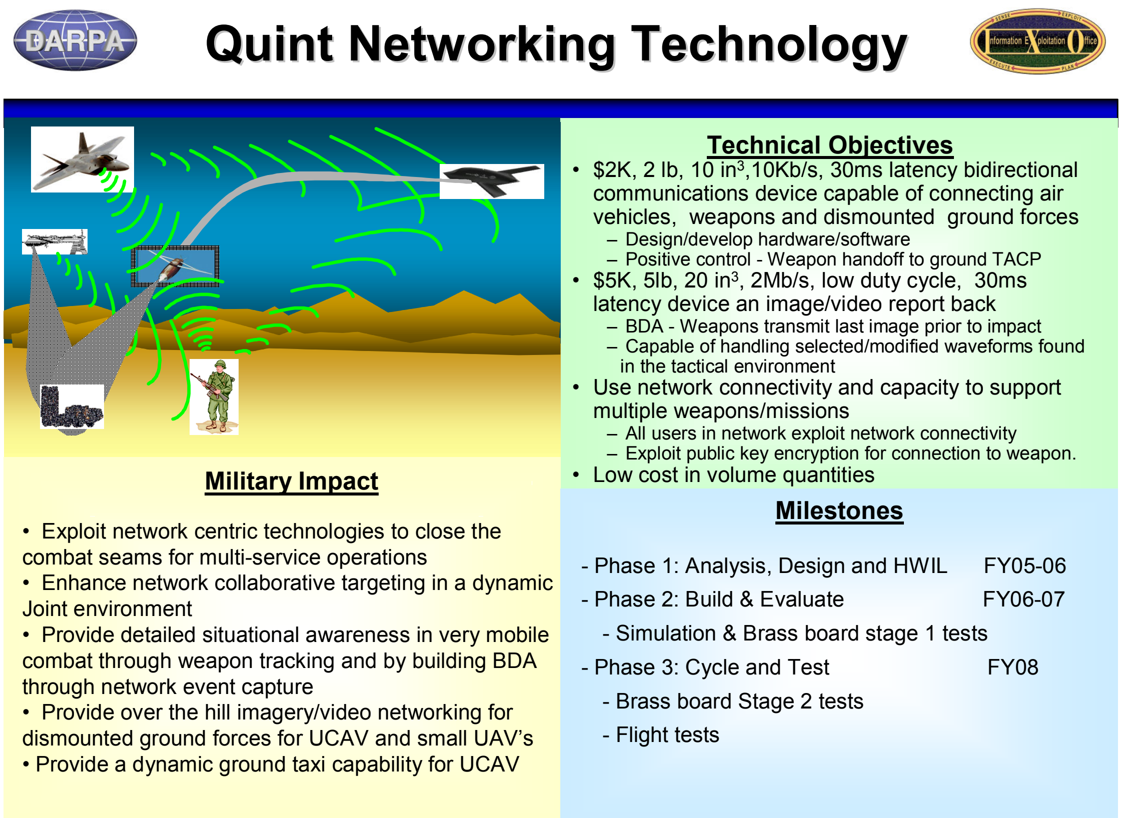

Figure 24 Quint Networking Technology (QNT) Overview. [36]

Three other programs of note involve the F/A-18 E/F and upgrades being investigated by Boeing and the F/A-18 Program Management (PMA-265). The first two are hardware upgrades to replace the F/A-18's Link 4 data link radio and the center Multi-Purpose Color Display (MPCD). Replacement of these items may benefit JSOW BlockThree through added capability to more effectively transmit and display network data. Both of these programs are still merely ideas, but may warrant further attention from JSOW. The third program is the F/A-18 E/F H6E software program, which is the follow-on effort to H5E. This program's timeline makes it the primary software build to fix anomalies found in the JSOW Block Three test program that will use H5E software.

H6E software will be released to the fleet at approximately the same time as JSOW Block Three. If funding is not allocated early to address integration issues noted when testing with H5E, they will not be fixed until approximately 14 months later when H7E is delivered.

CHAPTER V: JSOW Block Three Implementation

F/A-18 Pilot Cockpit Vehicle Interface Design

The JSOW Block Three integration with the F/A-18 E/F has undergone extensive design review and is well ahead of the weapon hardware development. This discussion was placed in the implementation chapter of the paper to provide the reader with insight into the planned cockpit vehicle interface. The design is based on the projected needs of the notional Block Three JSOW, capability of the WDLN message set, and F/A-18 operational and test aircrew inputs. Integration is taking place under the F/A-18 E/F H5E program, which is led by the F/A-18 Advanced Weapons Laboratory and The Boeing Company. PMA-201 and the JSOW Block Three Program are the customers.

The integration program consists of the four major items for the F/A-18 E/F listed below. Each of these items will be discussed briefly in this section, but the intricate details are well beyond the scope of this thesis. These details will be available in the Mission Systems Operation and Function Document (MSOFD) prepared by Boeing [37]. The document is being drafted now and should be available to JSOW Team members in May 2006.

- Weapon Data Link format design – displays and controls for weapon under control.
- JSOW WDL setup format – sublevel of JSOW format for pre-launch WDL setup.
- WDLN message selection and integration – Subset of WDLN message set integrated into the mission computer for WDL use.

- Overall integration with existing systems – Requires enabling WDL functions to interact and display on existing formats like the SA display, Head-up Display (HUD), and the Joint Helmet Mounted Cueing System (JHMCS).

Figure 25 shows an example of the Weapon Data Link format as of 15 February 2006. The WDL format is not weapon specific, and is designed to support and control JSOW Block Three and future WDL weapons. The figure explains some of the functionality associated with controlling a WDL weapon. It is important to note that the majority of the information displayed on this page will be received via a data link transmission between platforms or the weapon. This will be an important factor when discussing aircrew training requirements. An in-depth explanation of each function and its implementation is contained in the MSOFD previously referenced above.

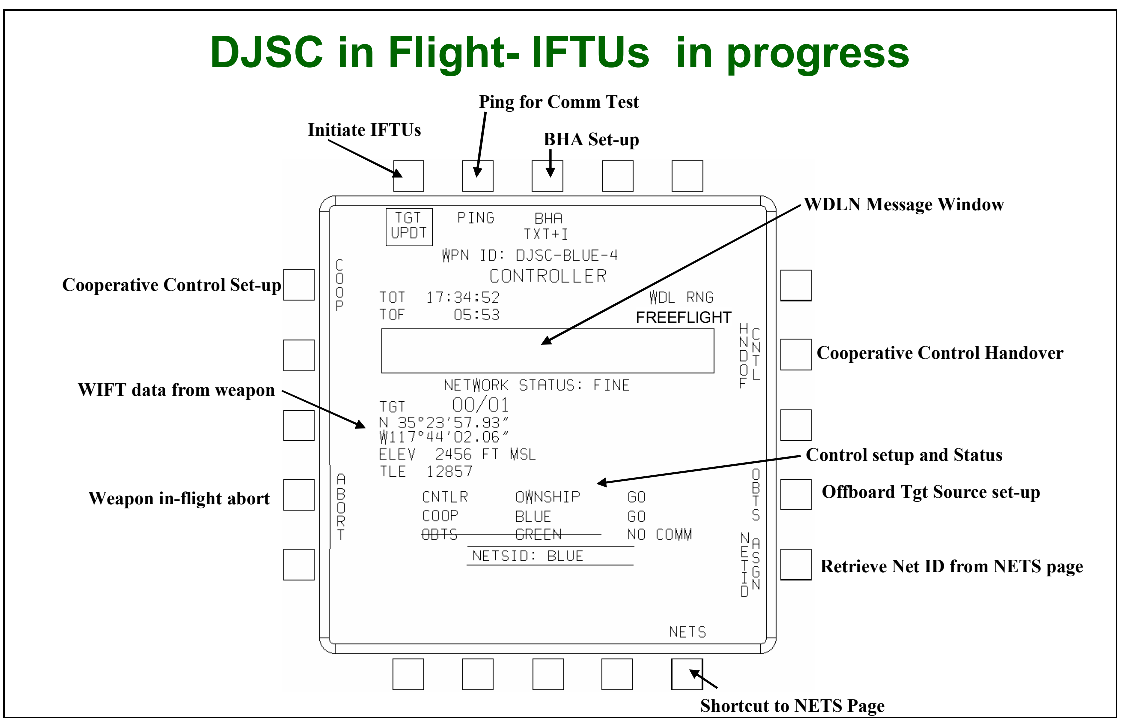

Figure 25 F/A-18 E/F Weapon Data Link Setup Format. [38]

There are two functions not included on the sample display in Figure 25 because their need and implementation are still being investigated. The first is a means to simulate WDL weapon engagements. As previously mentioned, the WDL format will display little information unless the weapon is in the network sending WDL messages. In order for aircrew to train with this new capability, training weapons called Captive Air Training Missiles (CATM) will need to be used. The "shooter" of the CATM must simulate launch of the weapon to enable its full functionality and allow OBTS platforms to simulate control of the weapon. The option to select Missile Simulation (MSim) mode needs to be implemented in the design when its functional details are better understood. The other functionality not shown is the previously discussed ability to rebroadcast VMF data link information if the Link 16 alternative is not selected. Selection of this button will simply retransmit, via Link 16, information presented to the shooter from the weapon via VMF. Again, the functional details of this capability are still under investigation.

The JSOW WDL setup format provides the JSOW specific controls for the weapon. The current JSOW family of weapons is already integrated on the F/A-18 E/F and they are controlled via the JSOW Display format. The WDL setup format will be a sublevel of this existing display. Figure 26 is an example of the JSOW WDL setup sublevel for H5E. It provides control over the weapon's radio and network status as well as the ability to set a controller, a third party target source (COOP), and an OBTS for the currently selected weapon. Then, using the ASGN WDLN button, the weapon and its settings can be pushed to the WDL format where settings may be further modified if necessary. This allows multiple weapons to be preset and pushed to the WDL

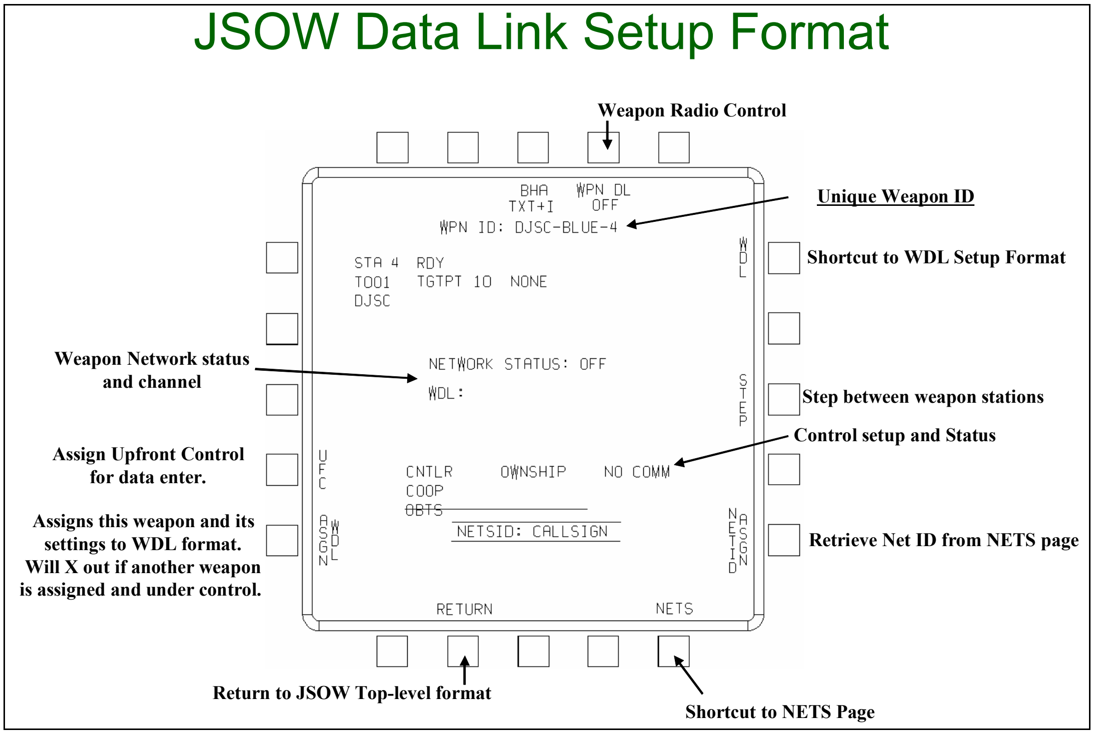

Figure 26 JSOW WDL Setup Sublevel. [38]

format as needed. One of the most critical aspects of this page and the JSOW Block Three integration is the assignment of unique weapon identifiers, which make it impossible for two controllers to interfere with one another. The weapon ID field shown above will eventually be the place where this unique ID is shown. Descriptors may be coded into the ID, as Vehicle Identification Numbers contain now, but each must be unique and factory set. The consequences of networked weapons having identity "confusion" and being misguided are too great to leave to the squadron or unit level deconfliction methods. The specifics of the weapon ID implementation are still under investigation, but must be given the appropriate attention to ensure standardization among WDL weapon programs.

The next integration task involves the development, scoping, and integration of the WDLN messages necessary to support WDL weapons. The JSOW Block Three program and the F/A-18 E/F H5E program continue to work on this task. The messages are developed by the WDLN program, but several inputs have been provided by the JSOW Block Three program as the weapon and CVI designs take shape. Continuing to route these design or message needs through the WDLN program will ensure standardization across the services. Developing specific weapon level solutions is not desired. Scoping of the message set has also been necessary because it was developed to support all WDL weapon needs. For example, some data link weapons will be powered and able to loiter, which requires data link messages not applicable to JSOW or the F/A-18 at this time. Finally, the messages must be integrated into the F/A-18 E/F mission computers so the content of the messages can be populated and transmitted. The JSOW GEU will also have to undergo a similar process.

Finally, WDL functionality will have to be integrated into existing displays that aircrew rely on to employ weapons and avoid threats. The two displays primarily affected by WDL integration are the HSI and SA formats. Currently, the HSI is the only format capable of displaying the JSOW LAR. The LAR indicates to the shooter when the launch platform and weapon are within range of the target. The shooter can then fly the aircraft and weapon into the Weapon In-Range region for release. The data link capability of the weapon adds a new aspect to the LAR, which is WDL In-Range. This region depicts the capability of the WDL subsystem to communicate to the controlling platform. Figure 27 is an example of the F/A-18 HSI display with the WDL In-Range

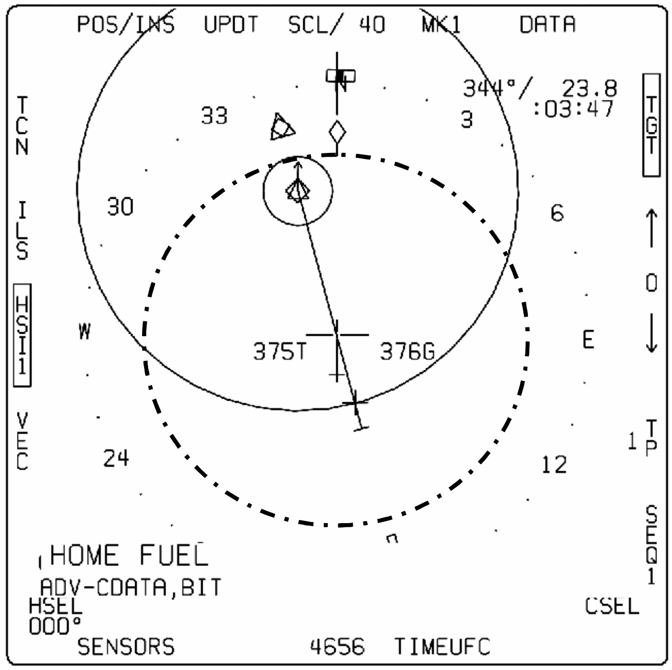

Figure 27 F/A-18 H5E HSI Display Example with WDL In-Range Indicator. [38]

region depicted as the dot-dash line. It will be necessary for the controller to be inside this region pre-launch for handoff communication as well as post launch for control communications. This region will need to be defined by the weapon and broadcast over the WDL network so that all involved can see the WDL In-Range region. An additional functionality being investigated may be the need for a weapon footprint that shows the capability of the weapon centered on itself, unlike a LAR that is centered about the target. This would prove useful for retargeting the weapon in flight or if displayed on the SA format, it could be used to screen for network targets that are In-Range. This eliminates the current requirement to designate each prospective target and generate a LAR.

