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Proposed improvement of system status displays for the F/A-18E/F Super Hornet aircraft

Peter Wilcox Matisoo

To the Graduate Council:

I am submitting herewith a thesis written by Peter Wilcox Matisoo entitled "Proposed improvement of system status displays for the F/A-18E/F Super Hornet aircraft." 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.

Peter Solies, Major Professor

We have read this thesis and recommend its acceptance:

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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U. Peter Solies

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We have read this dissertation
and recommend its acceptance:

Alfonso Pujol Jr

Charles T.N. Paladan

Jack H. Hansen

Accepted for the Council:

[signature]

Associate Vice Chancellor and
Dean of The Graduate School

PROPOSED IMPROVEMENT OF SYSTEM STATUS DISPLAYS FOR THE F/A-18E/F *SUPER HORNET* AIRCRAFT

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Peter Wilcox Matisoo
August 1999

DISCLAIMER

The data, conclusions, and recommendations contained in this thesis are the result of simulator and flight evaluation of the F/A-18E/F *Super Hornet*. The deficiencies and enhancements represent the opinion of the author and may or may not represent the official position of the F/A-18 Advanced Weapons Laboratory, the Naval Air Systems Command, or the United States Navy.

ACKNOWLEDGEMENTS

The author would like to thank the engineers and aircrew at the Advanced Weapons Laboratory, China Lake, California for their assistance and guidance. Special thanks go to my wife Michele and children Andrew, Connor, and Christian for their love, patience and support during many hours of study.

ABSTRACT

The gradual decline in Department of Defense weapons procurement dollars combined with increased weapon system costs has lead to reduced purchases of new tactical aircraft. In an effort to reduce costs and become more efficient, the services have chosen to procure multi-role tactical fighter aircraft. Each new aircraft takes the place of two or more single-mission, previous generation aircraft and the missions they performed. The modern multi-role aircraft, such as the F/A-18 Hornet and the F-15E Strike Eagle, are tasked with execution of numerous Air-to-Ground (A/G), Air-to-Air (A/A), and Suppression Of Enemy Air Defenses (SEAD) missions. These aircraft utilize complex weapon and sensor suites, though specific weapon and sensor requirements vary widely from mission to mission.

The weapon and sensor suites of modern, multi-role tactical fighter aircraft consist of both offensive and defensive systems. The status of these systems must be assessed prior to flight to determine if the aircraft is fully capable to execute the mission tasking. Equipment Built-In Test (BIT) can provide detailed information to the aircrew as to system status, but this information is frequently difficult to interpret. System health information must be presented in a manner which will allow aircrew to make a critical GO / NO GO decision. BIT information should detail performance of each weapon or sensor function critical to mission

execution. The BIT information also must be available in a timely fashion, particularly for United States Navy aircraft who operate under strict time constraints which limit time available to diagnose system degrades and failures.

This paper provides specific recommendations to improve the display of weapon and sensor status information in the F/A-18E/F Super Hornet aircraft. BIT display formats are modeled around the most recent FA-18 System Configuration Set (SCS), and apply to weapons and sensors carried on that platform. The goal of the display format improvements is to provide aircrew with timely presentation of weapon and sensor health in such a way that they can make educated GO / NO GO decisions. Information in this paper is UNCLASSIFIED, EXPORT CONTROLLED.

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LIST OF FIGURES

LIST OF ABBREVIATIONS

A/A	Air-to-Air
A/G	Air-to-Ground
AGM	Air-to-Ground Missile
AGR	Air-to-Ground Ranging
AI	Airborne Interceptor
AIM	Air Intercept Missile
AMRAAM	Advanced Medium-Range Air-to-Air Missile
ANFLR	Advanced Navigation Forward Looking Infra-Red
ASR	Advanced Special Receiver
ATFLIR	Advanced Targeting Forward Looking Infra-Red
AVMUX	Avionics Multiplex Bus
BIT	Built-In Test
BVR	Beyond Visual Range
CMWS	Common Missile Warning System
CR	Countermeasures Receiver
DCS	Digital Communication Suite
DWNLD	Download
ECM	Electronic Counter-Measures
ECU	Electronic Control Unit
EFD	Engine-Fuel Display
EO	Electro-Optic
EW	Electronic Warfare
F/A	Fighter / Attack
F2	Second F/A-18F aircraft produced
F4	Fourth F/A-18F aircraft produced
FMC	Full Mission Capable
FOTD	Fiber-Optic Towed Decoy

GHz	Giga Hertz
GPS	Global Positioning System
HOTAS	Hands-On Throttle And Stick
HUD	Heads-Up Display
IBIT	Initiated Built-In Test
IDECM	Integrated Defensive Counter-Measures
IMU	Inertial Measurement Unit
IR	Infra-Red
JSOW	Joint Stand-Off Weapon
LRU	Line Replaceable Unit
MC1	Mission Computer One
MC2	Mission Computer Two
MCL	Master Caution Light
MCT	Master Caution Tone
MDI	Multi-purpose Display Indicator
MIL-STD	Military Standard
MPCD	Multi-Purpose Color Display
MSP	Maintenance Status Panel
MUX	Multiplex
NAVFLIR	Navigation Forward Looking Infra-Red
NMC	Non-Mission Capable
OFP	Operational Flight Program
OOB	Order Of Battle
PBIT	Periodic Built-In Test
PMC	Partial Mission Capable
PVU	Precision Velocity Update
RADAR, RDR	Radio Detection and Ranging
RBGM	Real Beam Ground Map
RF	Radio Frequency

RFCM	Radio Frequency Counter-Measures
RFTF	Radio Frequency Tunable Filter
RWR	Radar Warning Receiver
SAM	Surface-to-Air Missile
SCS	System Configuration Set
SEAD	Suppression of Enemy Air Defenses
SES	Self-Escort Strike
SPCL	Special (Built-In Test viewing)
SRA	Shop-Replaceable Assembly
SSDD	System/Segment Design Document
SUPT	Support
TAC INFO	Tactical Information
TG	Techniques Generator
UFCD	Up-Front Control Display
USAF	United States Air Force
USN	United States Navy
UV	Ultra-Violet
WDEGD	Weapon Degrade
WFAIL	Weapon Fail
WRA	Weapon Replaceable Assembly

1.0 INTRODUCTION

Monitoring and reporting of the status of aircraft systems is essential for today's complex fighter aircraft. It is neither practical nor desirable to require aircrew to perform an airborne evaluation of the health of various aircraft systems in a combat situation. Every effort must be made to ensure aircraft are launched only when systems are performing within nominal tolerances or mission success rates will be sacrificed and aircraft losses may increase unnecessarily.

Modern tactical combat aircraft such as the F/A-18E/F *Super Hornet* are designed to fulfill a wide variety of air-to-air and air-to-ground missions. These aircraft, known as strike-fighters, tend to carry complex weapon and sensor suites and demonstrate multi-mission capability with minimal to no configuration changes. Specific functions of the suite may be required for one mission and not for another. For example, an aircraft assigned an air-to-ground mission with no air-to-air tasking may not require all the functionality of the on-board radar. Weapon and sensor functional requirements will also vary within the specific mission according to the threat type and density. A failure of the electronic countermeasures system in the low-band portion of the Radio Frequency (RF) spectrum would have no mission impact if no threats reside in that region. The definition of Full Mission Capable (FMC) for the strike-fighter, therefore, can be relative to the mission tasking and associated threat.

BACKGROUND

The Boeing F/A-18E/F *Super Hornet* is a strike-fighter aircraft designed for the United States Navy to replace the Grumman A-6 *Intruder* and F-14 *Tomcat*. The F/A-18E/F is a much-improved version of the F/A-18C/D in service today. A summary of the principal aircraft components can be found in Figure A-1.

From April 1998 to April 1999, the author conducted approximately 200 hours of laboratory, simulator and flight evaluation of the *Super Hornet* at the Advanced Weapons Laboratory, Naval Air Warfare Center China Lake, California. Recent testing has focused on integration of weapons, sensors, and the mission computer software utilizing F/A-18 F2 and F4 – the second and fourth 'F' model aircraft to be produced, respectively – during scenarios representative of real-world operations.

PURPOSE

This thesis evaluates certain human factors aspects of the current weapon and sensor BIT interface on the F/A-18E/F aircraft, and proposes an improved interface designed to aid the aircrew in the assessment of system health. A select number of weapons and sensors were chosen for the evaluation to illustrate deficiencies in the current interface and enhancements provided with the proposed interface.

SCOPE

The scope of this thesis is limited to the software interface designed to convey avionics system status information to the aircrew. Specific weapon and sensor capabilities will not be evaluated.

AIRCRAFT DESCRIPTION

The Boeing F/A-18E/F *Super Hornet* (Figure A-2) is an adverse-weather, day-night, multi-mission strike fighter aircraft for the U.S. Navy. The aircraft is designed to successfully execute a wide variety of air-to-ground and air-to-air missions, to include Interdiction Strike, Close Air Support, Combat Air Patrol and Fighter Escort.

The avionics compliment and architecture is an essential component in giving the F/A-18E/F the flexibility to carry out its missions. Aircraft avionics are connected through a redundant-path MIL-STD-1553 time-multiplexed digital data bus, allowing rapid data transfer. The aircraft employs two general-purpose digital mission computers. Mission Computer 1 (MC1) performs navigation, Built In Test (BIT), status monitoring, and provides limited backup capability for MC2 functionality. MC2 is responsible for air-to-air and air-to-ground tactical displays, weapons delivery computations, and provides limited backup for MC1 functionality. The Operational Flight Program (OFP) software is hosted in the Mission Computers and supports integration of the entire aircraft system configuration.

The F/A-18E/F Multi-purpose Displays and Hands-On Throttles and Stick (HOTAS) controls provide a highly integrated man-machine interface, allowing a single operator to successfully perform the demanding tasks associated with strike fighter missions. F/A-18E displays include the Heads-Up Display (HUD), Up-Front Control Display (UFCD), Multi-Purpose Color Display (MPCD), two Multi-purpose Display Indicators (MDI), and an Engine Fuel Display (EFD). A representative MDI along with the pushtile numbering scheme is shown in Figure 1-1. The F/A-18F aircraft has a similar compliment of displays in the rear cockpit, with the exception of the HUD. Controls are provided on the throttles and control stick, and hand controllers in the aft cockpit of the F/A-18F, which allow rapid reconfiguration of the aircraft from ground attack to the air-to-air role. This concept is known as Hands-On Throttles and Stick (HOTAS). Figures A-3 through A-7 in Appendix A detail the crew station layout for the forward cockpit, throttles and control stick for the F/A-18E/F, and the aft cockpit and hand controllers for the F/A-18F.