As mentioned, the SA format is primarily used to display network (Link 16) information in a top down view. The data link track files are overlaid on the same air

navigation chart used on the HSI. For WDL integration, the primary concern is display of weapons in the network and the target under missile attack (TUMA) line connecting the weapon and its target. Figure 28 shows a mockup of the F/A-18 H5E SA format with a data link weapon in flight. The figure also shows a data link track designated on the weapon's target, which could indicate the track is an OBTS or the cooperative controller. The TUMA capability should be similar to the current air-to-air weapon displays, but the integration challenge lies with the display itself. First, the SA format does not display JSOW LARs and it might not support the WDL In-Range without some compromise. Currently, there is no plan for this to change in H5E due to the hardware throughput limitations. Therefore, the shooter and controller, if different, must have both the HSI and SA formats displayed to maximize their situation awareness as they employ the

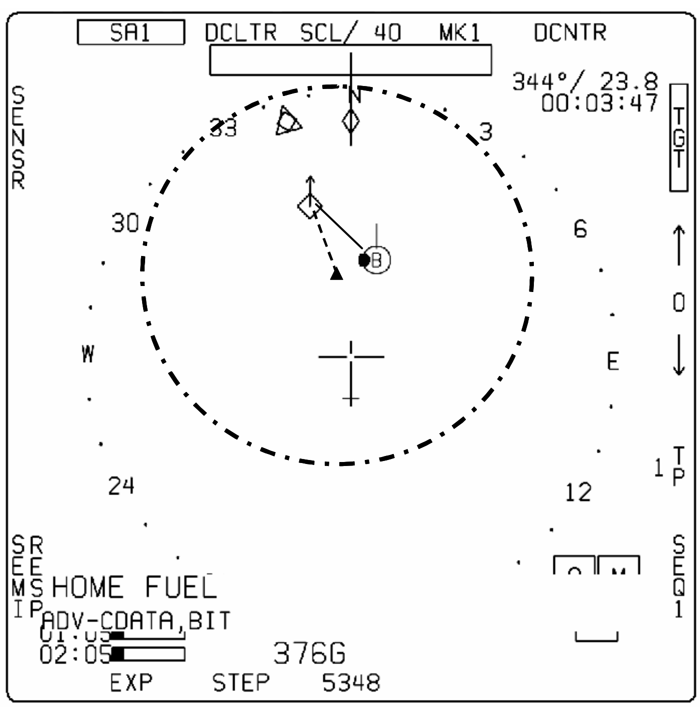

Figure 28 F/A-18 H5E SA Display with WDL In-Range and TUMA. [38]

JSOW Block Three. F/A-18 aircrews typically only fly with one or the other display up at a time. However, both displays may be required post-launch because the SA format will show the weapon flyout and the HSI will show the WDL In-Range. To avoid monitoring two displays, the WDL In-Range should be displayed on the SA format as shown in Figure 28.

Other displays will also be affected by WDL integration. Standard cues for each weapon type are found in the HUD, JHMCS, and on the Stores format. Each of these displays will have to be adjusted to accommodate WDL integration, and care will have to be taken so other established functionality is not disrupted. Should the reader wish to further explore the H5E WDL CVI design, Appendix 3 includes a set of slides developed to walk one through the setup and control of a Block Three JSOW in the cooperative control scenario. The slides also illustrate some of the other displays modified to enable WDL functionality. When reviewing the first slide, Cooperative Handover CONOP, note which aircraft is blue and which is green. This will help the reader understand the remainder of the slides.

Development and Testing Timeline

Figure 29 is the simplified schedule presented to give the reader some insight into the development and testing timeline associated with the JSOW Block Three program. One of the critical things to note from the schedule is the H5E program is complete just as JSOW Block Three flight testing should begin. In addition, H6E will have locked its design requirements by this time, and will probably only be willing to make software changes to fix anomalies, not add new functionality. Therefore, it is paramount that the

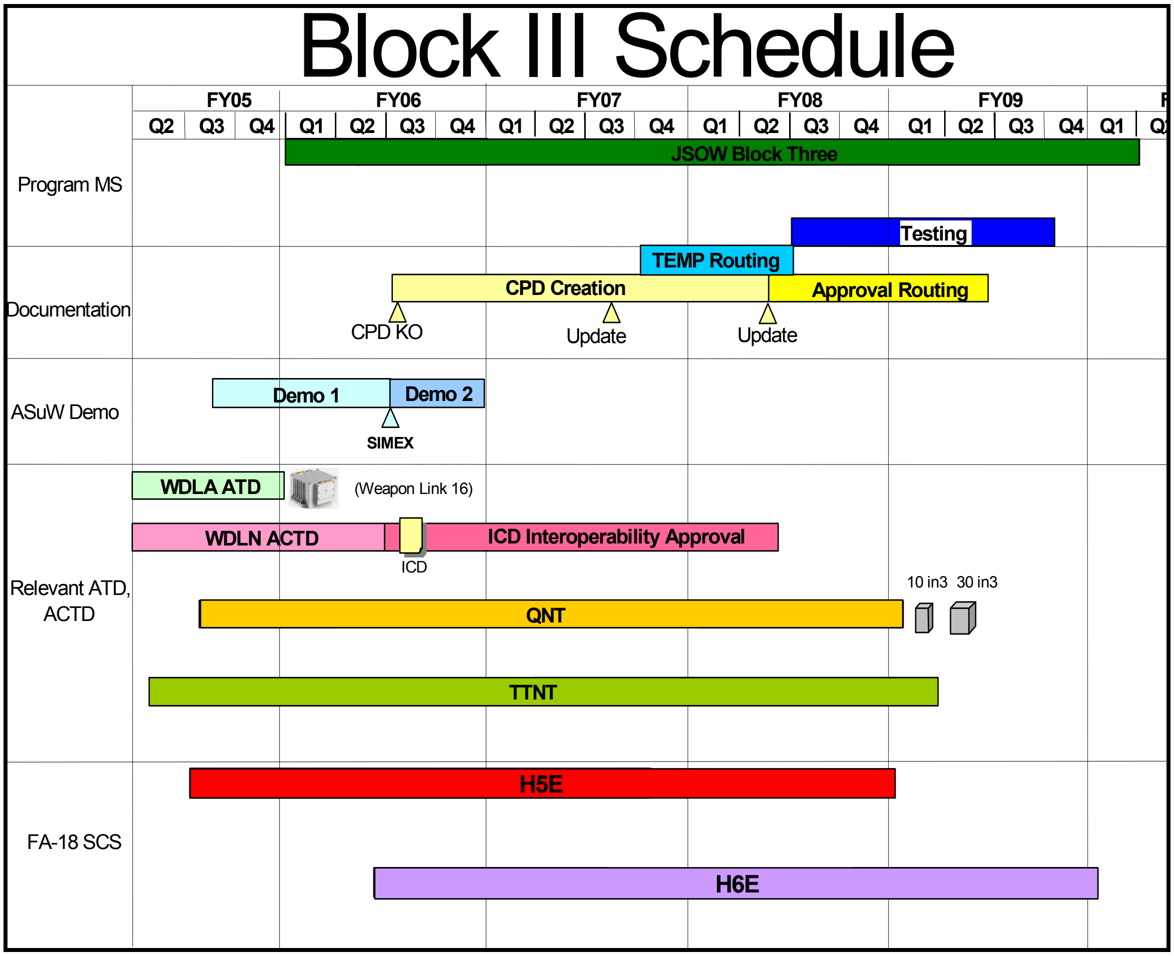

Figure 29 JSOW Block Three Program Schedule January 2006.

JSOW Block Three Program front loads all capability into the H5E program and begins a rigorous laboratory and ground verification and validation test program. This can be done while waiting for flight worthy Block Three JSOW, and will allow software anomalies to be reported early enough to be acted upon in H6E. Anything less will delay the program beyond its desired IOC date.

JSOW Block Three Demonstration Phase

In parallel with the JSOW Block Three development is an ongoing set of technology demonstrations. These demonstrations will serve as risk reduction efforts for the Block Three design by helping to highlight areas of concern within the CONOPS, technology, and platform integration, to name a few. The first three demonstrations listed below, and on the schedule, are already in the planning stages, with Demo 1 well underway having flown a captive flight test in September 2005. The fourth demonstration, labeled "Other Demonstration", is not currently planned, but is highly recommended as discussed below. It is presented here, vice Chapter 6, for continuity. Each demonstration's purpose and desired data products are briefly discussed below.

Demonstration 1: Anit-Surface Warfare (ASuW)

The ASuW demonstration was developed to showcase the concept of guiding a JSOW C via data link to a "seeker basket" where the target would then be autonomously detected and tracked. This demonstration will use JSOW C weapons with modified seeker algorithms, inert payloads, and a UHF VMF data link. The weapon will be employed from an F/A-18 E/F using the ATFLIR as a targeting sensor. The target will be an instrumented target ship underway in the open ocean. The laboratory testing and

preparation for this demonstration have been vital in understanding the integration issues that will be faced by the Block Three program. Additionally, it continues to provide the insight necessary to effectively design the CVI currently being implemented in H5E. One of the major data products from this demonstration will be the seeker's detector and moving target algorithm performance. The outcome will influence the seeker design and selection criteria for Block Three. This demonstration was to be completed in time for the results to be included in this paper, but the schedule has slipped the live demonstration date beyond the submission date required for this thesis.

SIMEX: Third Party Targeting Demonstration

The Joint Time Sensitive-Targeting/Precision Engagement (TST/PE) Simulation Experiment (SIMEX) 06-2 is designed to meet the objectives below. By employing networked simulation and real world assets, the experiment, among other things, will further the JSOW program's understanding of the Time Sensitive Kill Chain and highlight interoperability issues that may have to be overcome.

SIMEX 06-2 Objectives [39]:

- Evolve CONOPS/TT&P JSOW BLK THREE employment
- Examine JSOW Kill Chain and identify potential gaps
- Examine role of Strike Planning Cell in JSOW Kill Chain
- Examine role of LSRS in JSOW Kill Chain
- Explore JSOW targeting Scenarios
    - External
    - Organic
    - Third party

Demonstration 2:

The specifics of the second demonstration have not yet been determined, but the plan is to use data link hardware similar to Demo 1. Preliminary objectives include investigating the use of an alternative payload, a different target set, and no seeker. The alternative payload may be some form of area munition like the ones carried in the JSOW A and B variants. An area munition could be an alterative way to compensate for TLE, when the weapon does not have a terminal seeker.

Other Demonstration

This fourth demonstration is suggested based on the previously recommended Link 16 data link solution, and in anticipation of the H5E software design being complete prior to delivery of JSOW Block Three test assets. This demonstration would allow a test vehicle to be produced that would enable early testing of the H5E software. This will be a critical advantage to the Block Three program because of the development overlap between H5E and H6E, refer to Figure 29. Any anomalies in the integration that can be detected early and provided to H6E for resolution will be advantageous to JSOW in both cost and schedule. Additionally, should a Link 16 data link solution for JSOW Block Three become desirable, this demonstration would afford the program some level of risk reduction regarding the weaponization of the a Link 16 terminal. The early adoption of a weaponized Link 16 terminal, in a demonstration weapon, would also allow the JSOW Block Three program to provide the Link 16 programs feedback from a weapon customer in hopes of improving their product. Combined, these considerations justify the additional demonstration on a risk and cost basis, but may also be advantageous to JSOW

by further refining the scope of the Block Three program.

CHAPTER VI: Conclusions and Recommendations

Conclusions and Recommendations

The following conclusions and recommendations are primarily based on the previous analysis, but also draw from knowledge gained serving as the JSOW and JDAM Project Officer for PMA-201, flying as a test pilot at NAWS China Lake, and while assigned to operational squadrons in the U.S. Navy. While there are numerous design recommendations and conclusions throughout the previous chapters regarding the weapon design, there are some program level recommendations that need to be discussed. They are JSOW Block Three specific or address programs and issues that may directly affect the success of the JSOW Block Three Program.

Short Term

In the opening paragraphs of this thesis, it was stated that defining the target set is one of the first steps in weapons development. A notional set of land and sea targets was presented, which is still under investigation and development. The following recommendation offers specific items for consideration as threshold (minimum capability) and objective (desired capability) targets by the JSOW Block Three program. The recommendations are based on employment from medium standoff ranges, and therefore it is assumed that targeting would be accomplished using radar sensors.

Seaborne targets will certainly be suitable for the Block Three JSOW variant, but not all of them. First, vessels capable of high speed, >35 knots, and that are highly maneuverable exceed the kinematic capability of the unpowered JSOW and present an enormous challenge to the seeker. Although, "pleasure craft" and small patrol type boats

may be valid targets when considering a terrorist threat, these vessels seem to be an unreasonable quarry for the JSOW weapon, and should not be design drivers. Not all small seaborne targets are fast and maneuverable. Amphibious tanks and armored vehicles will fall with in the kinematics of the JSOW, but may present a considerable challenge to the seeker and tracking algorithms. These vehicles travel through the water nearly submerged and may have little thermal signature. They are certainly viable targets, but recommended as objective targets because of their small signature, and are typically in the company of the next target group when seaborne.

Medium (approx. 75 - 250 ft) to large (>250 ft) sized hull borne or displacement vessels will be the main group of targets for the JSOW. The medium vessels are represented by landing craft, amphibious troop transports, and up to the smallest of combatants like corvettes. They are typically not as fast as their longer hulled counterparts are, but may present challenges with their maneuverability. The larger vessels will typically represent combatants like frigates, destroyers, and even aircraft carriers. These vessels can be fast, approaching 35 knots, and will be heavily guarded and/or armed. Both of these vessel types should be considered threshold targets and drivers for the weapon design.

Land moving targets present an even more challenging target set due to their maneuverability, speed, typically small size, and lower thermal contrast. It is recommended that vehicles at high speed, a specific number will have to be determined, not be considered design targets. That is not to say targets of the size usually associated with speed should be ruled out, just not considered when at or able to obtain full speed.

This includes all but the largest land vehicles as even tanks can reach 50+ mph. Their potential maneuver envelop may exceed the JSOW's capability and will certainly challenge the ability of the targeting sensor to provide reasonable coordinates if the vehicle were to maneuver. However, it is recommended that vehicles of this size be considered as relocatable and "engagable" when slow or even stationary. When stationary, it may be possible for the targeting platform to provide precision coordinates, which can enable the JSOW to engage the target even if the seeker does not acquire it. However, this will not always be the case depending on the platform, and the seeker must be able to contribute by attempting to locate and track the target. The threshold target will be a tank or armored fighting vehicle at nominal patrol speed in an urban environment. The objective target would be that same vehicle approaching the determined kinematic limit of the JSOW in an open rural environment, which will probably be less than the vehicles top speed. For the large target group, each of these targets should be considered threshold due to their size, typical speed, and value. A possible exception may be a tractor-trailer going flat out on the highway. The opportunity to strike a moving missile transporter-erector-launcher (TEL) cannot be missed. These vehicles are large and typically slow and must be "engagble" with JSOW regardless of their background.

Specifically characterizing these various targets and analyzing their speed and maneuver potential should result in a threshold and objective target maneuver envelop. This envelope can then be designed for and used to test the weapon. This should be the goal of the target set trade study.

The next issue that needs to be addressed immediately is the seeker. The selection process has already begun at the contractor level, and the trade studies associated with Block Three have not concluded. Programmatic concerns like cost and risk are being considered while mission accomplishment is taking a very distant third place. These programmatic concerns have quickly led to the preliminary selection of a form, fit, and function replacement for the Block II seeker, despite the fact that all involved recognize that this type of solution might severely limit the JSOW Block Three "engagable" target set. Some speak of the need for development spirals where a more capable seeker can be integrated later, or more advanced system level or algorithm solutions can be developed to upgrade the weapon. The bottom line, all of these upgrades cost money and more money to test and re-test them. A capable seeker with capability growth must be considered now. The success of this weapon depends on the seeker, and it is an enormous risk to make it the weakest link in the system. It is very possible that every dollar spent on the Block Three seeker now will save the program money in the future by eliminating costly algorithm development iterations and testing, as well as costly hardware upgrades. There are advanced seeker technologies out there now that need a home, such as the Eagle Eyes described in the seeker section of Chapter IV. The Block Three Team must engage this issue now.

The recommended Block Three design in Chapter IV selected Link 16 as the primary data link solution. This solution requires the production of a weaponized data link terminal that only currently exists in very small demonstration quantities or only on paper in the case of the QNT technology. The JTRS and QNT programs and technology

demonstrations like WDLA are leading the way in radio development and software encryption techniques. They have been given guidance and design specifications to direct their programs, but not the motivation that could be provided by a weapon system customer with specific needs. The Block Three Team needs to engage these programs to not only provide system level inputs, but provide them a customer that is willing to test their developmental hardware. Nothing motivates a defense systems engineer more than seeing his efforts lead to a successful employment of that equipment.

The F/A-18 E/F H5E program is rapidly proceeding towards a design that JSOW will have to live with for years to come. The Block Three engineering team has eagerly participated in the discussions that have led to the design presented in Chapter V. However, there are some, if not many, open issues associated with the F/A-18 integration and CVI design that require input from the JSOW customer. As pointed out, the weapon development lags the F/A-18 software development, which is a concern, and probably the reason some of the integration questions generated during CVI development have gone unanswered. There is a risk that if these questions remain unanswered they will be answered incorrectly or overlooked. A specific example is the implementation of the Abort Function, which currently only has a placeholder on the F/A-18 side. This function is supported by the WDLN message set, but needs to be refined for JSOW purposes. JSOW might not have the functional details available at this time, but the general concept needs to be determined so the CVI will support it. It is highly recommended that the Interface Control Working Group be established at this time for JSOW Block Three to recognize these issues and manage them until such time as the answers are revealed.

Finally, it is recommended that the JSOW Block Three begin an early and cooperative relationship with the Joint Interoperability Test Command (JITC). They are at the forefront of software reprogrammable radio and network testing. Requirements for interoperability can quickly bring an otherwise successful weapon system program to its proverbial knees. Early involvement of the JTIC will ensure JSOW is on the right track, it may also provide the program cost saving engineering ideas or test procedures. Their mission and contact information can be found at: http://jitc.fhu.disa.mil.

Long Term

The longer term recommendations involve hardware procurement that will directly benefit the JSOW Block Three Program and the warfighter. The first two involve equipment upgrades for the F/A-18 E/F that are sorely needed for many programs, but will also benefit Block Three JSOW. Currently, the Multi-Purpose Color Display (MPCD) in the F/A-18 is primarily used to display the "SA" format with data link information and the "HSI" Format for navigation purposes and display of weapon LARs. The MPCD hardware display capability is exceeded by the information desired for presentation on that display. This limitation is the reason weapon LARs are not displayed on the SA format. This has been severely limiting the utility of the display for years with current needs. As data link weapons come online, the display needs will increase to accommodate the additional information while the currently displayed information becomes no less important. Replacement of this display is currently in discussion at the F/A-18 Program Management (PMA-265) level. Any additional support the JSOW Program and PMA-201 could lend this effort will directly benefit the weapon

programs.

Next is the F/A-18's Link 4 replacement radio program. Link 4 is a legacy data link system that is being phased out in favor of Link 16 and other modern systems. The PMA-265 may remove this radio once its capability is no longer needed or they may replace it with another radio. Discussions are underway to replace the existing radio with a third radio that is DCS capable, thereby providing a radio that could be dedicated to VMF transmissions when needed. If JSOW Block Three or other data link weapon programs decide to implement VMF as their WDL control waveform, this third radio will be a tremendous advantage. It will alleviate many deconfliction problems associated with the current implementation. Again, this has the potential to benefit many of the programs managed by PMA-201 and any support it could provide PMA-265 will be rewarded by the capabilities of this third (second DCS) radio.

The final recommendation is related to the need for aircrew training. As mentioned, JSOW Block Three may very well be the first networked weapon to be deployed to the fleet. There will be a desire and requirement to train with such a weapon before it is employed in combat. The largest stigma with current weapons that employ legacy data links is their complexity and lack of available training weapons or CATMs. JSOW must develop and deploy JSOW Block Three CATMs in parallel with the all-up-round weapon. JSOW currently has a history of overlooking this requirement and Block Three will be the place to remedy the issue. As the future JSOW Project Officer heads out to the fleet to begin training instructors and aircrew about the capabilities of this weapon, the greatest factor influencing the weapon's reception will not be its awesome

capabilities, it will be the availability of CATMs for aircrew training.

Summary

The ultimate goal of the JSOW Block Three Program must be successful accomplishment of the assigned mission. Every other aspect of the program must be subservient to that idea. To field an inexpensive weapon system that carries very little program risk and was technically successful during DT testing but fails to meet the mission needs is unacceptable. If cost and schedule become the primary concerns, the program should be delayed until such time that an effective design becomes viable. There is no need for another technologically sophisticated but ineffectual weapon system that will go through a lifetime of upgrades just to meet its true threshold requirements. Fortunately, the JSOW Block Three Development Team has not allowed this to happen. However, there will always be pressure to reduce cost, risk, and to “re-write” the performance specifications to lower them to current performance. This is not to imply that cost and risk are not important considerations, but they must not be managed by sacrificing the mission. The Block Three JSOW must succeed in combat the first chance it gets!

The discussion and analysis in this thesis have outlined a design oriented to achieve that success. However, it does not address every detail associated with such a complex endeavor. There will be critical issues that are not discovered until the weapon is placed in its intended operating environment, which is combat. This is the reason that the components of a complex system like JSOW and the F/A-18 must be rigorously flight tested in an operationally representative environment. It will also be critical that the

program expect flight testing to uncover unforeseen issues and plan the resources to resolve them before the weapon reaches the fleet.

As the Block Three program continues to expand its knowledge and begins to make final decisions, it is the hope of the author that this thesis will provide each team member with a better understanding of the warfighter's perspective. It will then be up to them to ensure that each decision is in the best interest of the aircrew and warriors that will depend on the JSOW Block Three while engaged in combat.

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APPENDICES

APPENDIX 1: F/A-18 Target Location Error White Paper (excerpt) [15]

Target Location Error

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Classification: Unclassified

Introduction:

With the deployment of GPS based Smart Weapons, today's F/A-18 aircraft must be able to utilize their ownship sensors to generate WGS-84 compatible position information on targets or threats of opportunity. This target position information (provided as Latitude, Longitude, and elevation,) gives a fixed location on the earth that can be provided to ownship GPS based "Smart Weapons" or to other aircraft platforms or information centers so that other assets can be accurately targeted against these threats.

TLE (Target location error) is a measure of the inaccuracy in these target coordinates. This inaccuracy is the result of all of the errors introduced by subsystems within the F/A-18 (A/B/C/D versions addressed here) that are involved in calculating target coordinates from a designation. Subsystems contributing as error sources include the INS, GPS, AGR radar ranging, ATFLIR laser ranging, radar altimeter, and barometric altimeter. AGR and ATFLIR Sensor angular errors are also contributors to TLE. Other sources of error include aircraft boresight errors, data truncation of latitude and longitude sent and received via data link, and aircrew induced sensor cursor placement.

The errors induced when the radar altimeter, barometric pressure altimeter, or AGR Radar (APG-65/73) are the only primary contributors to the designation are so large that the target position coordinates generated should never be used to directly target Smart weapons. In the MIDS real-time track quality value, they should never score higher than a 12.

Currently the only sensor system that can consistently provide target coordinates on targets of opportunity that meet the MIDS Real-time Track quality value of 15 is the ATFLIR in one of its primary track modes lasing the target with a good GPS (small double digit HERRs/VERRs ie: < 50feet) aiding the INS, and straight and level flight (< three G's for more than 40 seconds with the CAINSII/MAGR, < three G's for more than 4 seconds with the EGI).

The INS, GPS, ATFLIR/FLIR, AGR radar and MIDS (Multifunction Information Distribution System) are the sensors/ subsystems that will be discussed in more detail below.

INS

The INS (Inertial Navigation System) is the aircraft subsystem responsible for keeping track of the aircrafts position. It provides this 'position' information to other sensors and subsystems that are part of the aircrafts ownship suite. At the speeds the F/A-18 operates at, the staleness (time it takes to communicate this information) in this aircraft position data would really only be telling you where the aircraft had been. To improve on this, the INS was optimized to provide very accurate velocity and acceleration data. This implementation worked well for the 'relative' targeting that was a primary capability of the F/A-18 prior to the deployment of GPS based 'Smart' weapons.

Besides staleness in the position information, the INS has an inherent 'drift' in position. This 'drift' affects both INS's utilized in the F/A-18. In most deployed C/D (and E/F) aircraft, the CAINSII ring laser gyro based INS is used. The CAINS II 'drift' accuracy specification is 1.0 nm/hr. Normally unaided units actual drift is between 0.2 - 0.4 nm/hr. The CAINS II/MAGR system is known as a loosely coupled system (two separate boxes, 2 kalman filters). During aided operations, the GPS updates the INS once every 40 seconds for position and once every 5 seconds for velocity. The GPS will aid the INS as long as it is tracking four GPS satellites with a quality of state 5 and FOM < 5 (FOM < 5 means HERRs and VERRs

are both < 230 ft). In the A+ aircraft the EGI INS is used. The EGI 'drift' accuracy specification is 0.8 nm/hr. Normally operating unaided units actual drift is between 0.6 - 0.8 nm/hr. The EGI system is known as a tightly coupled system (1 box, 1 kalman filter). During aided operations, the GPS aids the INS once every 4 seconds for position and velocity. The GPS will aid the INS as long as it is tracking four GPS satellites with a quality of state 5 and FOM < 5 (FOM < 5 means HERRs and VERRs are both < 230 ft).

GPS

CNO policy states (per CNO message R 021516Z SEP 98) that aircraft will fly with a keyed GPS receiver at all times. A keyed receiver gives better accuracy and provides a greater level of spoofing protection. An unkeyed GPS receiver will aid the INS as long as the GPS quality criteria is met. This is true for either the original GPS or the MAGR2K if the INS mode switch is moved to the IFA position. An unkeyed MAGR2K with NOSEC boxed, (option PB2 on HSI / DATA / A/C page), has proven that it is an acceptable alternative to a keyed GPS (though with reduced spoofing protection) and has been used in some of the recent flights conducted to determine the F/A-18 system TLE with the ATFLIR sensor.

The production GPS specification is 16 m (50 ft) spherical error probable (SEP).

- Keyed MAGR will usually give HERRs and VERRs of 16 - 24 feet.
- Unkeyed MAGR will usually give HERRs and VERRs of 100 - 150 feet
- Unkeyed MAGR2K with NOSEC boxed will usually give HERRs and VERRs of 16 - 24 feet
- Keyed EGI will usually give HERRs and VERRs of 8 - 24 feet
- Unkeyed EGI will usually give HERRs and VERRs of 8 - 50 feet

Dropped satellites cause the system to revert to POS/INS. Dropped satellites happen primarily during maneuvers. MAGR will start dropping satellites at approximately 20 degrees angle of bank. By 30 degrees angle of bank the aircraft will have reverted to POS/INS. Satellites will return with the end of the maneuver. Dropouts due to maneuvers along with other INS errors very quickly show up as additional TLE error in the high precision sensor derived target coordinates needed for GPS weapons.

The Air Force maintained website at http://www.schriever.af.mil/gpssupportcenter/request.htm is a source of information on basic GPS coverage and predicted accuracies. As stated on the website "…In the PDOP Predictions, the color bands indicate the maximum PDOP experienced at each grid point over the course of the day. Remember, for most military operations, any PDOP less than 6 (white, yellow, and light blue on chart) is acceptable. In the Position Error Predictions, the color bands indicate the 95th Percentile Position Error seen at each grid point over the course of the day. In brief, the 95th Percentile indicates, not the maximum position error, but the most probable range of position errors. As an example, if the chart indicates a color band of 4 - 8 meters for the 95th Percentile (assume 8 meters for simplicity), there is a 95% chance that any position fixes will have 8 meters or less of error. Barring any kind of satellite outage/anomaly, the remaining 5% rarely exceeds 20 meters of error. " In other words, ownship GPS performance can only be as good as the data being provided by the GPS constellation.