The specific examples utilized in this paper are drawn from the Boeing F/A-18E/F *Super Hornet* aircraft with the 16E System Configuration Set (SCS), which is scheduled to enter fleet service in late 2000. Pertinent aircraft subsystems to be discussed include the AN/ALR-

67 (V) 3 Advanced Special Receiver, the Integrated Defensive Electronic Countermeasures (IDECM) system, the Advanced Targeting Forward Looking Infra Red (ATFLIR) Pod, the AN/APG-73 RADAR, the AGM-154 Joint Stand-Off Weapon (JSOW), and the AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM). The concepts discussed in this paper can be applied to other weapons, sensors, and a wide variety of glass-cockpit tactical combat aircraft.

BUILT-IN TEST & THE STRIKE FIGHTER

Significant effort has been expended toward using Built-In Test (BIT) of electronic and mechanical equipment to reduce the number of aircraft maintenance actions and increase the effectiveness of such actions at returning the aircraft to a Full Mission Capable (FMC) status (i.e. increase availability) [7]. Very little effort, on the other hand, has been expended toward providing adequate BIT display formats that can be used by the aircrew to make GO / NO GO decisions based on mission tasking and threat type and level. This is evidenced by the current state of BIT display formats in the F/A-18, which will be evaluated in this paper.

Whereas the importance of the health of the basic aircraft – engines, flight controls, hydraulics, communications, navigation and identification equipment – is generally independent of mission tasking and threat level, such is not the case for weapons and sensors. Current status monitoring displays could be improved to present weapon and sensor system health information to the aircrew in a manner that will allow aircrew to effectively compare mission tasking to aircraft status. As a result, mission readiness and effectiveness is sacrificed.

Section two of this paper focuses on the fundamentals of system status monitoring and reporting. The differences between the goals of the maintainer and aircrew with regards to system status information are presented. Section three documents the current displays for select examples weapons and sensors on the F/A-18E/F Super Hornet. The display formats are evaluated in the context of a mission scenario. Section four presents the new design concept, evaluated against the same mission scenario for direct comparison.

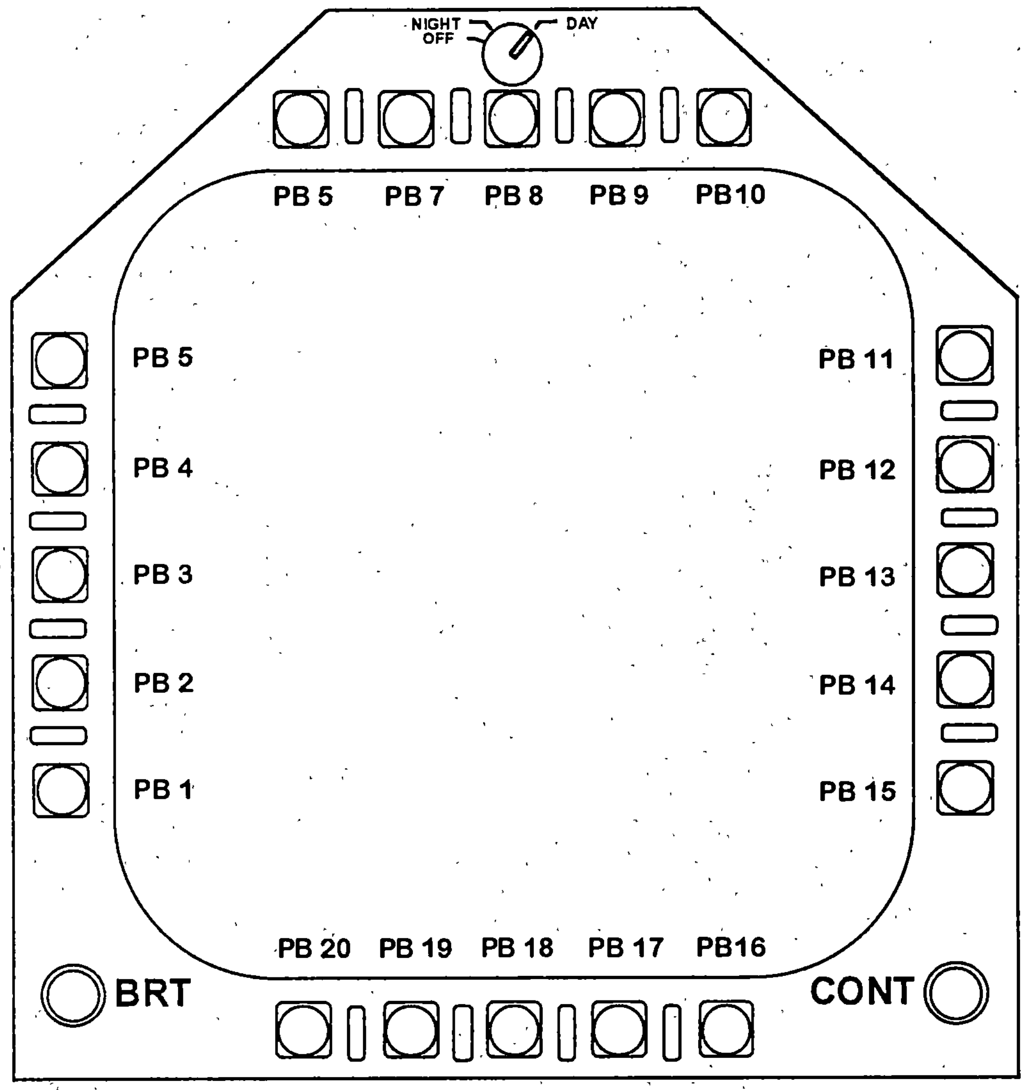

Figure 1-1. F/A-18 Multi-purpose Display Indicator (MDI)

Adapted from: Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System configuration Set. Naval Air Warfare Center, China Lake, California, 1999.

2.0 SYSTEM STATUS MONITORING AND REPORTING

Individual diagnostic system tests are utilized to verify the operational capabilities of electronic and mechanical components of modern aircraft. These self-diagnostic capabilities, often referred to as Built-In Test (BIT), are designed to monitor system performance through the incorporation of fault detection and isolation techniques and report the results to the operator.

STATUS MONITORING

The goal of BIT is to ***detect*** a failure or potential failure of the hardware or software with minimal ***false alarms***, and to accurately ***isolate*** the actual or potential failure location. Comprehensive diagnostics are difficult to implement without interfering with normal system operation. For example, it is important to know the performance status of gimbals for airborne RADAR, but they cannot be thoroughly tested without interrupting normal scanning or tracking operation. At the same time, it is important to continuously monitor systems to detect failures such as an in-flight RADAR overheat.

Four types of BIT have been developed in order to satisfy these requirements - power-up, in-line (periodic), on-line (initiated), and off-line. Power-up BIT is typically an extensive diagnostic test designed to provide aircrew with a pre-flight indication of system health. Periodic

BIT (PBIT), also known as continuous BIT, runs in the background and provides system monitoring without interrupting normal system operation. BIT functionality time-shares with the remainder of the system functions. Initiated BIT (IBIT) is commanded by the operator, and it interrupts normal system operation to test the system up to the capabilities of the BIT. IBIT is typically very similar to power-up BIT. Off-line BIT is a specialized BIT utilized by maintenance crews for detailed system diagnostics, and often requires specialized external support equipment.

STATUS REPORTING

Modern avionics systems have detailed BIT capabilities that can provide a large amount of data concerning system health and performance. The type of information, when it is reported, and in what format are important when considering the overall effectiveness of the health monitoring system.

Types of Status Information

The results of weapon and sensor BIT consist of validity, readiness, and health data. Validity information reflects whether the data being reported is valid or invalid. This information is used in the F/A-18 to initiate an automatic tactical reversion that provides graceful degradation of system functionality [1]. Readiness data conveys to the operator whether the system is off, operating, in test, or not communicating on the related multiplex bus. Health data provides the operator with an indication of the results of the latest BIT.

Status Reporting Timeline

The timeliness of reporting system status information is an essential element in a sound health monitoring system. Most modern weapons and sensors incorporate a power-up BIT designed to determine the operational readiness of the system prior to flight and then provide continuous in-flight monitoring through a periodic BIT.

In the pre-flight mission phase, a comprehensive assessment of the health of aircraft systems is necessary to allow aircrew to either make a GO decision or attempt to have maintenance fix degraded systems. Prior to flight, aircrew can generally afford to have BIT interrupt normal system operation, allowing initiated BITs to be performed. Airborne, periodic BIT is preferred to avoid interference with normal system operation. After flight, it is important to assess the health of the system for the next mission so any required maintenance actions can be readily initiated. A record of failures experienced throughout the flight is very valuable for that purpose.

Status Reporting Formats

System health may be indicated by maintenance codes, maintenance codes with cautions and advisories, and display features.

Display Evolution

As aircraft have become increasingly complex, the need for more detailed display of system status information has grown considerably. Previous generation fighter aircraft designs such as the F-14 Tomcat relied upon extensive panels of caution and advisory lights to display system health, as shown in Figure 2-1. The amount of information that can be displayed is limited by cockpit space. These displays are also not easy to reconfigure in the event of either a change in aircraft systems or a desire to display new information.

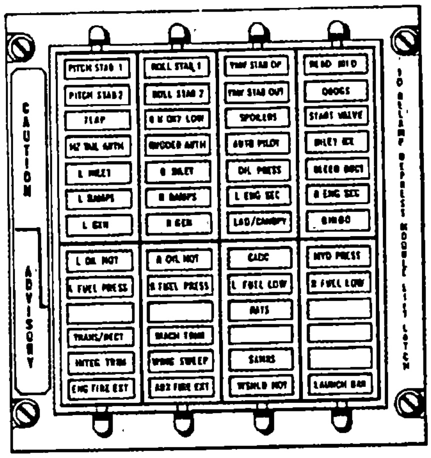

Figure 2-1. F-14D Caution and Advisory Panel

Source: *NAVAIR 01-F14AAD-1, F-14D NATOPS Flight Manual, Philadelphia, Pennsylvania, Naval Air Technical Services Facility, 1997*

The advent of the digital computer and the use of Multi-purpose Display Indicators (MDIs) in the cockpit together have provided a quantum leap in capability to display system status information in the tactical fighter aircraft. Status information from a multitude of aircraft systems can be selectively chosen, synthesized, and displayed in virtually any format desired. Information may also be sent to special maintenance displays for use by ground personnel or stored for later retrieval.