APPENDIX 2: JSOW Block Three Concept of Operations [18]

Slide 1

JSOW-C Block III CONOPS

CDR Neal Kraft, JSOW Class Desk
LCDR Kyle Turco, JSOW Project Pilot

1

Slide 2

JSOW-C Block III

- Provide land and sea moving target capability for JSOW-C weapon
  - JSOW-C w/ addition of Weapons Data Link (WDL) terminal
  - Seeker HW / SW improvements
  - Guidance and Navigation SW improvements
- Limited funding
  - Capitalize on current data link capabilities of FA-18 E/F
    - Interim UHF solution possible due to technology immaturity
  - Develop in FY07-08, IOC in FY10 on FA-18 E/F HOL a/c only
- Design the system now with the ability to flex to the emerging D/L network architecture

2

Slide 3

H5E S/W Development

- Derived Operational Concept:
  - "Productionization" of various demonstration efforts:
    - Affordable Moving Target Engagement (AMSTE)
    - Resultant Fury
    - Current ASuW Demonstrations
  - Concept Similar to SLAM-ER 19C Moving Target Engagement
  - Synergistic opportunities with other WDL programs

- Improved Mission Capability:
  - Time-critical strike against moving/relocatable targets
  - Networked weapon operations
  - Improved sensor to shooter connectivity

3

Slide 4

Scenarios

- Assumptions:
  - Weapons Data-Link Network (WDLN) messages will be used as the standard for weapons' control
    - Developed during joint ACTD, finishes Mar 06
    - Addresses current and future needs of D/L weapons
    - At IOC, only FA-18 E/F will have WDLN message capability
  - Moving target solution w/out requiring an ATA file
    - Moving / relocatable targets, both land and sea
    - Potential solution: Selectable category system
  - Capability to pass JSOW mission data files (w/ ATA template) to aircraft in flight via Link 16 at IOC
    - "MiDEF over Link 16" is separately funded effort for FA-18 in H5E

4

Slide 5

Scenarios

- Assumptions (cont):
  - F/A-18 E/F shall support control of one weapon at a time
  - New Weapon Data Link Controls and Displays
    - Capitalize on existing control formats (ie AWW-13 Pod format, SLAM-ER 19C Moving Target)
    - Needs to be developed for controlling future WDL weapons
  - BHA
    - Supported by current imagery message format (J16.0 or K04.17)
    - Weapon "text" BHA report integrated w/ F/A-18 BHA report/display
    - BHA Image/report recorded on DTD as post-flight file

- Ongoing efforts
  - 10 Jan 2006 (China Lake) – Paper DAG
  - April 2006 (St Louis) - DAG

Slide 6

Scenario Definitions

- Shooter
  - Launch platform – FA-18 E/F
- Targeteer
  - Platform that provides in-flight target updates (IFTUs) to the JSOW-C Block III weapon via WDLN mesages
- Controller
  - Platform that provides other commands to the JSOW-C Block III weapon in flight via WDLN msgs, including:
    - Retarget or abort commands during flight
    - Allowing offboard sensor to provide IFTUs directly to the weapon
    - Executing a control handoff to another platform

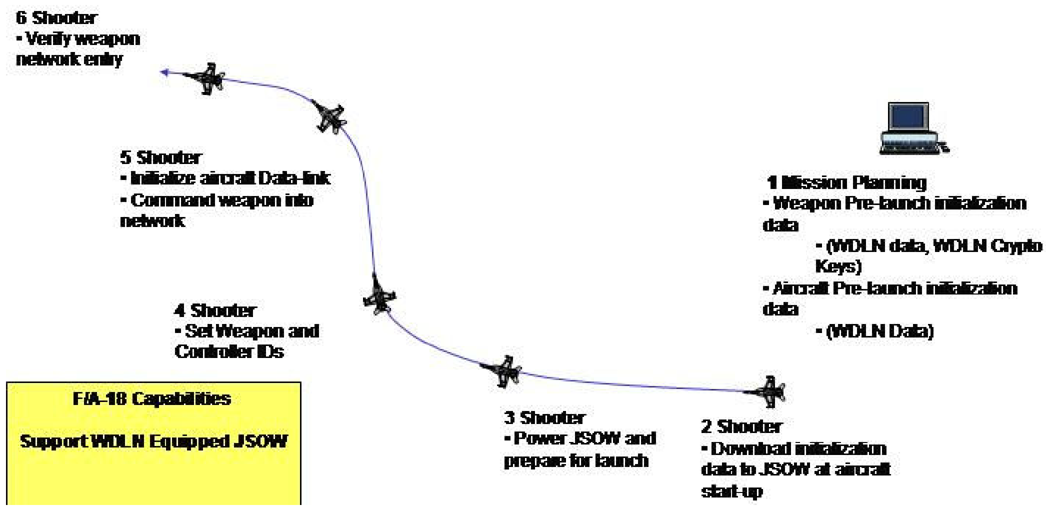
Note: CONOPS slide represent capabilities of the WDLN message set and do not represent actual aircraft flightpaths.

WDLN Communication (Arrowheads indicate direction)

Other Network Communication (Arrowheads indicate direction)

Slide 7

Pre-launch Setup (All scenarios)

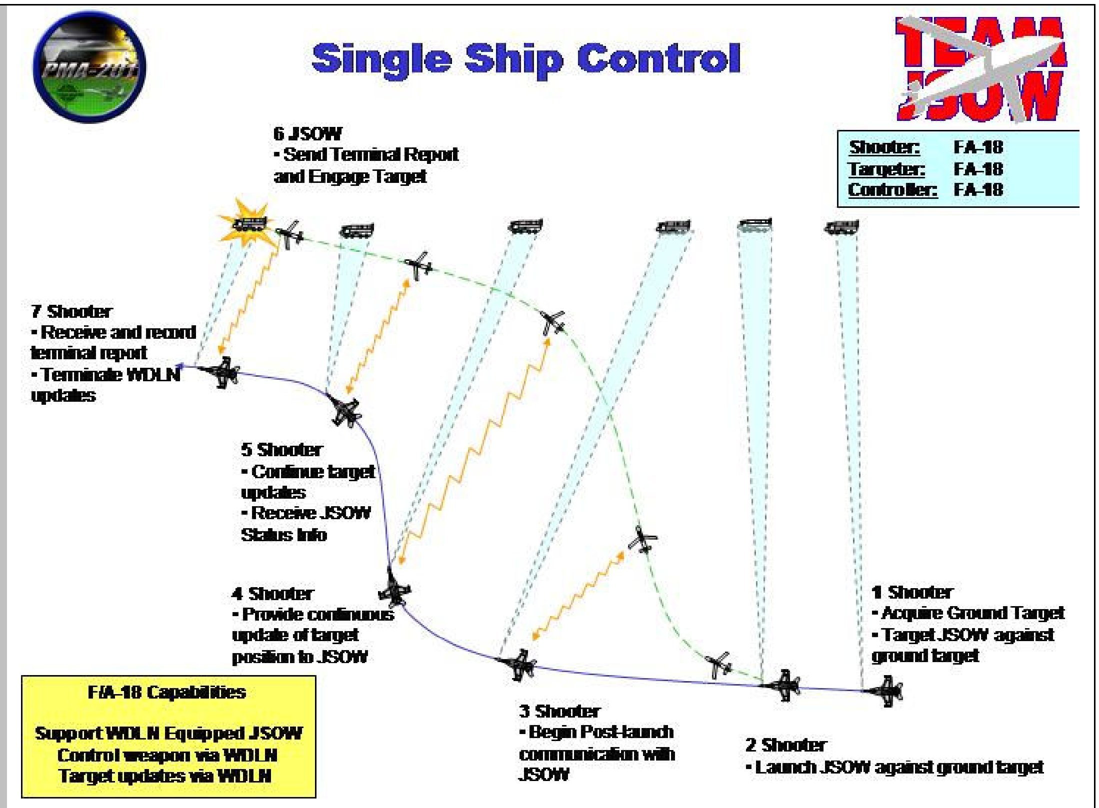


Slide 8

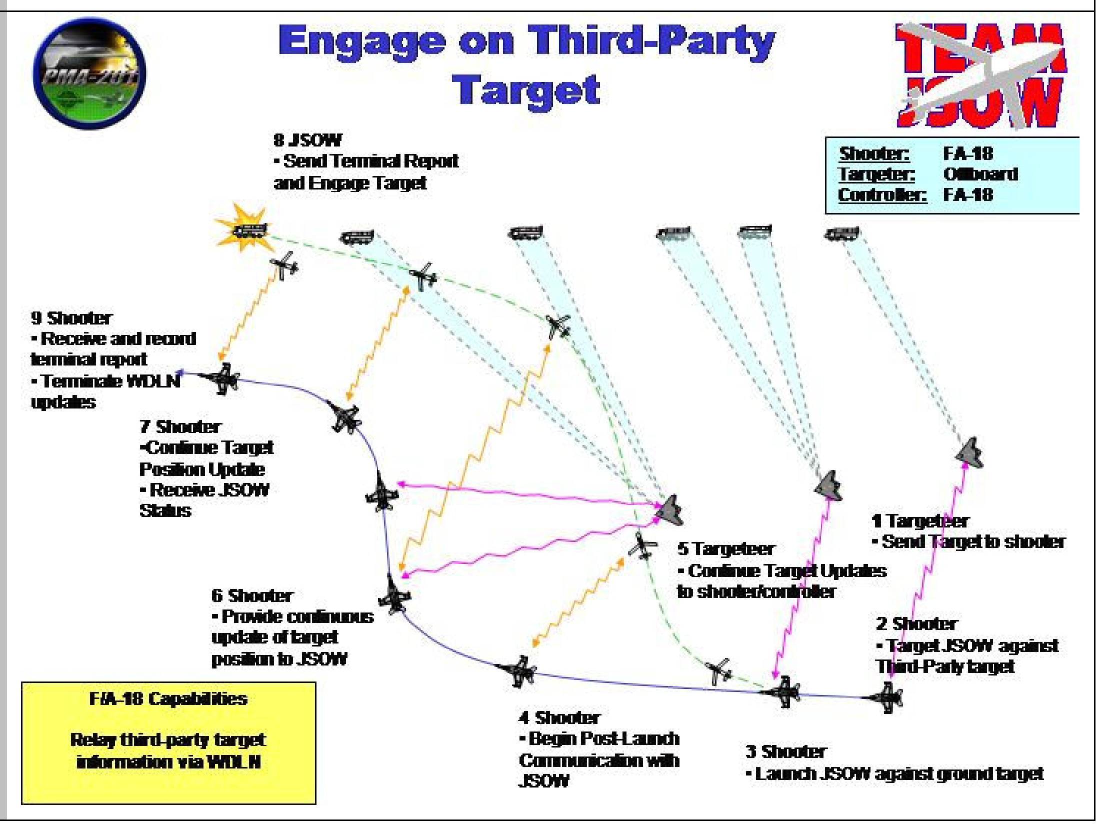
Pre-Launch Issues

- JSOW WDL Crypto type is TBD.
  - D/L weapons want to avoid Type 1 HW encryption/cost issues
  - Type 3 S/W keying (crypto loaded from mission planning is desired
- J-weapon CUPC packages WDLN Group Init files into JSOW BDF data.
- F/A-18 UPC modified to transfer larger/additional files for JSOW mission.

Slide 9



Slide 10



Slide 11

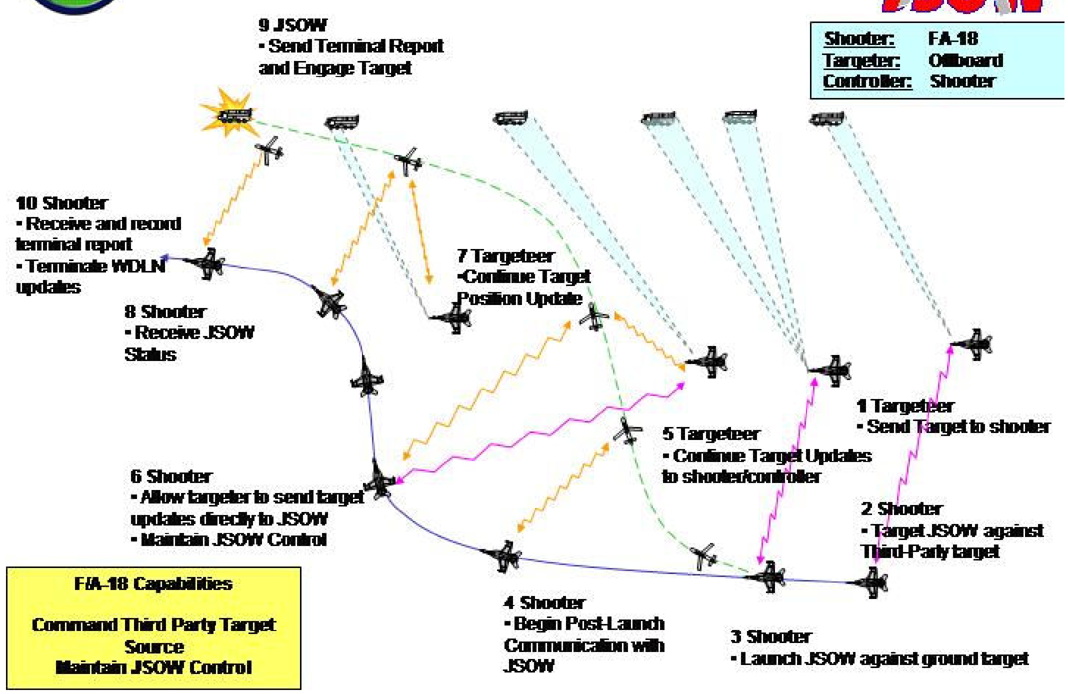
Engage on Third-Party Target

- **Offboard sensor could be UAV, JSTARS, etc**
  - No requirement to "speak" WDLN messages
  - Passes target track to shooter/controller FA-18 E/F via Link 16 or other means
- Shooter/controller relays third-party target info to JSOW
  - via WDLN messages
- Shooter/controller never requires sensor on the target
- Shooter/controller retains weapon control
  - By designating "linked" track

11

Slide 12

Third Party Target Source



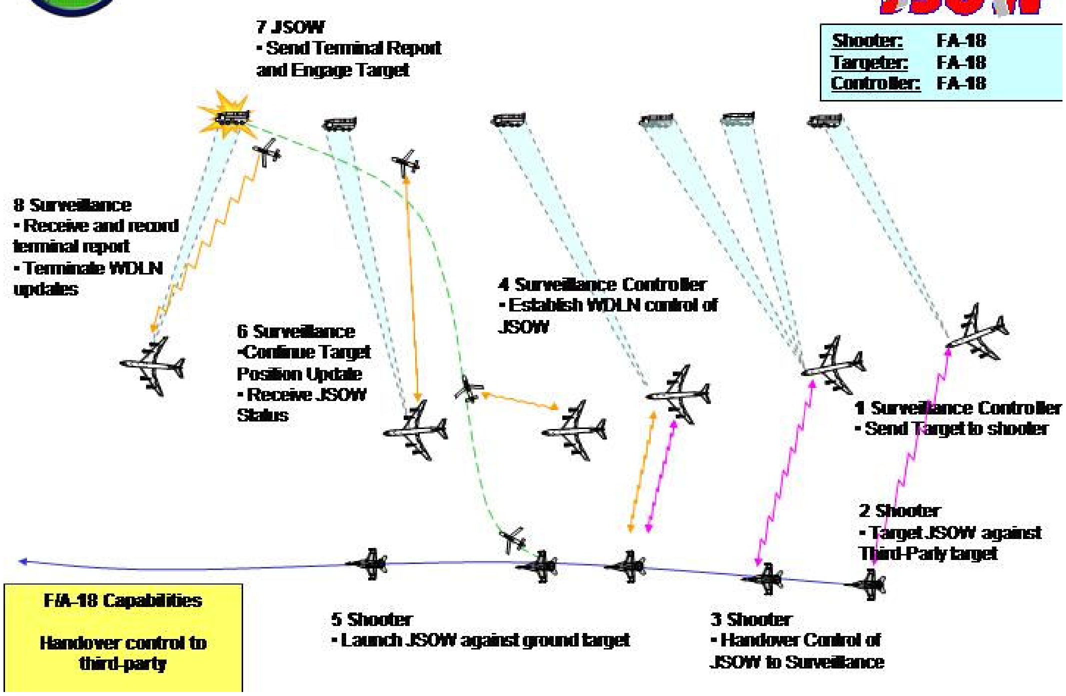
Slide 13

Third-Party Target Source

- **Assumes offboad sensor can "speak" WDLN msgs**
  - Offboard sensor provides IFTUs directly to weapon via WDLN messages
  - Initially, only a 2nd FA-18 E/F
  - Eventually, more offboard sensors such as UAV, JSTARS, etc
- Shooter/controller must "allow" this capability to a specific offboard sensor and target track
  - No other offboard sensor can "take" control
  - The designated offboard sensor can't change the target
- Shooter/controller never requires sensor on the target
- Shooter/controller retains weapon control