Display Conventions

System status information can be conveyed to the aircrew or maintainer in a number of ways. In the F/A-18, conventions have been established to allow for consistency as system software evolves. One convention is the use of alphanumeric codes, referred to as Maintenance Status Panel, or MSP codes, that are tied to a specific component or Line-Replaceable Unit (LRU). These codes are the primary source of maintenance information. In the cockpit, the BIT and STORES displays contain status messages for systems and weapons. A hierarchical series of Warnings, Cautions and Advisories, are used to alert aircrew to the presence of a fault and its priority. All warnings utilize cockpit-mounted lights or HUD displays and a voice aural alert. Cautions and advisories are displayed on the left MDI except in special circumstances. Most cautions also utilize a Master Caution aural tone to aid in alerting the aircrew, some cautions add a voice alert, and other cautions are displayed both on MDIs and on a cockpit-mounted caution light panel.

The F/A-18 utilizes multidimensional coding for display of system status, including location, size, and to a limited extent, color. Location coding involves establishing consistent locations where the status information can be found, reducing aircrew workload and the time required to assimilate the information. Cautions and advisories are location coded by nearly always appearing on the left MDI. BIT information is location coded by consolidating it at a fixed location on the BIT display. Size coding invokes the stereotypical behavior in which humans tend to consider larger things to be more important. Cautions and advisories follow the size coding concept, and are sized at 150% and 120% of normal text, respectively.

MAINTENANCE PERSPECTIVE

A well-designed BIT architecture is what is known as an expert system – a system structured to "capture the knowledge and expertise of a subject-matter expert and transfer it to a computer program that ... will emulate the problem-solving and decision-making performance of the expert" [4]. BIT can be a tremendous benefit to aircraft maintenance.

Military aircraft experience high utilization rates in the operational environment. A tactical aircraft such as the FA-18 Hornet may fly five 1.75 hour sorties every day while aboard an aircraft carrier. Times from shutdown to aircrew man-up for the next mission are typically under thirty minutes. High aircraft reliability and effective diagnostic capabilities are paramount in order to maintain required sortie rates. The primary focus of system status reporting has been to increase full mission capable rates by providing the maintainer with a fast and simple fault diagnosis and repair procedure.

Despite advances in design and manufacturing, aircraft components do not maintain 100% reliability. In order to speed time-to-repair, components have been modularized into Line Replaceable Units (LRUs) wherever possible. Under this maintenance concept, BIT is utilized to isolate specific LRUs reported as failed, which are subsequently removed and replaced. BIT also attempts to isolate the fault to the specific Shop Replaceable Assembly (SRA), so the defective LRU can be repaired at the shop level and returned to the available pool in a timely manner [7].

Fault reporting requirements for the line, or operational, maintenance team are limited to codes specifying which LRU has failed and needs to be replaced. Detailed fault information is not required. It can be stored either within the unit itself or on an aircraft memory cartridge for subsequent retrieval and use at the repair location. If the failure code system is working correctly, there should be few occasions where it is necessary for maintenance personnel to be seated in the cockpit to diagnose a system failure. This includes failures of components, such as aircraft wiring, that cannot be modularized easily. Fault codes can be reported via a maintenance panel like the one in the nose wheel well of the F/A-18 (Figure A-9) and on the removable aircraft memory cartridge.

AIRCREW PERSPECTIVE

The utility of BIT extends beyond aircraft maintenance. Aircrew are responsible for making GO / NO GO decisions based on their understanding of the capability of their aircraft to successfully execute the mission, and BIT can help provide aircrew the information necessary to make those decisions.

The strike fighter is capable of a wide variety of roles, and GO / NO GO criteria will vary according to the specifics of the assigned mission. The GO / NO GO criteria may include sub-functions of specific LRUs. For example, take the case of an F/A-18E assigned an interdiction mission for which there is no air-to-air threat. The aircrew may not require the air-to-air functions of the on-board RADAR, even though these functions are contained within the same LRU in which the air-to-ground functions reside. A simple fault code indicating a LRU failure would not provide adequate information to allow the aircrew to make an appropriate GO / NO GO decision.

There have been limited efforts to provide system status information to the aircrew in such a format to allow them to make pre-flight GO / NO GO decisions. The F/A-18 AN/APG-65 and 73 RADAR units offer the unique display of "TAC INFO", for TACtical INFOrmation, which is designed to translate engineering terms into those which reflect the status of modes and capabilities of the RADAR system.

3.0 SYSTEM DESIGN

DESIGN GOALS

The primary goal for the design of new weapon and sensor BIT display formats was to enhance aircrew awareness of the status of the aircraft's weapons systems. Displays must provide, in as plain English as possible, a summary of weapon and sensor failures in such a way that aircrew can assess mission impact. Aircrew should not be required to have engineer-level knowledge of the systems in order to make an accurate assessment of the operational capabilities of the weapons system.

SYSTEM DESCRIPTIONS

A small subset of the weapons and sensor systems available on the FA-18E/F was chosen to demonstrate the potential for the restructuring of system status displays. The focus was on Electronic Warfare (EW) systems, tactical sensors, and weapons.

Electronic Warfare Systems

AN/ALR-67 (V) 3 Advanced Special Receiver (ASR) – The AN/ALR-67 (V) 3 is an advanced RADAR warning receiver. It combines superior sensitivity, fast processor speed, wide bandwidth, high pulse-density, and a large threat library to detect, identify and localize radio frequency threats.

AN/ALQ-214 - The AN/ALQ-214 Radio Frequency Counter Measures (RFCM) is an advanced electronic countermeasures unit. It combines receive, process, and transmit capabilities along with response management. It is the cornerstone of the FA-18E/F Integrated Defensive Counter Measures (IDECM) suite, and is capable of being utilized in either an on-board and/or off-board application when used in conjunction with a Fiber Optic Towed Decoy (FOTD).

CMWS - The Common Missile Warning System (CMWS) is an advanced missile approach warning system operating in the Ultra-Violet (UV) portion of the spectrum. It provides virtually complete coverage around the aircraft to warn the aircrew of an approaching missile by detecting and tracking the missile plume. The system is effective only at low altitude due to the nature of UV plume detection and tracking.

Sensor Systems

AN/APG-73 - The AN/APG-73 RADAR is a multi-mode, pulsed-Doppler RADAR capable of performing numerous air-to-air, air-to-ground and navigation functions. It is the principal sensor of the F/A-18E/F.

ATFLIR - The Advanced Targeting Forward Looking Infra-Red (ATFLIR) pod is designed to provide the FA-18 with long-range, precision weapons identification and targeting capability. The system incorporates Infra-Red (IR) and Electro-Optic (EO) sensors, LASER designation and ranging, LASER spot tracking, and NAVigation Forward-Looking Infra-in other cases they were altered and expanded upon. The objective was to enhance the man-machine interface of the BIT display formats.

Location

F/A-18 display formats, in general, code information according to location. The advisory line and caution area on the left MDI, as shown in Figure 3-1, provide aircrew with a familiar location to scan for top-level status information. Location coding is also used on the BIT format. Individual equipment failures are listed in the center of the top-level BIT format. Equipment is grouped according to functional area, and group status information is listed on the left and right-hand portions of the display (Figure 3-2).

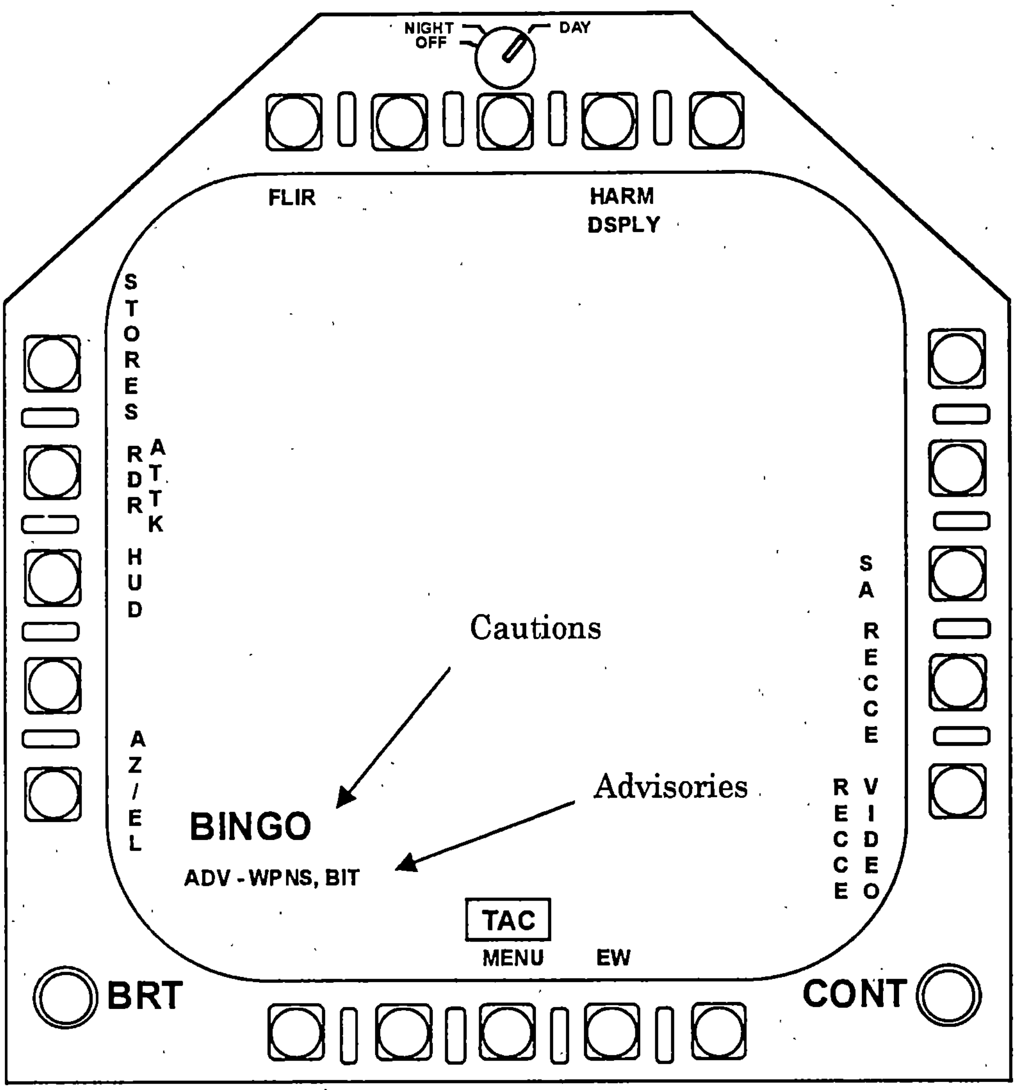

Figure 3-1. F/A-18 Multi-Function Display Format

Adapted from: *Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set, Naval Air Warfare Center, China Lake, California, 1999*