Slide 14

Third-Party Control



Slide 15

Third Party Control

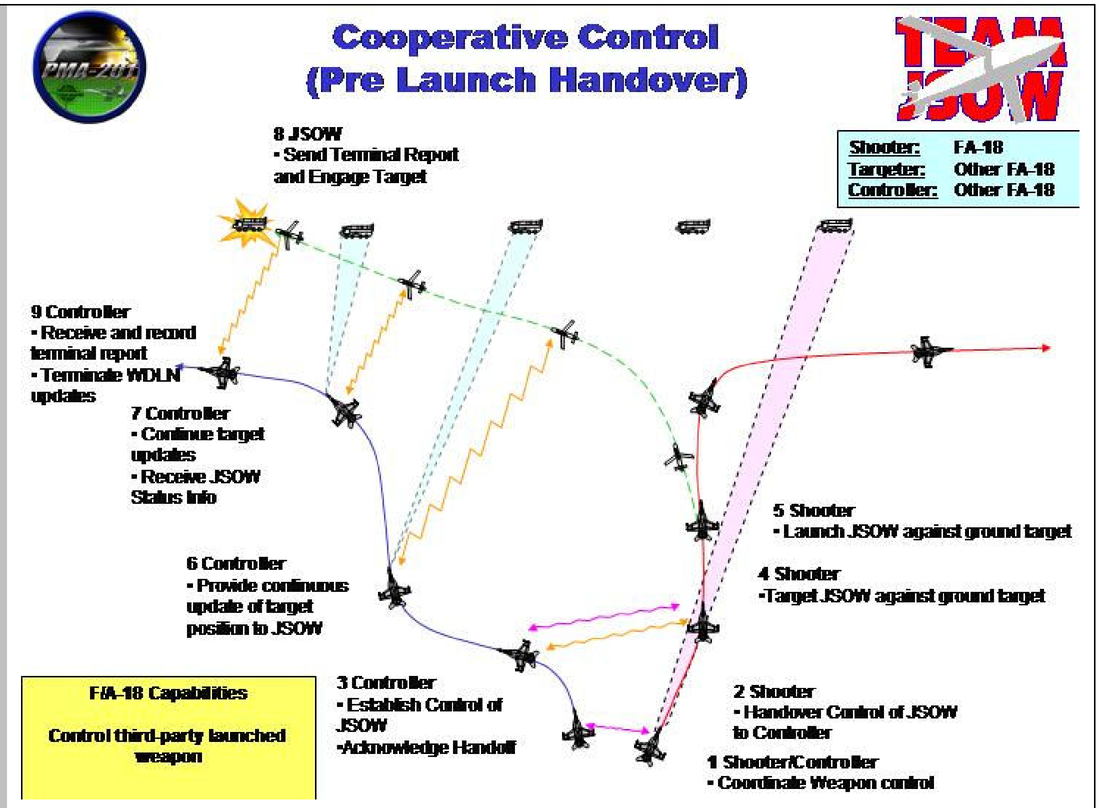
- Can be accomplished pre- or post-lauch
- Shooter/controller aircraft has to "assign" control of a specific weapon to a designated offboard sensor
  - No offboard sensor can "take" control
- Shooter no longer can influence weapon during flight
  - Effectively "launch and leave" after control handoff
- Questions:
  - CONOPS of giving weapon control over to someone other than the shooter?
    - Other FA-18 E/F or offboard sensor w/ WDLN message capability
  - How does initial handoff communication happen?
    - Voice / D/L message / Other?
    - WDLN message exists to perform handoff

Slide 16

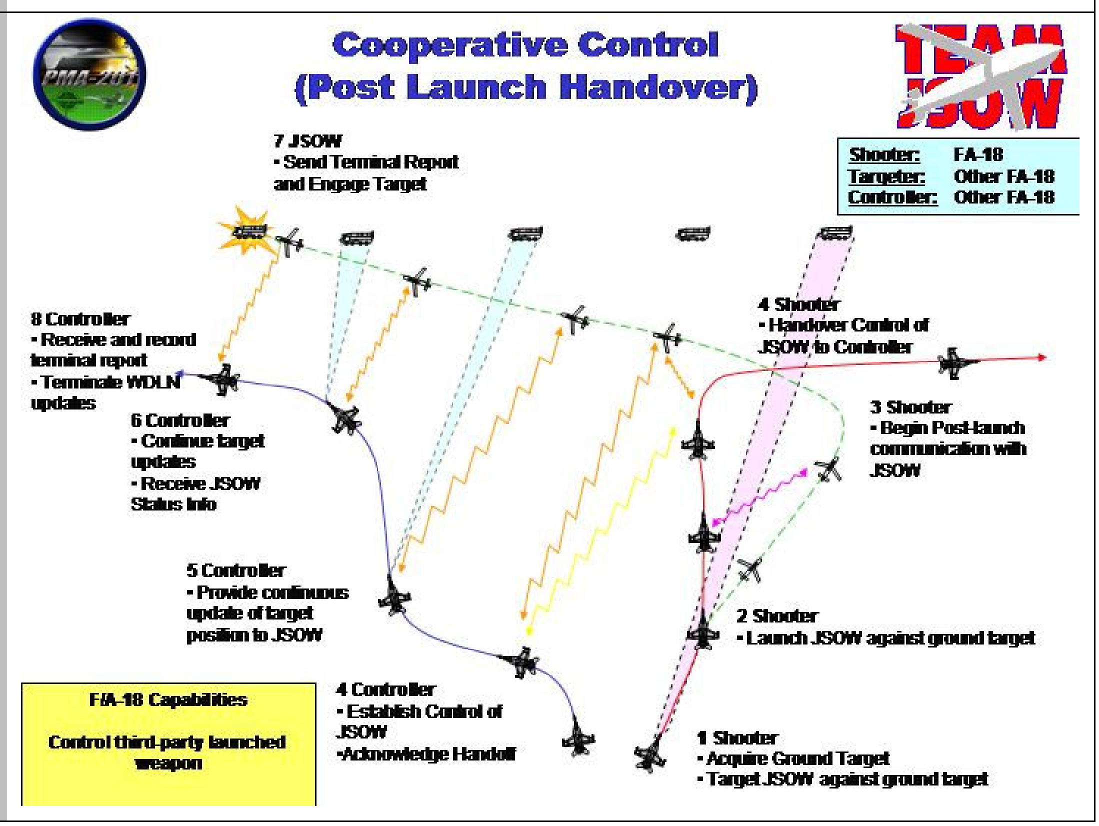
Third Party Control

- Other types of control handoffs:
  - Cooperative Control (Pre-launch)
  - Cooperative Control (Post-launch)
  - JTAC Control

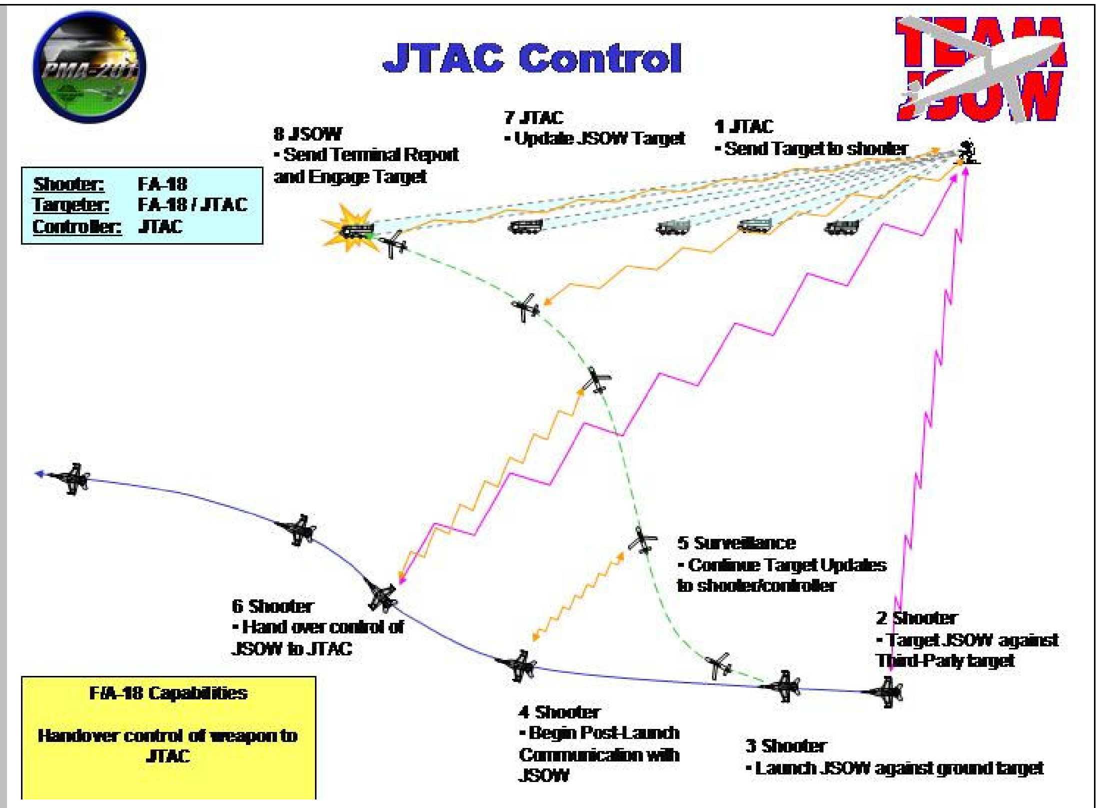
Slide 17



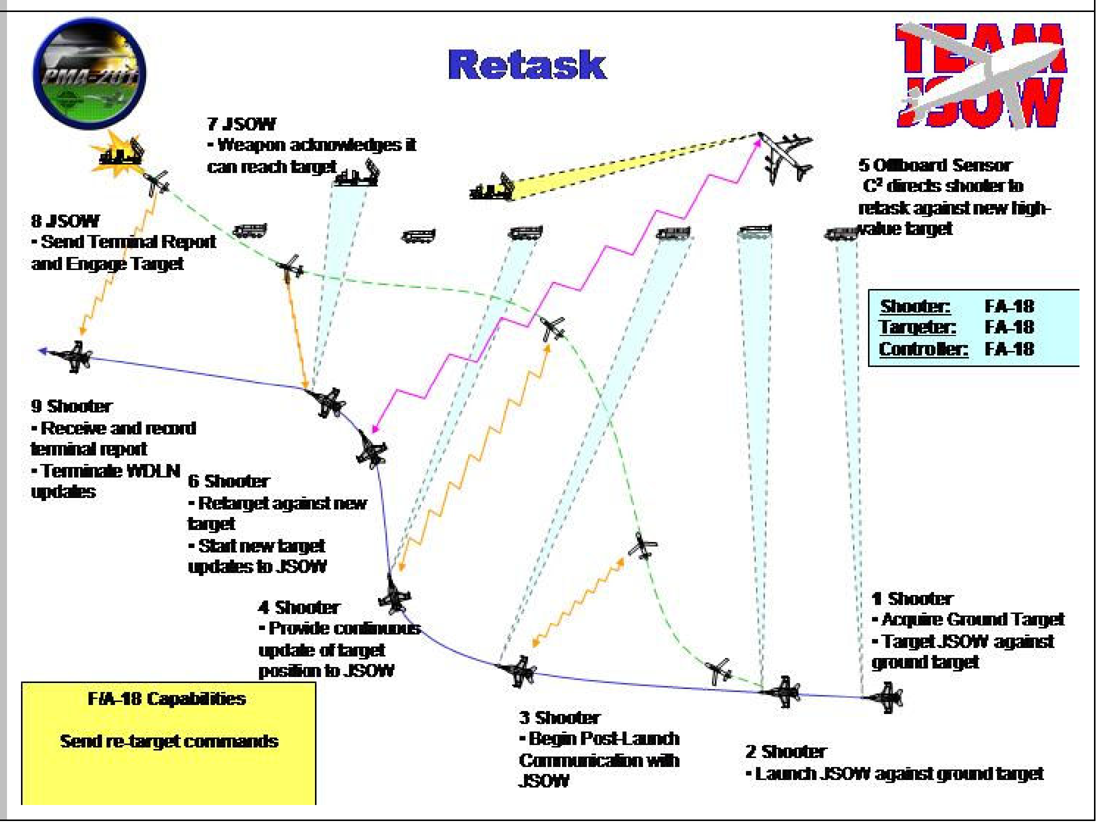
Slide 18



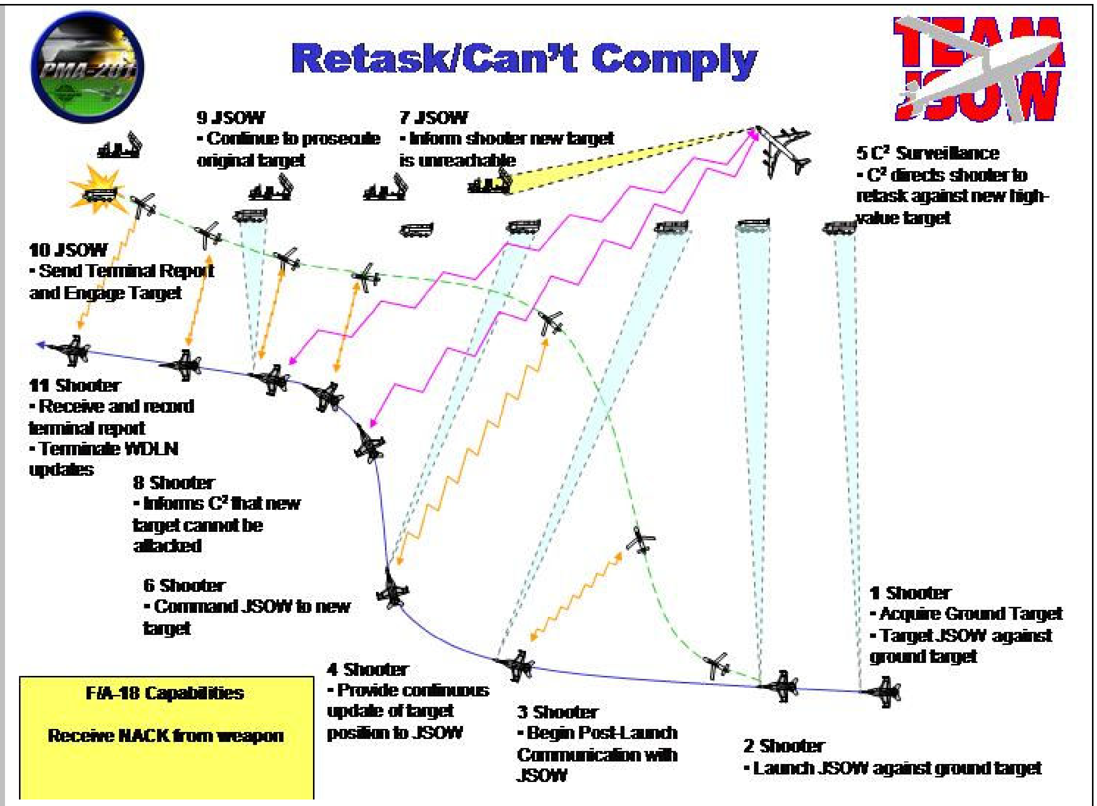
Slide 19



Slide 20



Slide 21



Slide 22

Retask

- **Assumes shooter/controller can find new target**
  - Most likely - Third-Party target source (designate Link 16 track)
  - Other: Could "handoff" weapon to the offboard sensor for same result
- WDLN Retarget Message
  - Query weapon
  - If weapon can reach new target, then weapon will prosecute new target
  - If weapon can't reach new target, will reply with "CANTCO" and continue prosecuting the current target