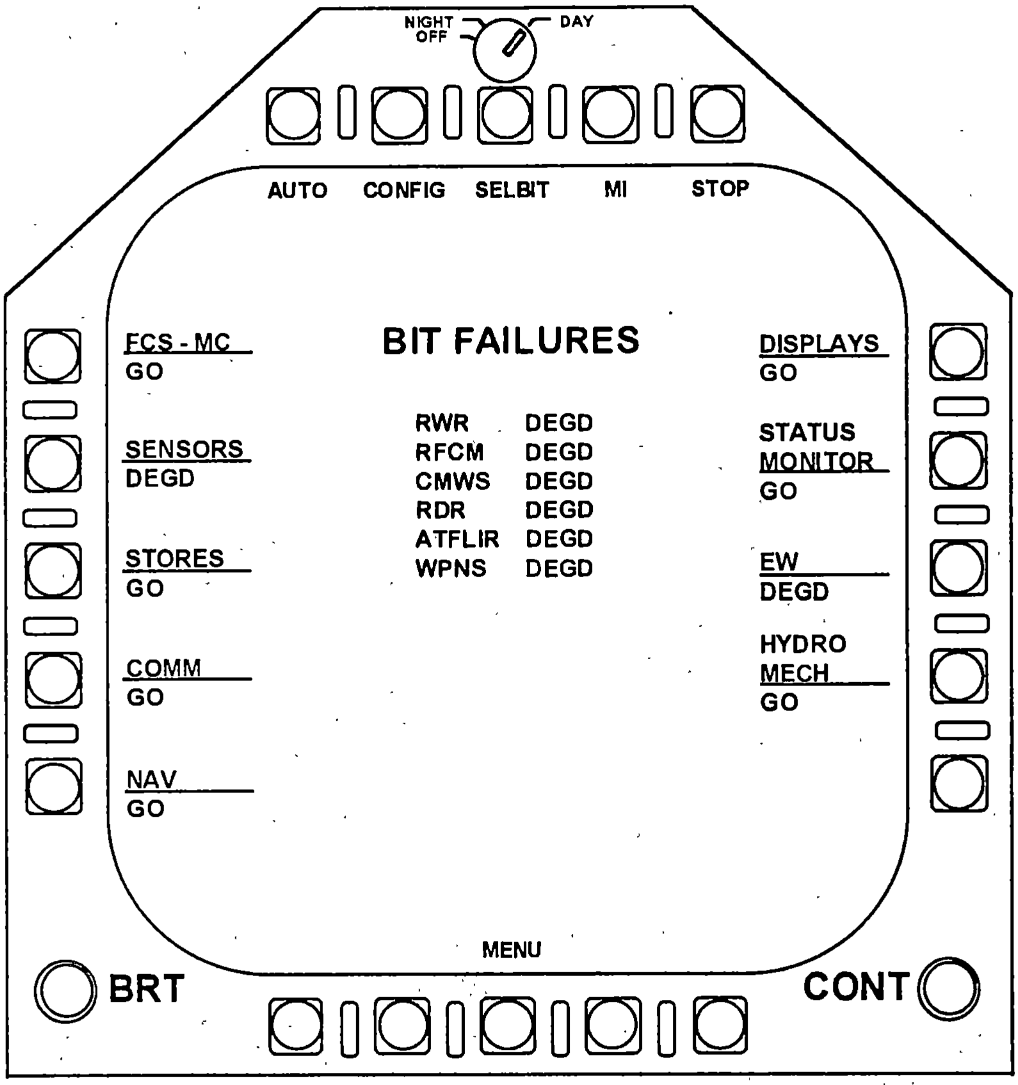

Figure 3-2. F/A-18 Top-Level BIT Format

Adapted from: Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set, Naval Air Warfare Center, China Lake, California, 1999

Color

Color-coding is used to a very limited extent in current F/A-18 displays. The only system status information that currently uses color coding is on the Engine format, where red is used to indicate an out-of-tolerance condition. The proposed systems status displays use a tricolor coding scheme extensively. Research has indicated that "pilots responded more quickly to alerts in a distinct 'deviant color' in a three-color display than to ones in either mono or full color". [5] Red, yellow and green appear to be the colors that are most easily distinguished irrespective of external light conditions [5]. Color discrimination problems among Naval Aviators are not an issue, since color discrimination is required and tested often. For the proposed displays, the color red was chosen to represent a mission-critical failure, yellow to represent degraded or limited performance, and green to represent full system performance.

Size

Size coding is useful to convey relative importance. Current F/A-18 displays code the font size of Cautions and Advisories relative to standard display characters. Cautions are sized at 150% and Advisories at 120% of the standard display characters. This convention is appropriate, effective, and is maintained in the proposed display formats.

Nomenclature

Limited space on the MDI display surface has necessitated the use of clear, succinct system status messages. Table 3-1 details the current list of status messages used in the F/A-18.

Table 3- 1. Status Messages and Definitions

STATUS MESSAGE	MESSAGE DEFINITION
NOT RDY	Equipment OFF, not installed, or initializing.
IN TEST	Initiated BIT in progress.
SF TEST	Self-test in progress - cannot be operator terminated.
GO	Initiated BIT complete without failure.
DEGD	Failure detected - equipment operation degraded.
NO GO	Equipment ON but not communicating.
OVRHT	Overheat.
DEGD + OVRHT	Detected failure and overheat.
RESTRT	Reinitiate BIT; equipment did not respond to BIT command, remained in BIT too long and was terminated by MC.
OP GO	Non-critical BIT failure detected.
PBIT GO	Initiated BIT has not been run since ground power-up and periodic BIT is not reporting any failures.
MUX FAIL	Equipment is ON and not communicating on the AVMUX.

The proposed system status displays utilize the same status message scheme except for the addition of FAIL, which is used to indicate failure of a specific functionality.

Warnings, Cautions and Advisories are used to cue the aircrew to critical aircraft situations. These cues are listed from lowest to highest priority as follows – Advisories, Cautions with Master Caution Tone (MCT) and Master Caution Light (MCL), Cautions with Voice Alert and Master Caution Light, and Warnings with Voice Alert. The proposed display formats continue to use and expand upon these conventions.

4.0 SYSTEM EVALUATION

MISSION SCENARIO

The differences between the current displays and the proposed displays are best illustrated through the use of a representative mission scenario, providing in-depth insight into how system status information is used in the tactical decision process.

Self-Escort Strike (SES)

A self-escort strike is a mission in which the fighter aircraft fulfill the anti-air and strike warfare roles within the same mission. A group of dedicated fighter sweep aircraft is not assigned to the strike package, typically because the air threat is not assessed to be significant.

Target

The assigned targets consist of surface-to-air missile (SAM) sites and armored vehicles some of the SAM systems are protecting. There is one weapon assigned per target (i.e. no target redundancy).

Package Composition & Loadout

The Air Wing Commander has assigned a flight of four F/A-18E aircraft to execute the strike. Each aircraft is carrying two AGM-154A and two AGM-154B JSOW, two short-range AIM-9X Sidewinder IR missiles, three medium-range AIM-120C AMRAAM missiles, an ATFLIR, and a centerline-mounted external fuel tank.

Enemy Order of Battle

The Electronic Order of Battle (EOB) consists of one SA-2, one SA-3, and an unknown number of SA-6 and SA-8 surface-to-air missile systems. The SA-2 is a long-range (greater than 25nm) system, the SA-3 and 6 are medium-range (between 10 and 25nm) systems, and the SA-8 is a short-range (less than 10nm) system. The Air Order of Battle (AOB) is four MiG-23G Flogger aircraft loaded with AA-7C *Apex* semi-active RADAR missiles and AA-8 *Aphid* IR missiles. These are fairly capable fighter aircraft, though easily outmatched by the F/A-18.

Assessment of Mission Readiness - Existing Displays

Menu Format

The sequence in Figures 4-1 through 4-23 details the preflight information available to the aircrew to make a GO / NO GO decision with the existing displays. Arrows pointing to pushtiles indicate selections that will step through the displays in the figure order. The advisory line on the Left MDI of the current SUPT MENU format in Figure 4-1 indicates that failures have been detected in the CMWS and RFCM systems. The BIT advisory cues the aircrew to select the BIT format for additional failure information, and therefore provides a generic indication of system status. From the information presented the aircrew have an indication that some systems are not fully functional, but with the exception of CMWS and RFCM, it is not known exactly which systems are degraded and to what extent. The Advisory line does not provide an indication of the RWR, RADAR, ATFLIR and Weapons degrades. **The author recommends that the Advisory line be used to provide a top-level indication of all system degrades. [R8]**

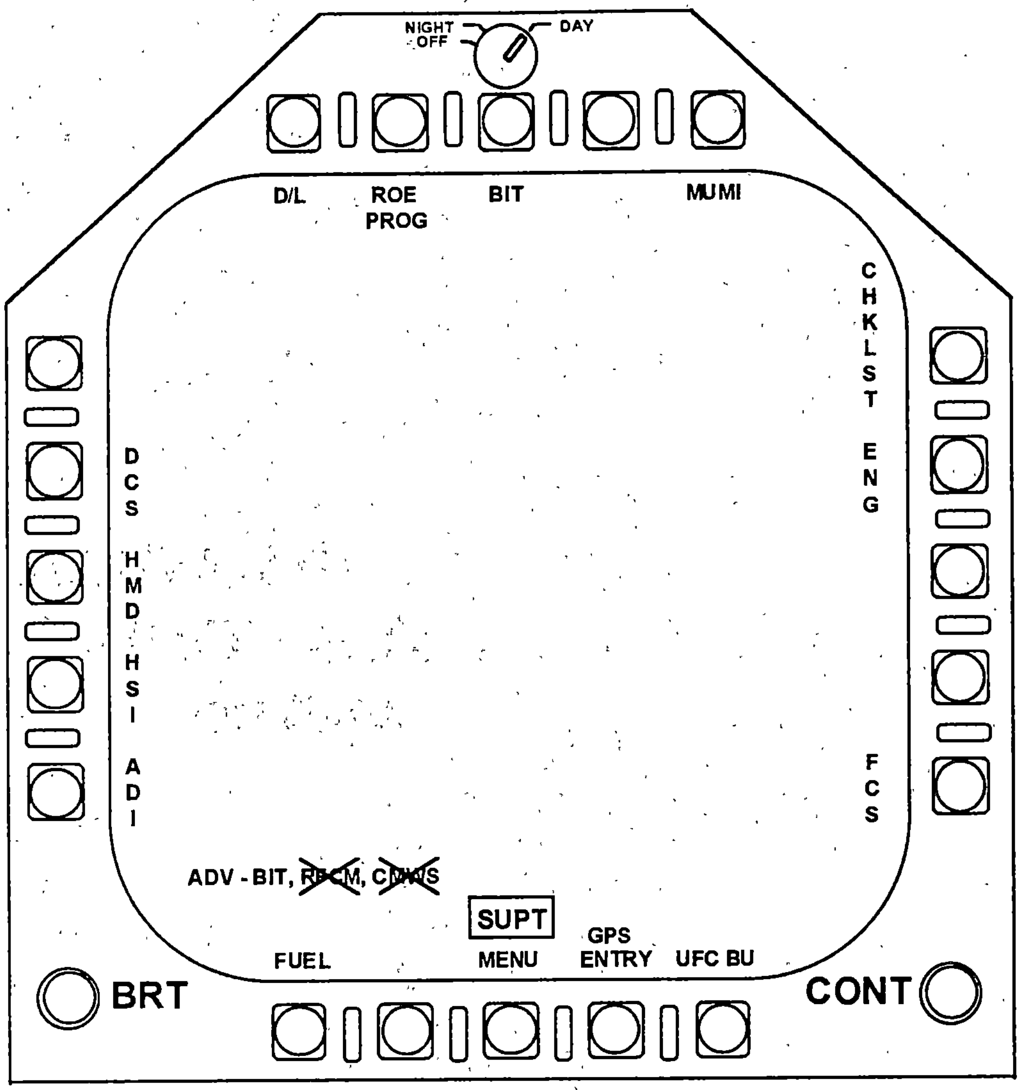

Figure 4-1. SUPT Menu

Adapted from: System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.

Top Level BIT Format

The top-level BIT format is selected from the SUPT MENU. The current BIT format in Figure 4-2 lists the degraded equipment in the center of the format. Specific equipment groups are listed next to the display pushbuttons. The status indication under the equipment group is prioritized according to the following structure – IN TEST, MUX FAIL, DEGD, NOT RDY, OFF, etc. In order to determine which equipment group a particular failed item belongs to, aircrew must rely on aircraft knowledge or attempt to match the status listed in the center of the display to that listed under the equipment group.

Equipment Group BIT Format

Additional information regarding the specific system failures can be obtained by selecting the pushtile next to the group to which the equipment belongs. The EW equipment group in Figure 4-3 indicates that the TG, or Techniques Generator, is degraded. The operator must understand the system well enough to know that the TG is part of RFCM, and that further information on the exact nature of the failure is available on the RFCM STATUS sub-level. The use of TG as compared to RFCM hinders the understandability of the information [7]. **The author recommends using plain-language system references to the maximum extent practical [R10].**

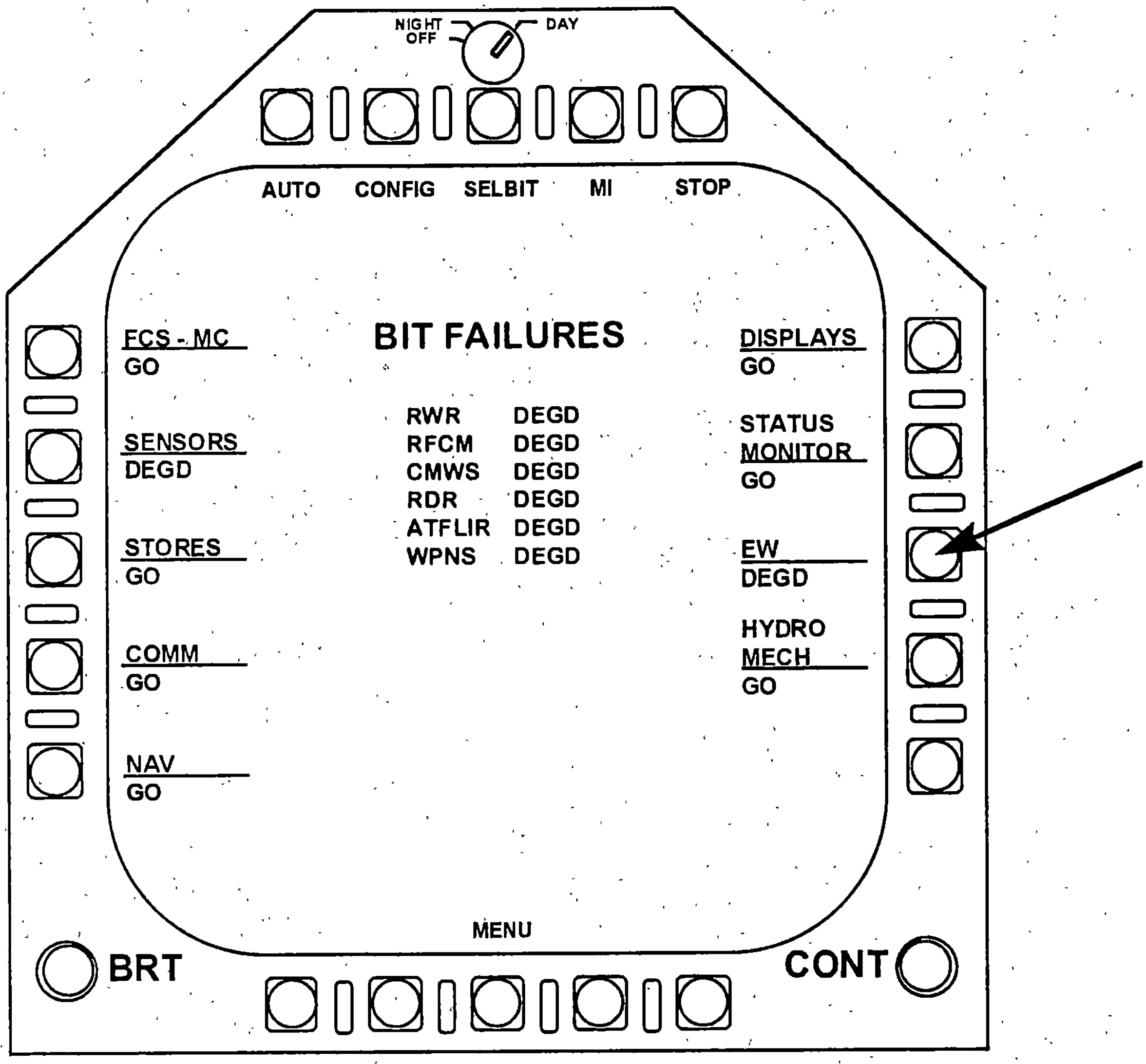

Figure 4-2. Top-Level BIT Format.

Adapted from: *System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.*

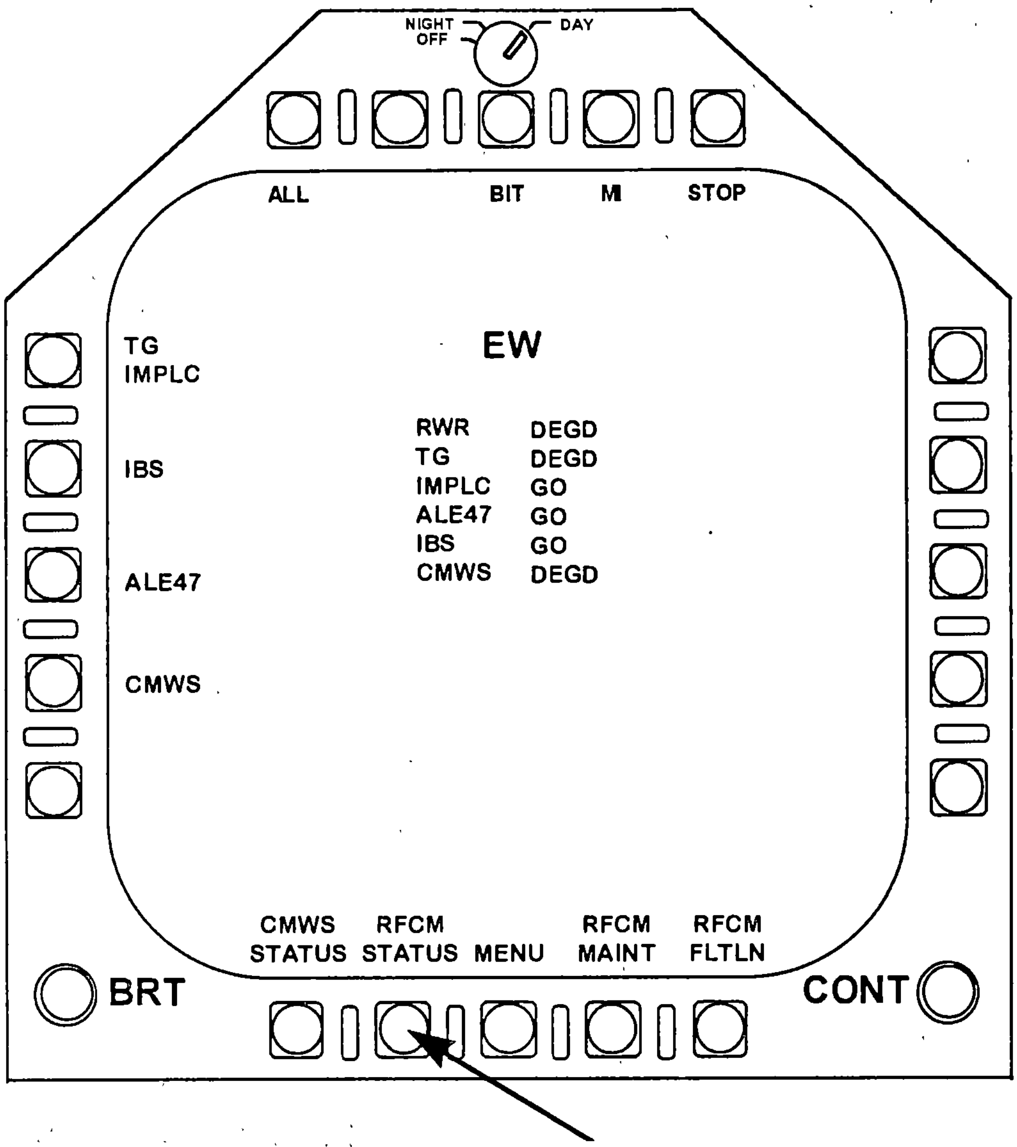

Figure 4-3. EW BIT Sublevel.