22

Slide 23

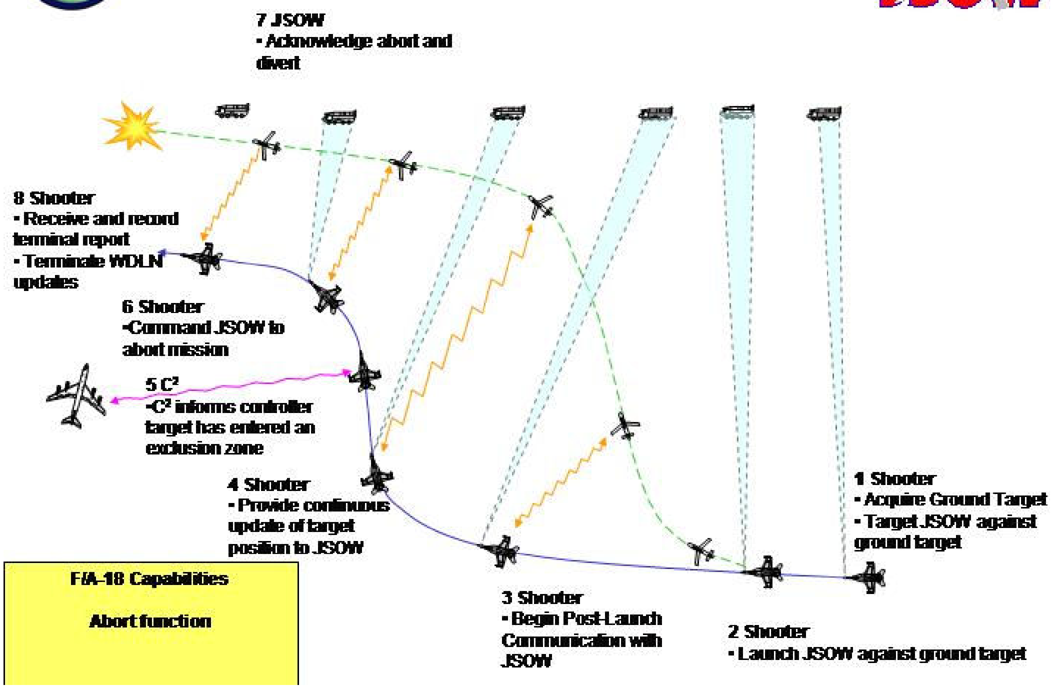
Retask

- Retask Questions:
  - Do you need to know whether weapon can reach new target?
  - Where does that calculation happen?
    - In JSOW-C
      - Current LAR NOT calculated in JSOW-C post-launch
    - Onboard FA-18 E/F
      - Display instantaneous LAR during flyout?
  - Any interest in a Footprint query message?
    - Query weapon – ask for current footprint
    - Weapon passes "simplified" LAR back to aircraft (rectangular LAR)

23

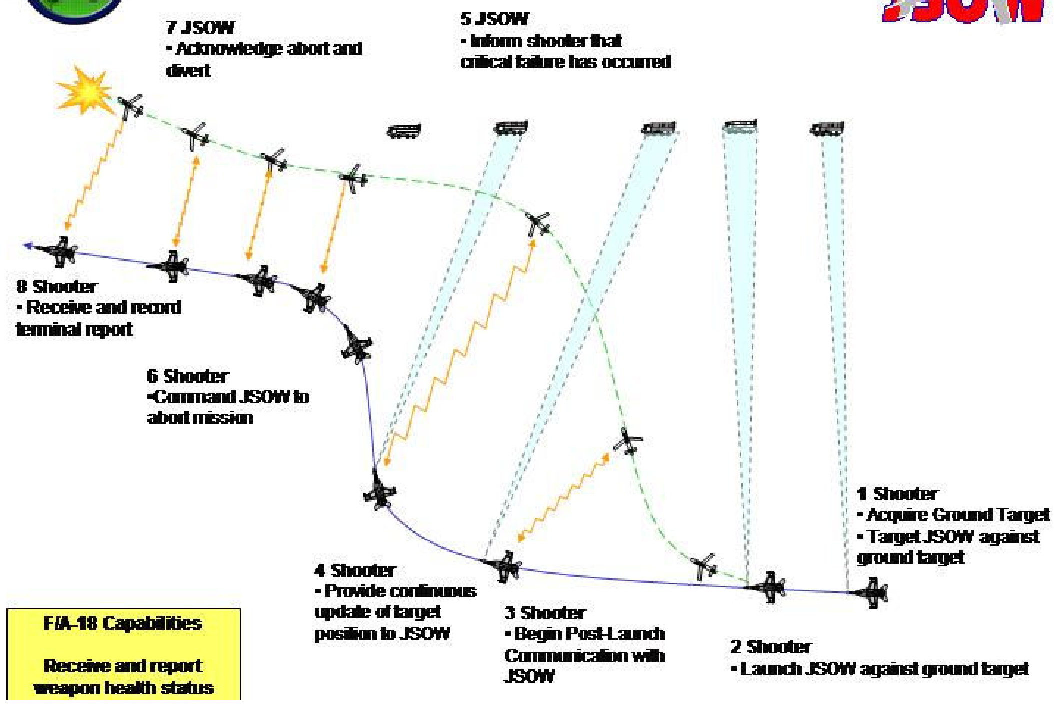
Slide 24

Abort Attack



Slide 25

Failure/Abort



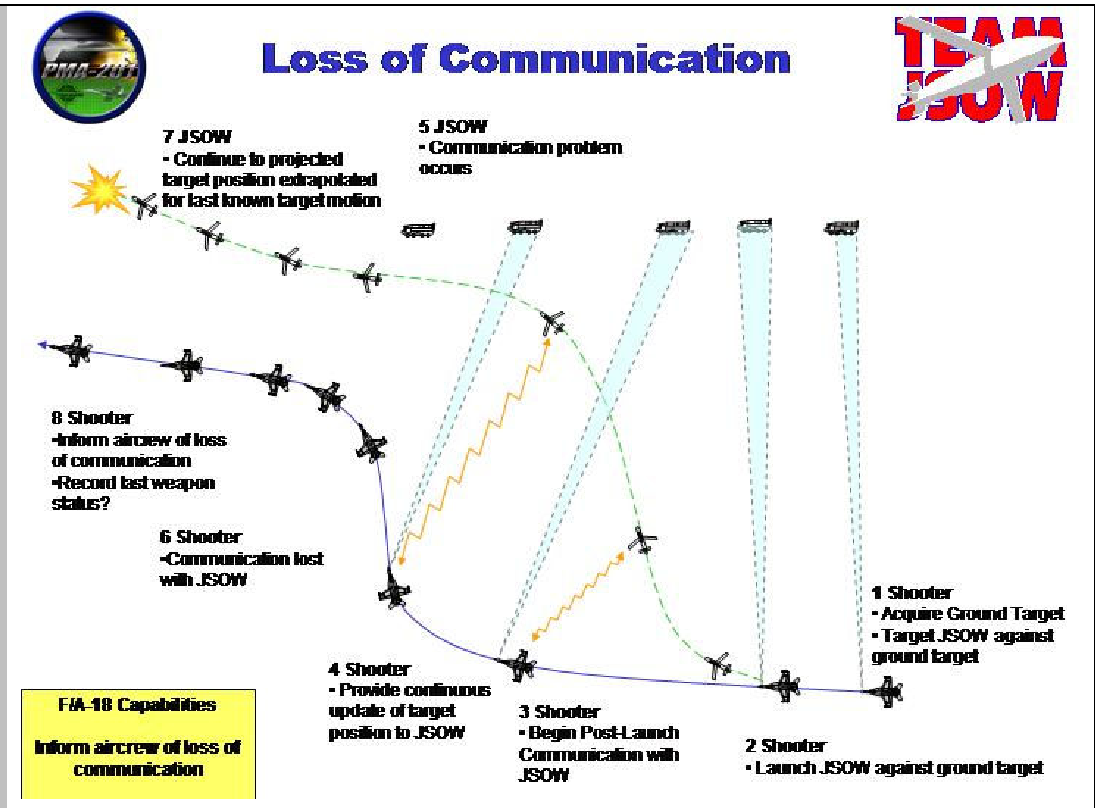
Slide 26

Abort Attack

- WDLN message Abort options:
  - Pre-planned: Fly to pre-planned abort location
    - Useful for PP missions
  - Designated: Provide abort coordinates in the Abort msg
    - How realistic?
  - Immediate: Detonate immediately
    - Not currently capable w/ JSOW-C
- Abort Questions:
  - What CONOPS authorized?
  - Why would you abort?
    - Directed by offboard controller?
    - Known weapon failure during time of flight?
    - Other?

26

Slide 27



Slide 28

Moving Target Sets

- Current study on target capabilities of JSOW seeker
  - Looking at improvements reqd to prosecute moving targets
  - Current seeker and possible improvements
- Target set categories used to bound study
  - Tried to group moving targets by target size, speed, maneuvering capability, etc
- Questions:
  - What is the required moving target set for JSOW?

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Slide 29

Moving Target Sets

Five notional Land target groups

- Large (>38 ft, transporter type vehicles)
  - SCUD, TEL, tank transporter, tractor-trailer
- Armored fighting vehicles
  - Tank, APC, etc
- Medium / Small (soft targets)
  - SA-6, truck, support vehicles, etc
- Scout (high speed)
  - HUM-V, scout, cars, light trucks, etc
- Train
  - Various length / composition

Slide 30

Moving Target Sets

- Five notional Sea target groups
  - Large warship (standard hull, >250 ft)
    - DD, FF, LST, etc
  - Small warship (standard hull, >100 ft)
    - Corvette, partrol boats, etc
  - Landing craft (barge hull)
    - LCM, etc
  - Fast attack craft (30 to 10 ft)
    - Boghammer, Zodiac, hydro-foil, "pleasure craft", etc
  - Air cushion
    - Hovercraft, etc

APPENDIX 3: F/A-18 E/F H5E WDL Cockpit Vehicle Interface Walkthrough [38]

Slide 1

H5E JSOW-C Block III System Design

The following slides are a subset of a larger brief by the above title .

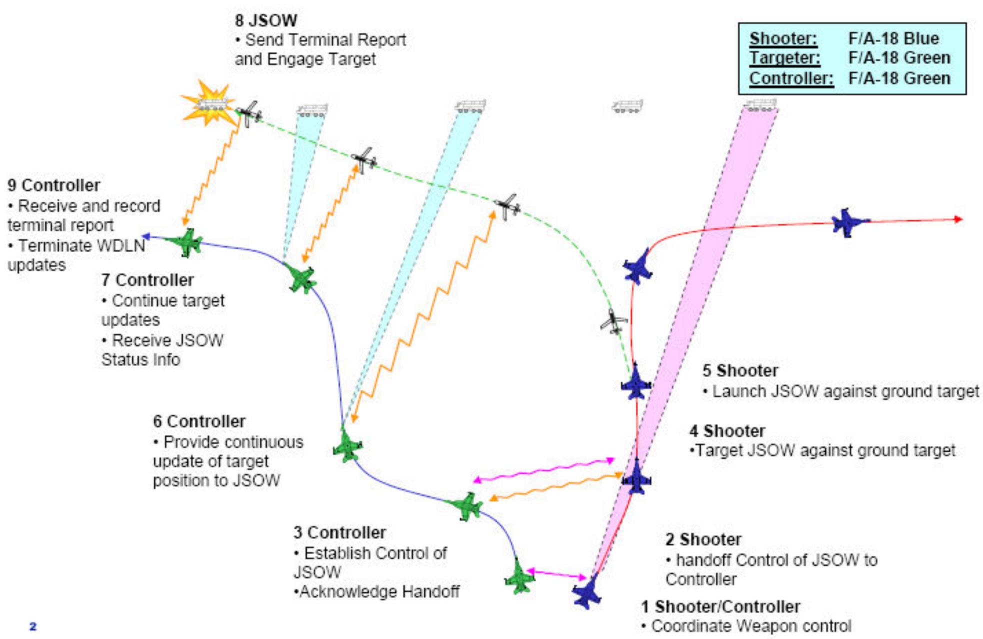
These slides depict the steps necessary to execute a cooperative control engagement between two F/A-18 E/F H5E Super Hornets. They are intended to demonstrate the H5E functionality. They are not intended for aircrew training.

Cooperative Engagement

1

Slide 2

Cooperative Control CONOPS (Pre Launch handoff)



2

Slide 3

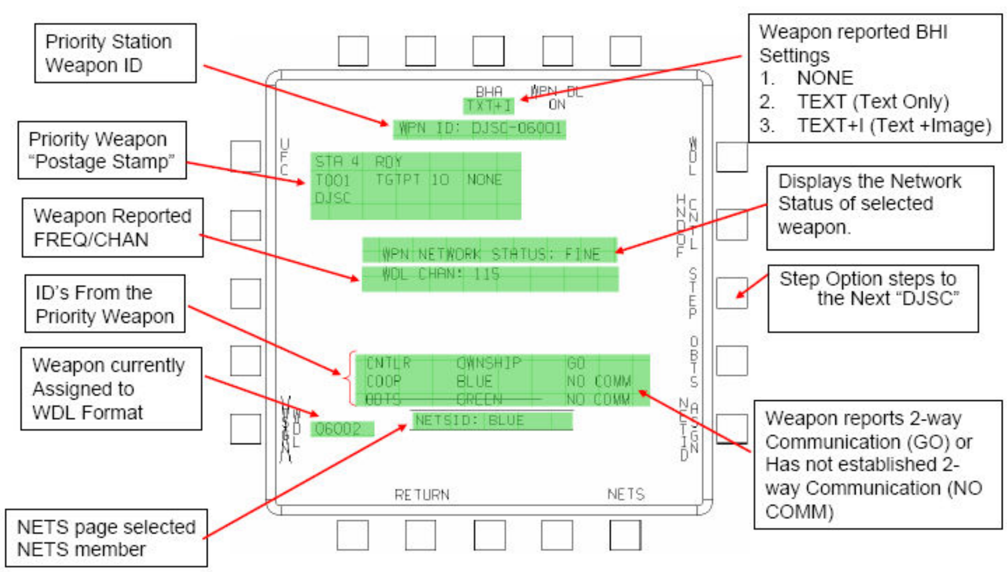
Control handoff CONOPS

- **Pre-Launch Handoff (Not pre-mission planned)**
  - **COOP controller**
    - Needs to enter shooter's weapon ID to WDL format
      - 1st option: Digital message to shooter requesting control (Accepting control will auto-set WPN ID)
      - 2nd option: Voice + Manual entry on NETS format
  - **Shooter**
    - Needs to enter COOP controller into weapon (using same option the intended controller initiates)
      - 1st option: Digital response message to coop controller with WPN ID (Accepting coop request sets COOP to requester's ID)
      - 2nd option: Voice + Manual entry on NETS format
      - Using either option, the shooter must execute the handoff by selecting HNDOF CNTRL

3

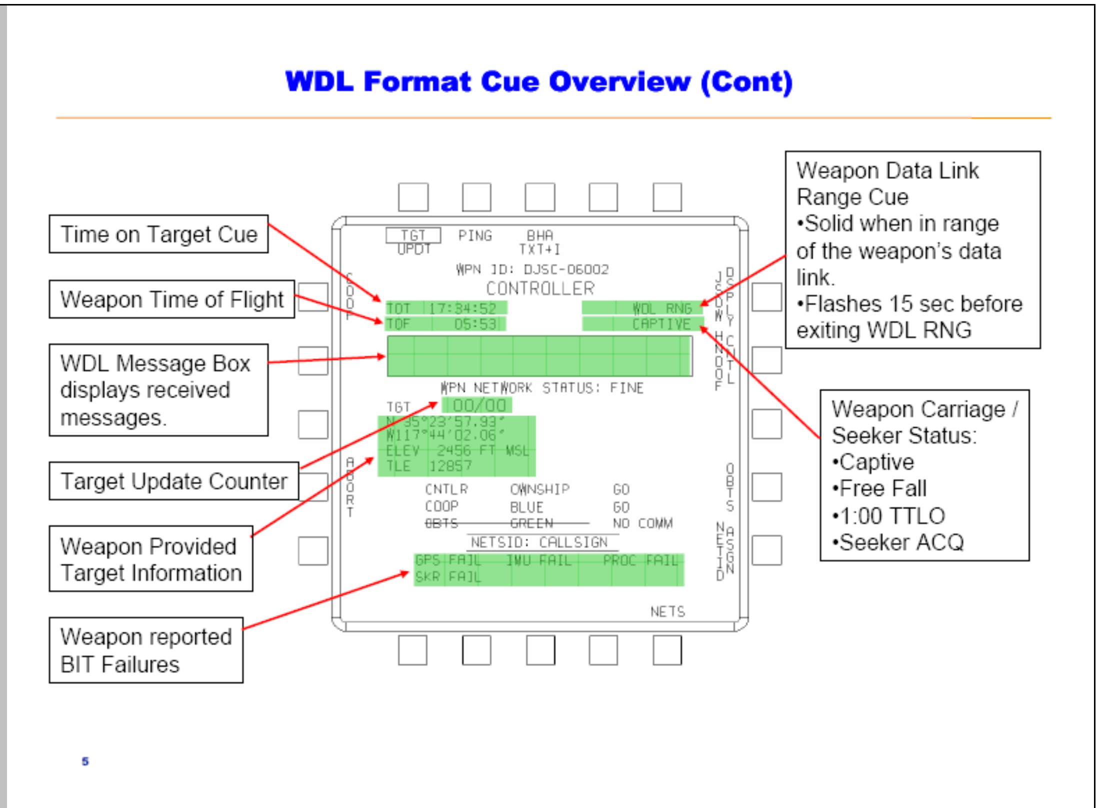
Slide 4

JSOW WDL Setup Format Cues

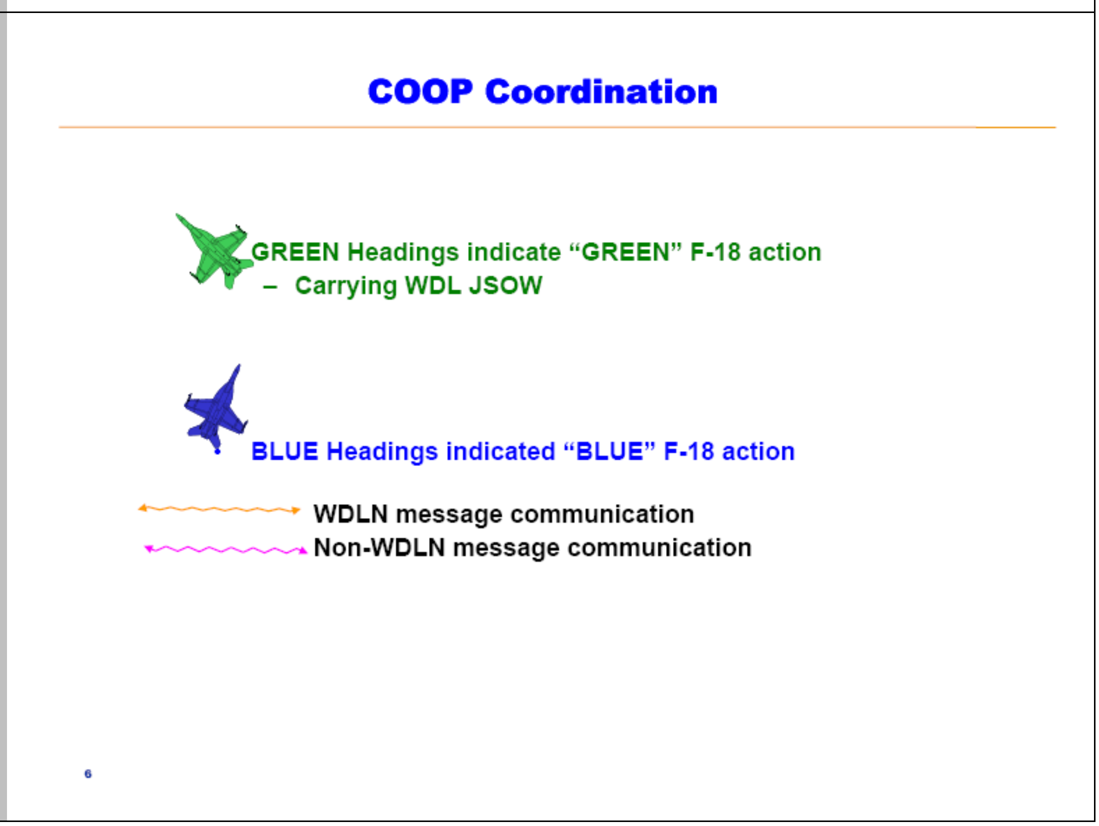


4

Slide 5



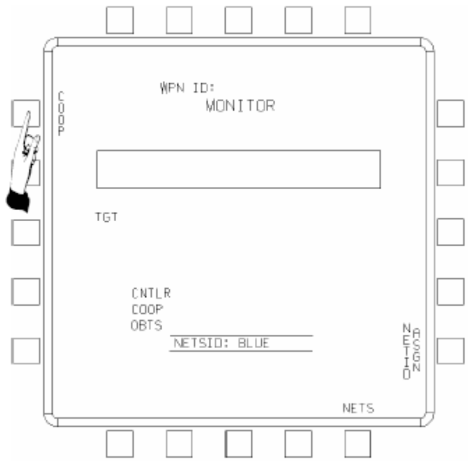
Slide 6



Slide 7

WDL Format – MONITOR

Green is the intended controller and desires to request control of Blue's weapon. The digital process is initiated on the WDL format by Green pressing COOP.



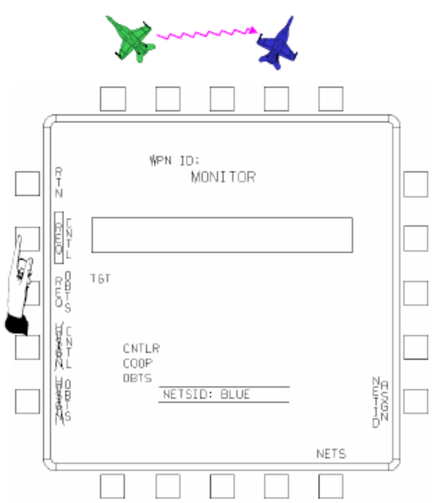
- WDL Format Options when not Controlling or providing Target updates to a weapon.
- Green was briefed Blue's NetID and entered it in the NETS page on deck. NETSID is set to Blue.

7

Slide 8

WDL Format – COOP Options

Green has pressed COOP and is now presented with the COOP options. Green does not have a weapon so ASGN CNTL/OBTS are X'd out.



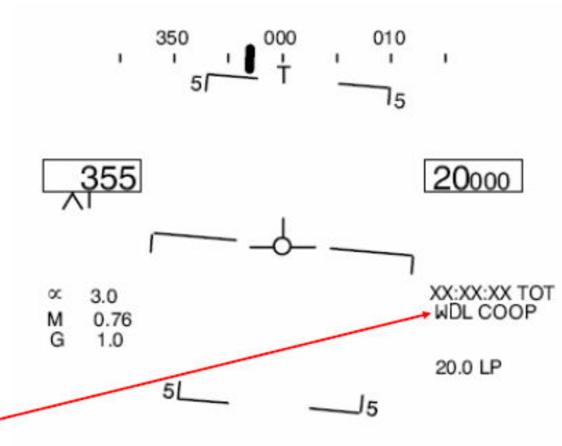
- These options initiate the digital message transfer to the Selected NETS member.
- Sends a Request to control a weapon to the selected NETS ID
- COOP Options of:
  - RTN – Return with no action
  - REQ CTRL – Request Control
  - REQ OBTS – Request to be an OBTS
  - ASGN CTRL – Assign control to a 3RD party Controller
  - ASGN OBTS – Assign someone to be an Off Board Target Source
- COOP option will return once message is sent

8

Slide 9

HUD – WDL COOP

Blue is receiving Green's message and being alerted in the HUD



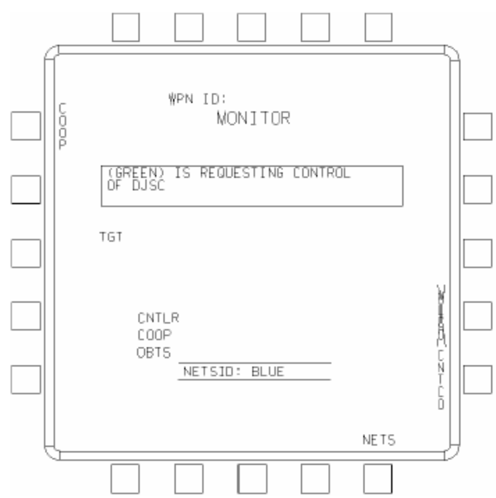
- WDL COOP is flashed in the HUD when a WDL message is received

9

Slide 10

WDL Format – COOP WILCO

Blue has received Green request on the WDL format and now has the option to WLCO or CNTCO



- WDL Format with No weapon selected and a Request for Handoff.
- WILCO will remain X'd out until a DJSC is prepared for Handoff

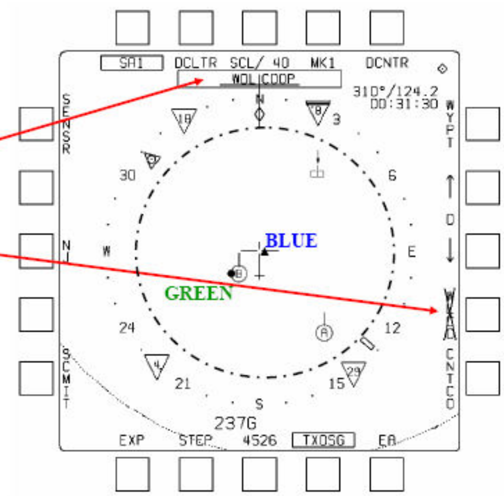
10

Slide 11

SA Format – COOP WILCO

Blue also receives notification and the option to WLCO or CNTCO on the SA Format. Note Blue is ownship in this picture and depicted by ✢

- "WDL COOP" is shown on the SA format.
- WILCO is X'd out until a DJSC is prepared for Handoff.



11

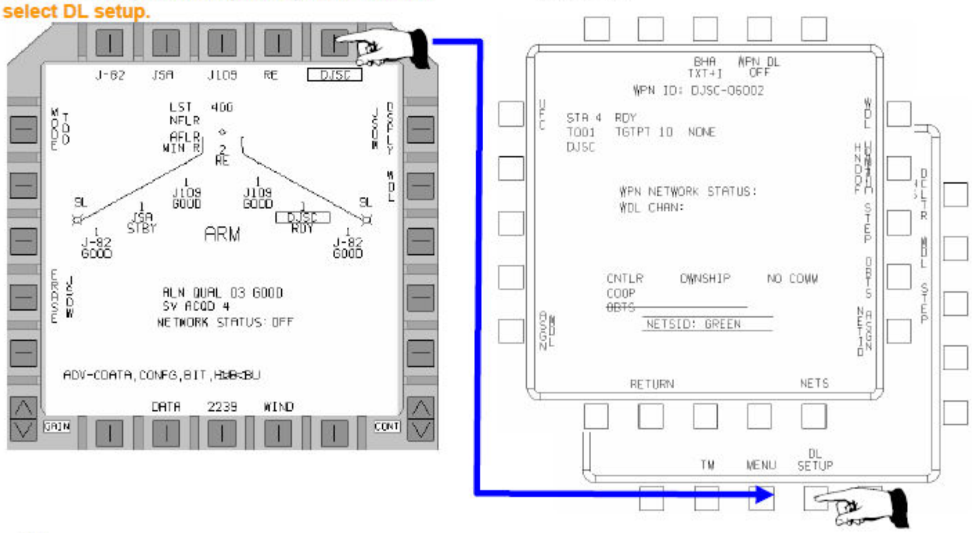
Slide 12

Store Format -Select DJSC

Blue selects DJSC from the Stores Format to initialize the weapon and enable the WLCO option. Selecting DJSC will automatically switch to the JSOW format (underlain picture), then Blue will select DL setup.

JSOW DL Format – Initial Setup

- DL initialized to "OFF"
- NETSID is the selected NETS page Member.



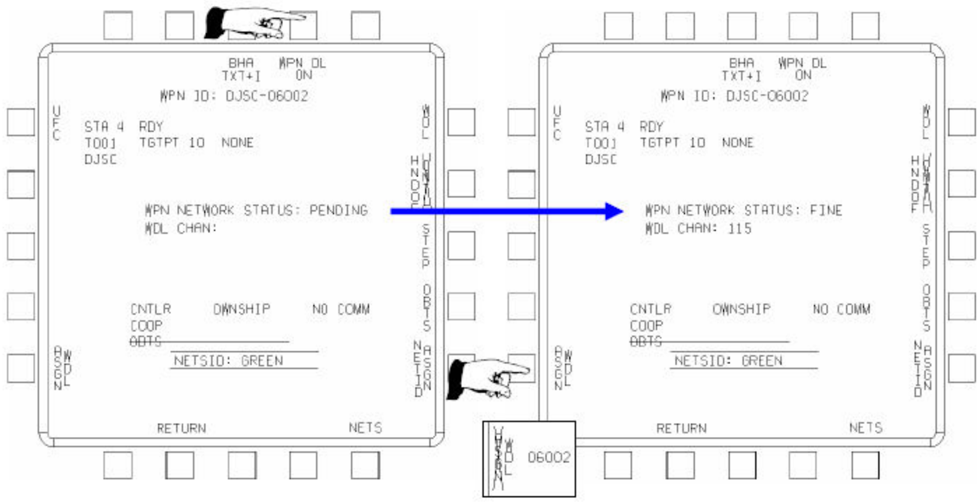
12

Slide 13

JSOW DL Setup – Turn on DL

Blue presses WPN DL ON and waits for the WPN NETWORK STATUS to indicate PENDING. Once the weapon synchronizes to the network, the status will indicate FINE and the WDL CHAN will be displayed.