Adapted from: System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set, *Boeing Aircraft, St. Louis, Missouri, 1998.*

RFCM and CMWS Status Sub-Levels

The RFCM STATUS sub-level in Figure 4-4 lists all the individual RFCM system components. The line through RFTF, or Radio Frequency Tunable Filter, legend indicates that sub-system is degraded. The line through the legend does not indicate if the RFTF is completely failed or operating in a degraded status. **The author recommends using color coding to convey more detailed status information [R6].**

In order to assess the mission impact of the RFTF failure, the aircrew must understand that the RFTF is a critical element in establishing RADAR and Electronic Counter-Measures (ECM) compatibility – operation of both systems concurrently in the same RF band. This feature, for example, allows the RADAR to detect threat aircraft unimpeded by the RFCM system that is transmitting ECM techniques against the threat RADAR in the same frequency band. The remainder of the equipment listed is in a GO status, which is extraneous information. A similar situation exists with the CMWS STATUS sub-level, shown in Figure 4-6. **The author recommends that equipment status sub-levels list only the components that are in a degraded status [R11].**

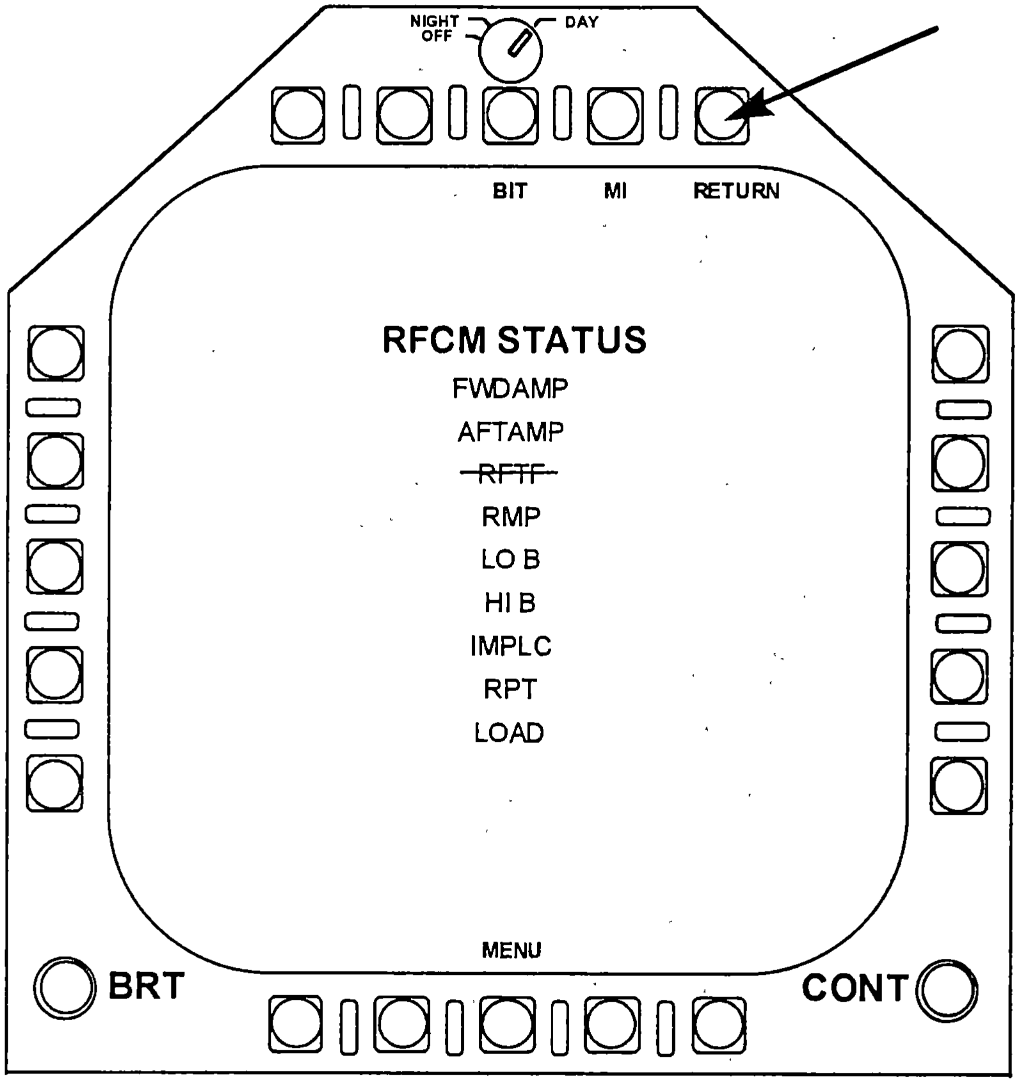

Figure 4-4. RFCM STATUS BIT Sublevel.

Adapted from: *System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.*

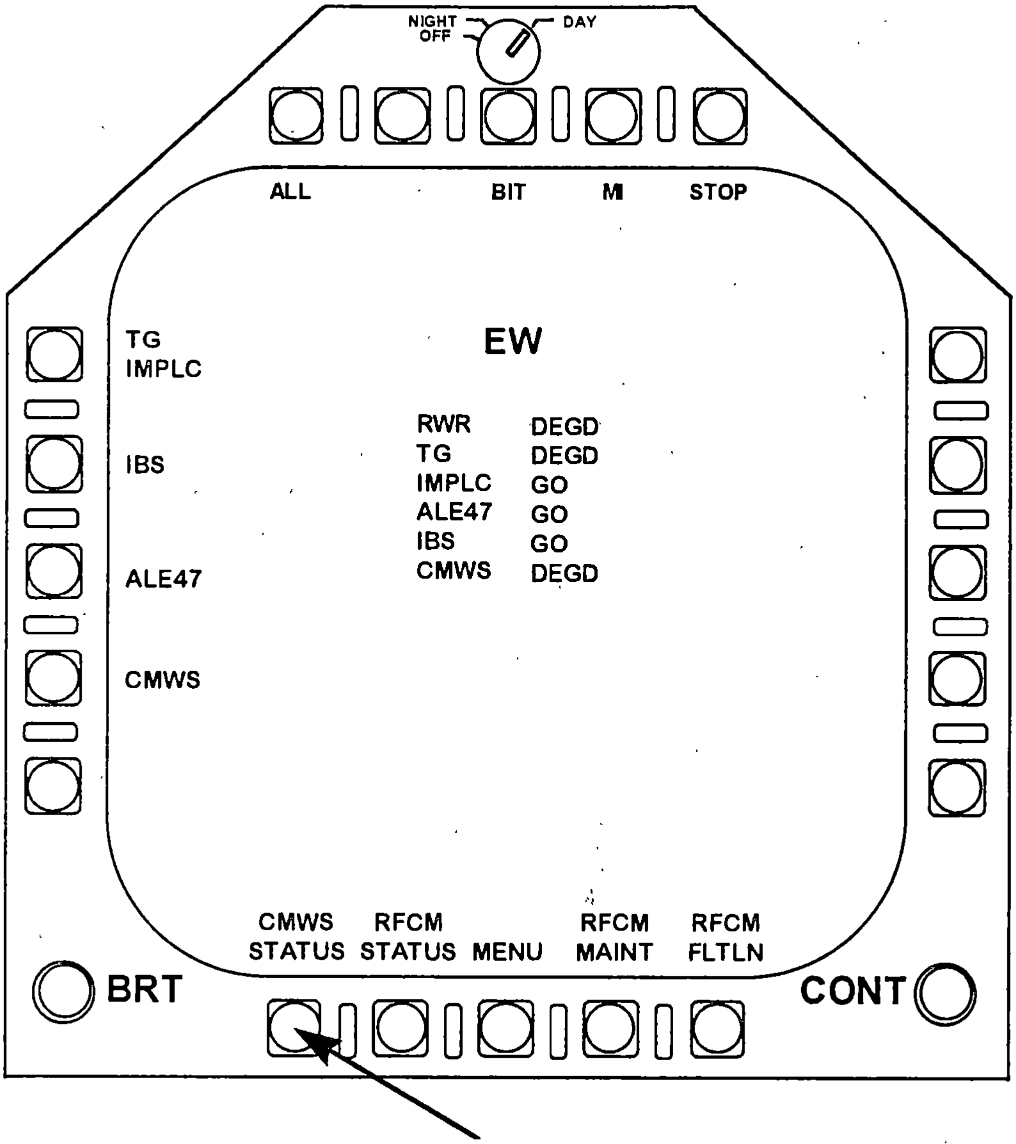

Figure 4-5. EW BIT Sublevel.