Once the weapon is in the network, it must be assigned to the WDL format using the ASGN WDL function. NOTE: If there is already a weapon assigned to the WDL format this option will be X'd out and display the WPN ID of the assigned weapon.

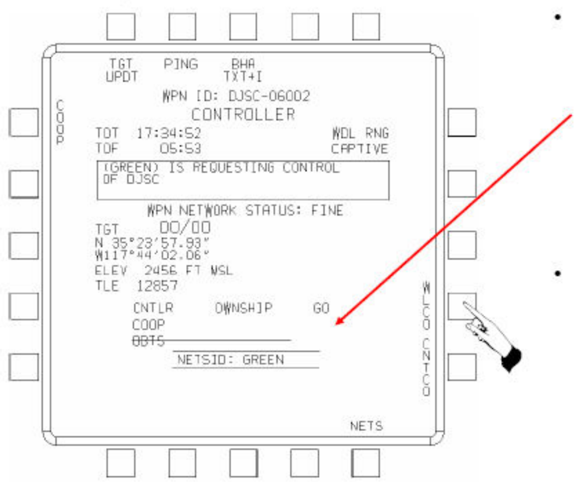


13

Slide 14

WDL Format – COOP WILCO

Blue has now returned to the WDL format and the WLCO function has enabled. Ownship communication with the weapon has been automatically initiated and is confirmed by the GO next to ownship.



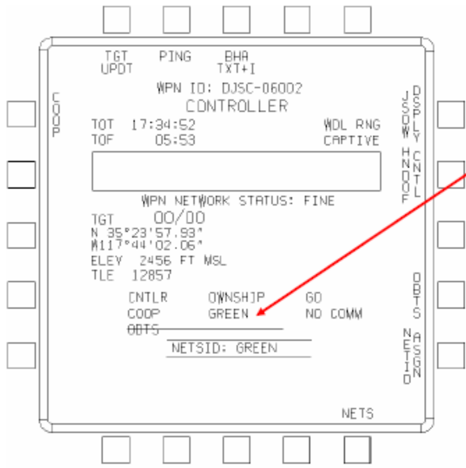
- Selection of WILCO automatically sets COOP to "GREEN".
  - A WILCO uses the information sent in the WDL message. NOT the NETSID
- WILCO will also send a message containing the WPN ID and Freq/Channel to the Requester.

14

Slide 15

WDL Format – POST WILCO

Blue has selected WLCO and the normal options return to the right side of the display.



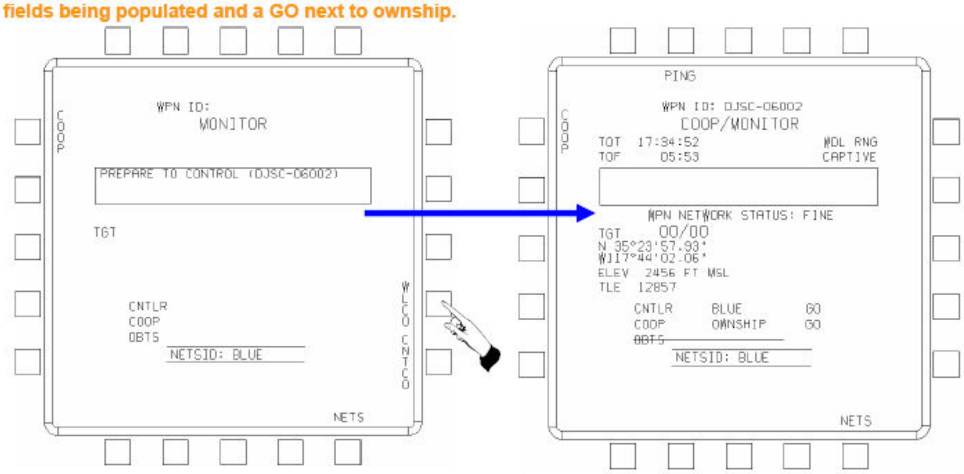
- Following a WILCO the COOP ID will be updated to the new COOP ID.
  - Handoff will not occur until HNDOF CNTL is selected.

15

Slide 16

WDL Format – COOP WILCO

Green has received Blue's WLCO message. When Green selects WLCO, the WPN ID field will be set to the weapon ID sent in Blue's message. The weapon will initiate an automatic check-in with the COOP controller. Its completion is signified by the WDL fields being populated and a GO next to ownship.

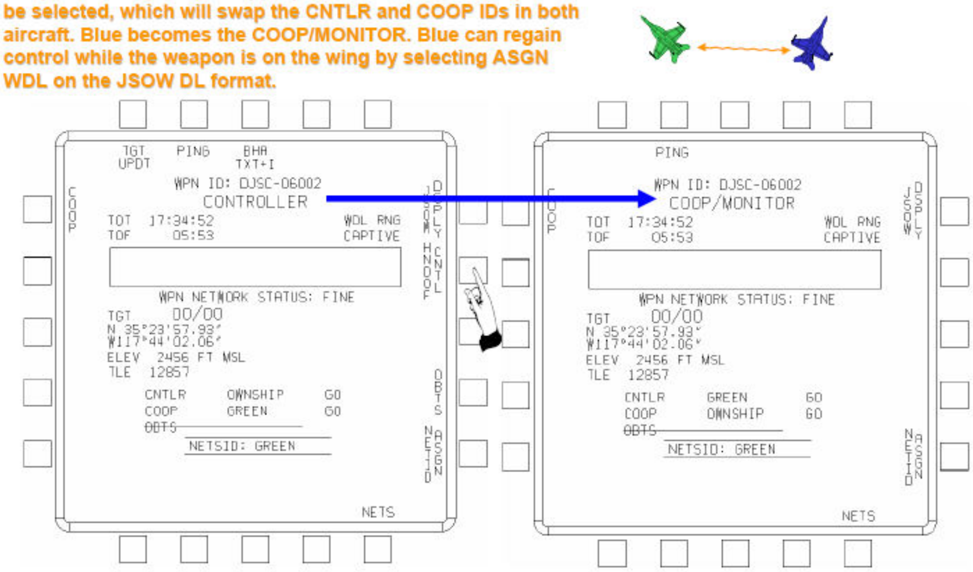


16

Slide 17

WDL Format – Handoff Control

Blue is now one button push away from giving control of the weapon to Green. At the appropriate time, HNDOF CNTL can be selected, which will swap the CNTLR and COOP IDs in both aircraft. Blue becomes the COOP/MONITOR. Blue can regain control while the weapon is on the wing by selecting ASGN WDL on the JSOW DL format.

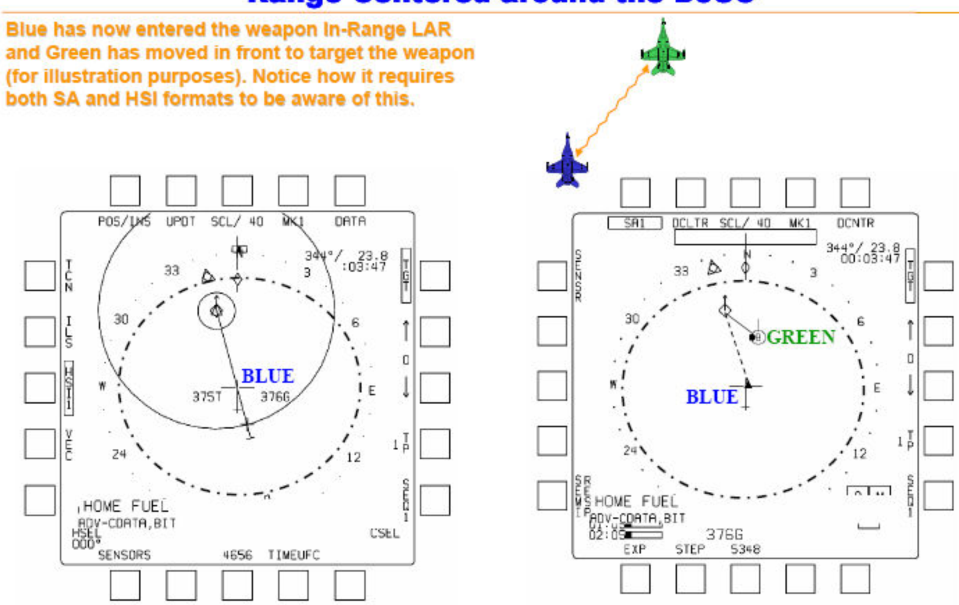


17

Slide 18

HSI and SA Format – Pre-Launch with the WDL In-Range Centered around the DJSC

Blue has now entered the weapon In-Range LAR and Green has moved in front to target the weapon (for illustration purposes). Notice how it requires both SA and HSI formats to be aware of this.

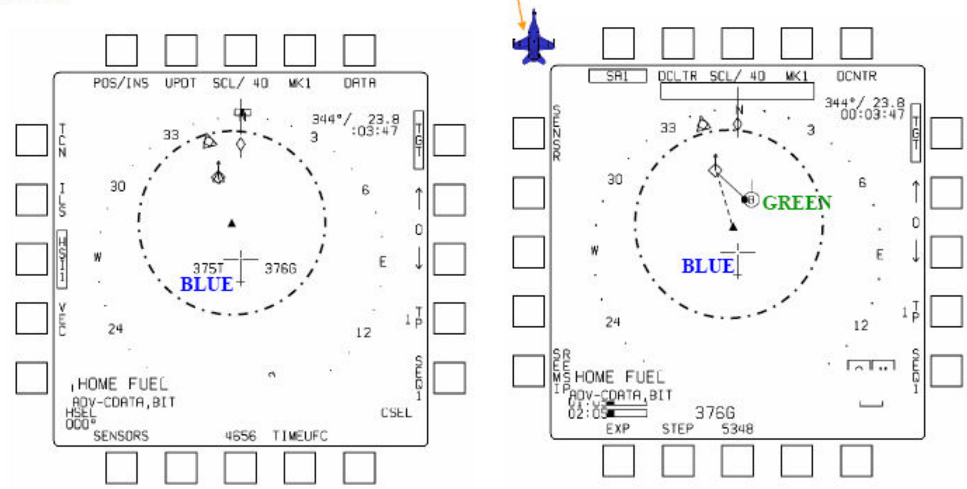


18

Slide 19

HSI and SA Format – Post-Launch with the WDL In-Range Centered around the DJSC

Blue has launched the weapon and it is now being guided by Green's IFTUs. Blue may only monitor the weapon at this point unless Green gives control back, which Green can by simply pushing HNDOF CNTRL.

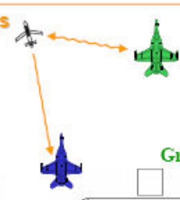


19

Slide 20

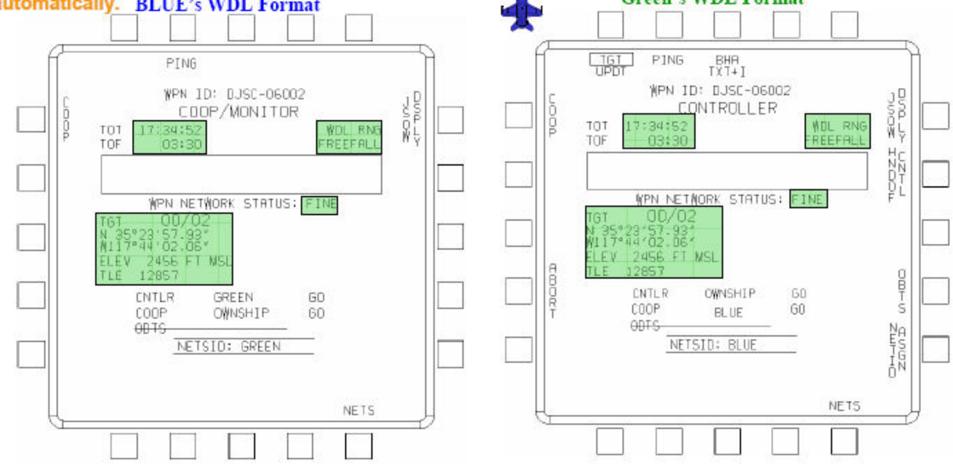
WDL Format – Post-Launch

The weapon is in-flight. The respective WDL formats are shown for each aircraft. Notice Green has the TGT UPDT option and the other control functions; all of which are missing from Blues display. Blue does retain the ability to PING the weapon if desired, but both see the WIFT information update automatically.



BLUE's WDL Format

Green's WDL Format



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VITA

Kyle T. Turco was born on October 30th, 1971 in Beeville, TX. He spent his early childhood bouncing around between different Naval Air Stations (NAS) while his father served his country as a Naval Aviator. Then, Kyle's family returned to their home in Montana where he graduated from Fergus County High School in 1989. Immediately after his high school graduation, he report to the United States Naval Academy to join the Class of 1993. While attending the Naval Academy, Midshipmen Turco was selected for the prestigious Trident Scholar Program, which enabled him to spend his senior year conducting independent research in fluid dynamics and computer aided design. In May of 1993, he graduated with honors as a Distinguished Graduate, and received a Bachelor of Science degree in Ocean Engineering. Ensign Turco then reported to the Naval Aviation Training Command for flight school. While there, he was earned his Wings of Gold in October of 1995 and was selected for F/A-18 training in Lemoore, CA. After completing his training at NAS Lemoore, he was assigned to the VFA-115 Eagles and deployed aboard the USS Abraham Lincoln to the Persian Gulf in support of Operation Southern Watch. In 1999, Kyle's next assignment took him to VMFAT-101 in San Diego, CA to serve as an F/A-18 C/D strike fighter instructor with the Marine Corps' Sharpshooters. While instructing at VMFAT-101, he was selected as a Test Pilot School (TPS) candidate. However, the needs of the Navy required him to serve at sea prior to attending TPS. In August 2001, he was assigned to the USS John C. Stennis as a Tactical Action Officer and was an augment pilot for Carrier Air Wing Nine, which deployed in October 2001 in response to the events of September 11th. Following an eight month

combat deployment to the Northern Arabian Sea, Lieutenant Turco received orders to attend the United States Air Force Test Pilot School at Edwards Air Force Base as the Navy's exchange officer for Class 03A. While attending TPS, Kyle married his lovely wife Lisa, whom he had met while stationed in San Diego, CA. After TPS graduation, he was assigned to Air Test and Evaluation Squadron Three-One (VX-31), which is located at the Naval Air Weapons Station, China Lake, CA. Kyle serves as the VX-31 Weapon System Test and Evaluation Coordinator and as the JDAM / JSOW Project Officer for PMA-201. It is in this position that he serves as a member of the JSOW Block Three program. He is also a member of the F/A-18 E/F H5E Software Requirements team for JSOW. In this capacity, Lieutenant Commander Turco was selected as the 2005 VX-31 Test Pilot of the Year and awarded his third Navy Achievement Medal. He recently transitioned career fields to serve as an Aerospace Engineering Duty Officer, where he will pursue a career in the Naval Aviation Enterprise as an acquisition, test and evaluation, and program management specialist. Throughout his career, he has been awarded a number of accommodations including the Strike Flight Air Medal, 2 Navy Commendation Medals, 3 Navy Achievement Medals, and various others. LCDR Turco has accumulated over 2,300 flight hours and has flown over 30 aircraft types to date.