Adapted from: *<u>System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set</u>, Boeing Aircraft, St. Louis, Missouri, 1998.*

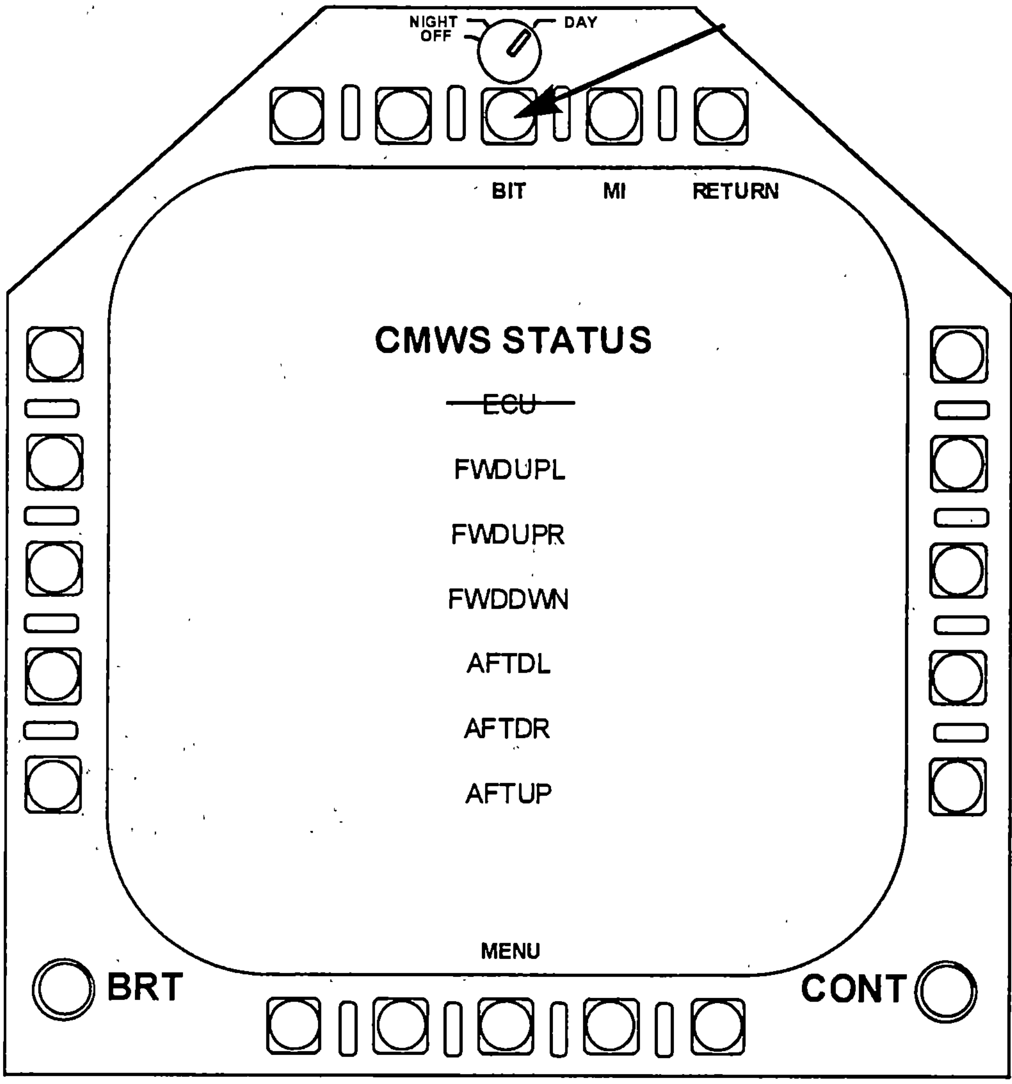

Figure 4-6. CMWS STATUS BIT Sublevel.

Adapted from: *System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set*, *Boeing Aircraft, St. Louis, Missouri, 1998.*

RADAR BIT Formats

System status information for the RADAR is located within the SENSORS BIT group, as depicted in Figure 4-8. Detailed BIT information is available on the RDR MAINT sub-level, Figure 4-9. The RDR MAINT sub-level contains the overall RADAR status in the center of the format and options to initiate partial system BIT when full IBIT is impractical. The presence and location of these options is unique to the RDR MAINT sub-level. **The author recommends that IBIT options for specific systems be arranged in a consistent fashion on BIT sub-levels [R13].**

Options to select display of tactical and engineering information are also present on the RDR MAINT sub-level. The TAC INFO sub-level displays failure information in terms that are very useful to the aircrew for evaluating the mission capability of the aircraft. BIT failures are separated according to air-to-air and air-to-ground functions, followed by specific modes within the functional area. In the example shown in Figure 4-10, the Air-to-Ground Ranging (AGR), Precision Velocity Update (PVU), and Real Beam Ground Map (RBGM) functions are shown as degraded and Fixed Target Track as failed. **The author recommends BIT information on all tactical systems be provided in terms of system capability and functionality lost due to the equipment failure [R1].**

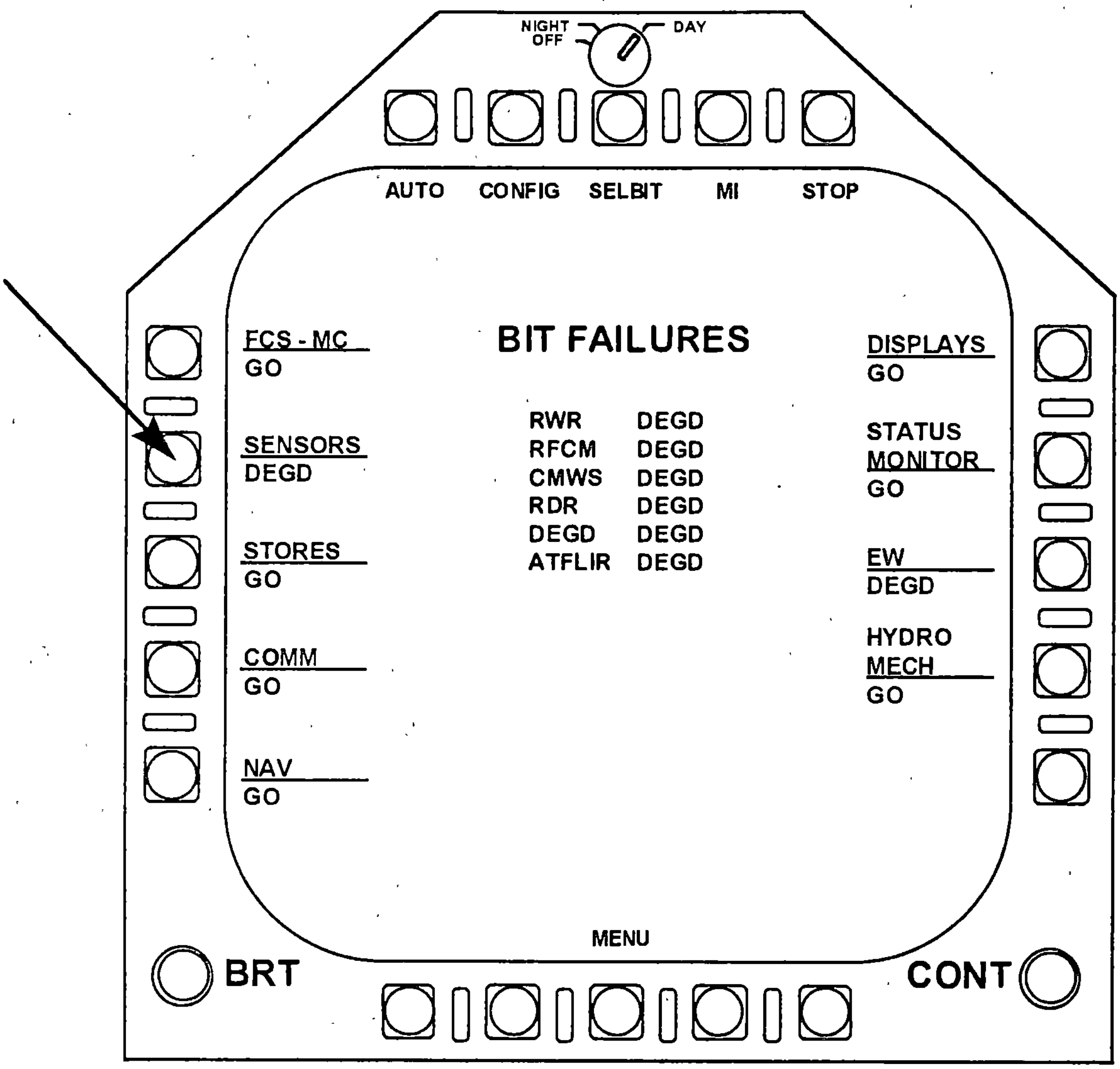

Figure 4-7. Top-Level BIT Format.

Adapted from: *System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set*, *Boeing Aircraft, St. Louis, Missouri, 1998.*

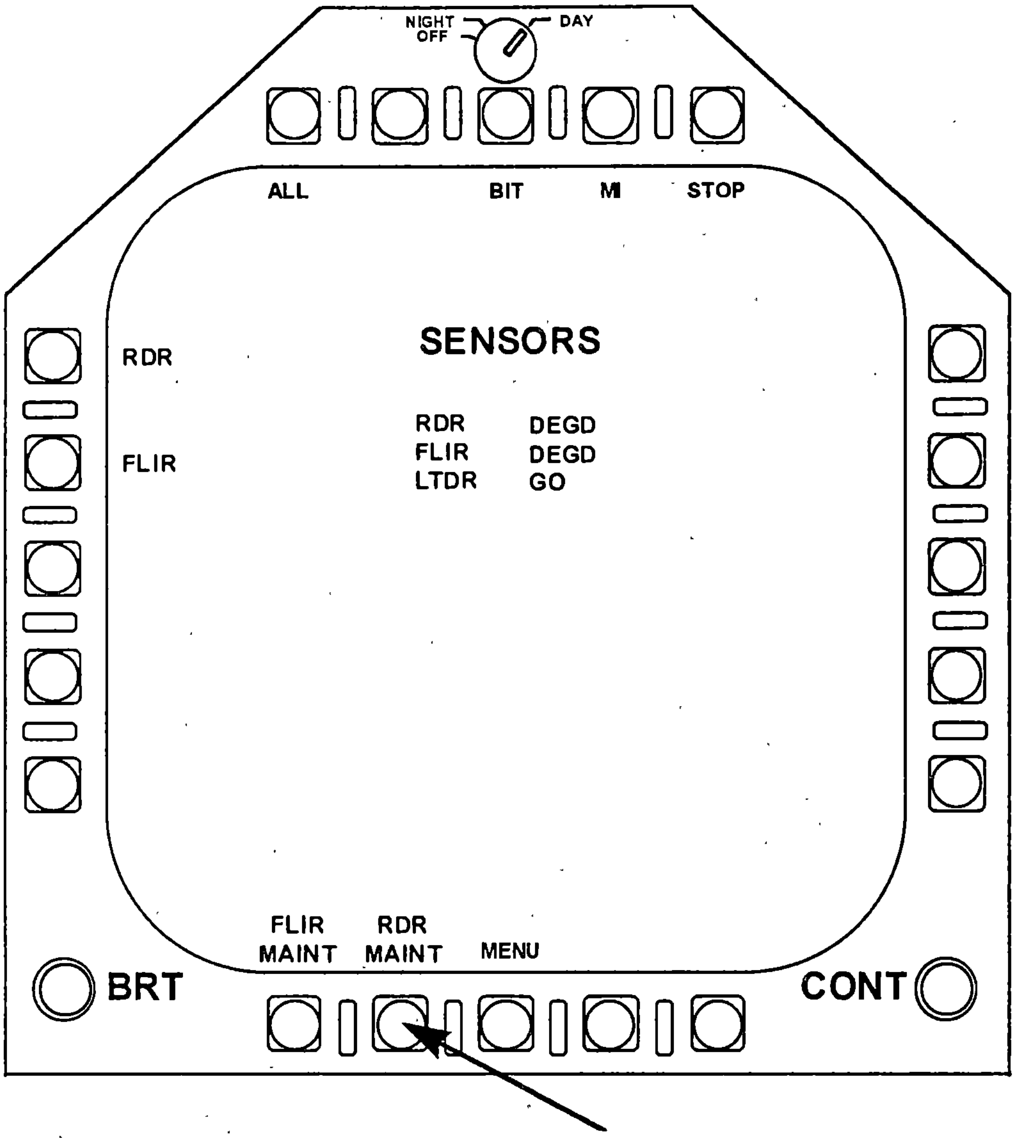

Figure 4-8. SENSORS BIT Sublevel Format.

Adapted from: Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.

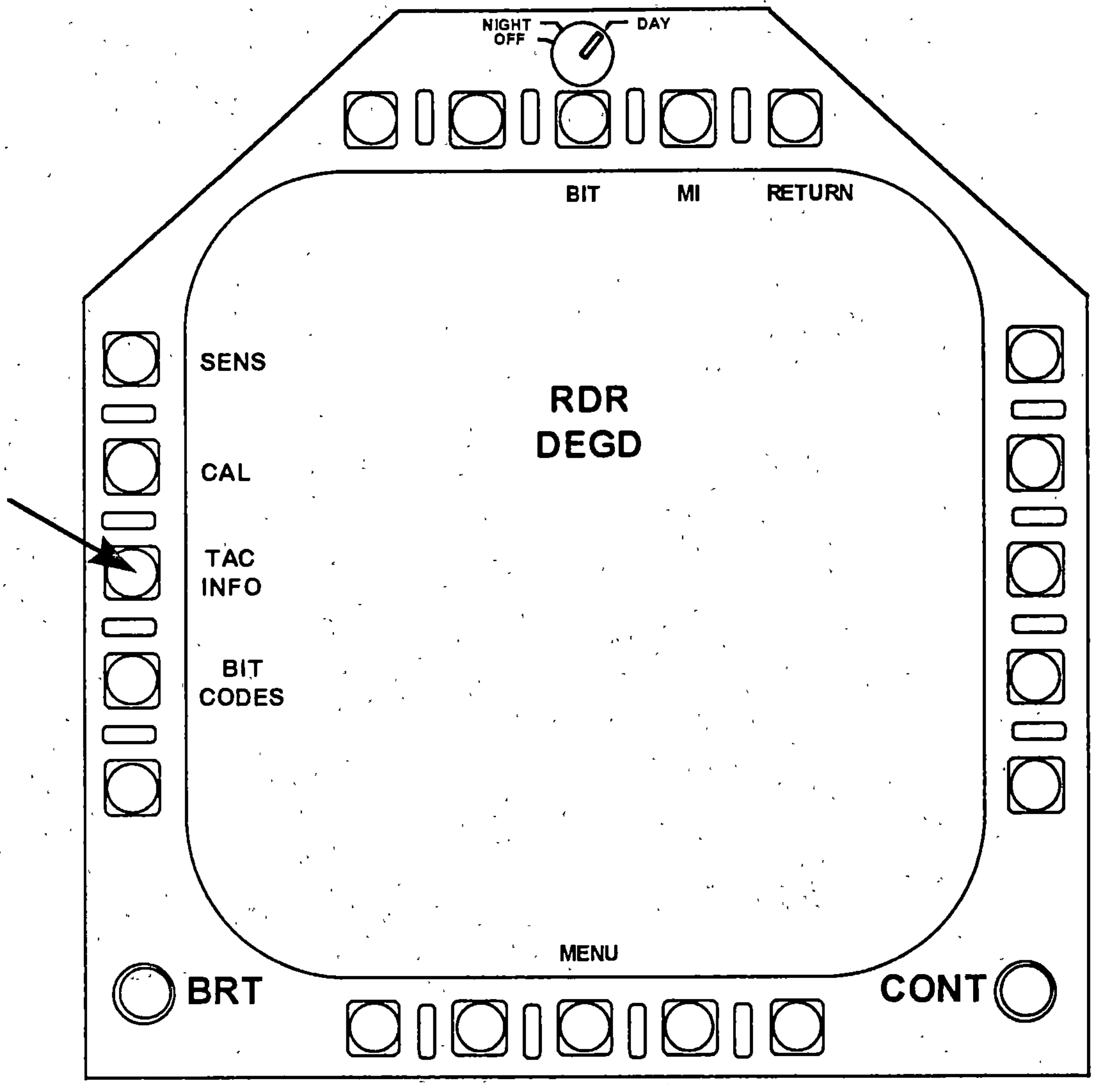

Figure 4-9. RADAR MAINT BIT Sublevel Format.

Adapted from: Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.

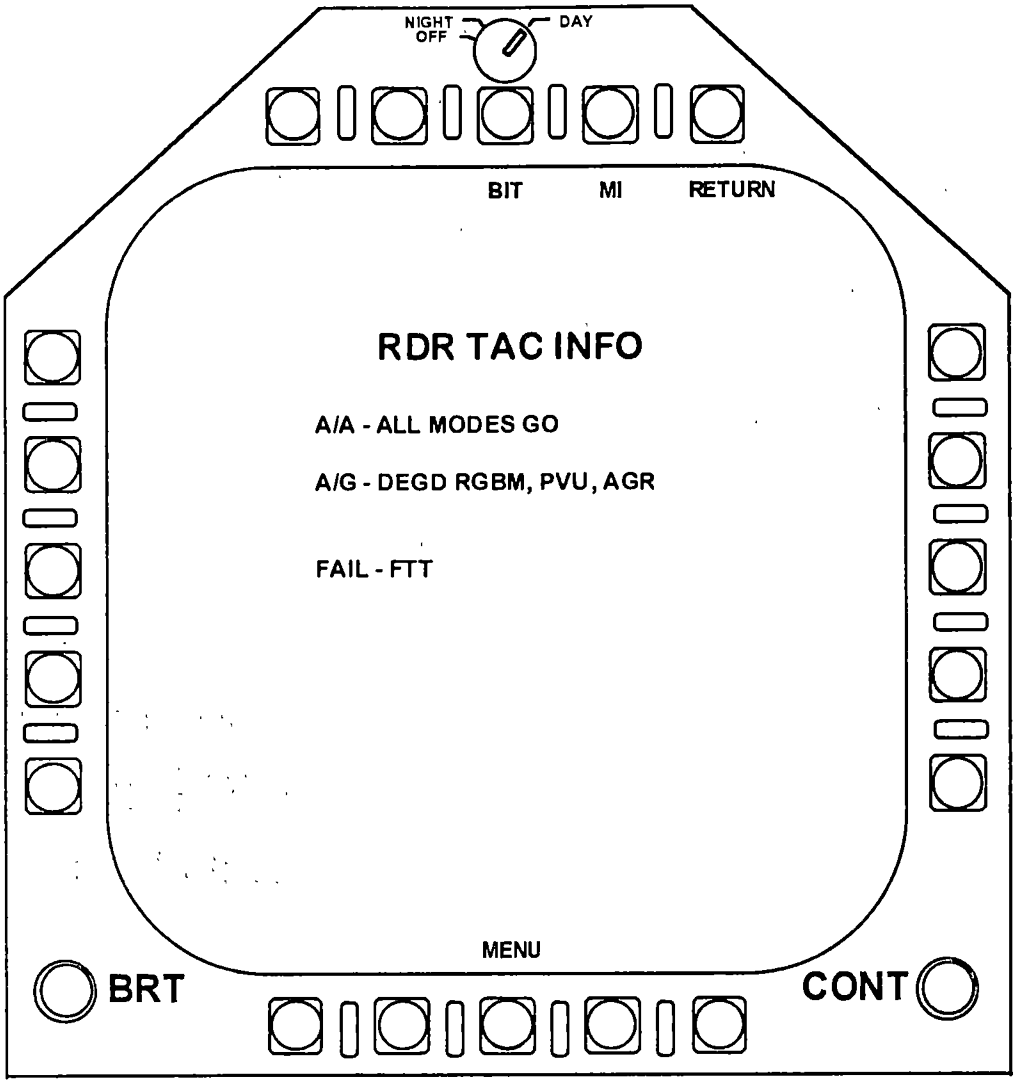

Figure 4-10. RADAR TACINFO BIT Sublevel Format.

Adapted from: Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.

ATFLIR BIT Formats

System status information for the ATFLIR is located within the SENSORS BIT group, as depicted in Figure 4-12. Detailed BIT information is available on the FLIR MAINT sub-level, shown in Figure 4-13, which is yet another BIT display configuration. It lists the status of eleven functions of the ATFLIR, the status of each, and test number for any BIT failures. The FLIR MAINT format contains important elements the aircrew can use to make a GO / NO GO decision. The status information, however, provides an ambiguous indication of the tactical significance of the failure, since no distinction is made between degraded and failed modes. A functional assessment of the ATFLIR is required to determine the mission capability of the system. **The author recommends incorporating the term FAIL into the list of system status descriptors to indicate a total loss of system capability [R7].**

The format also provides options to view specific failure information on each function. An option to view the fault log, a summary of Weapons Replaceable Assembly (WRA), date and time of the failures. This is useful information to the maintainer, but it must be hand-recorded either by aircrew or maintenance personnel. **The author recommends automatically recording all fault information to the aircraft maintenance memory cartridge, and deleting fault log displays [R9].**

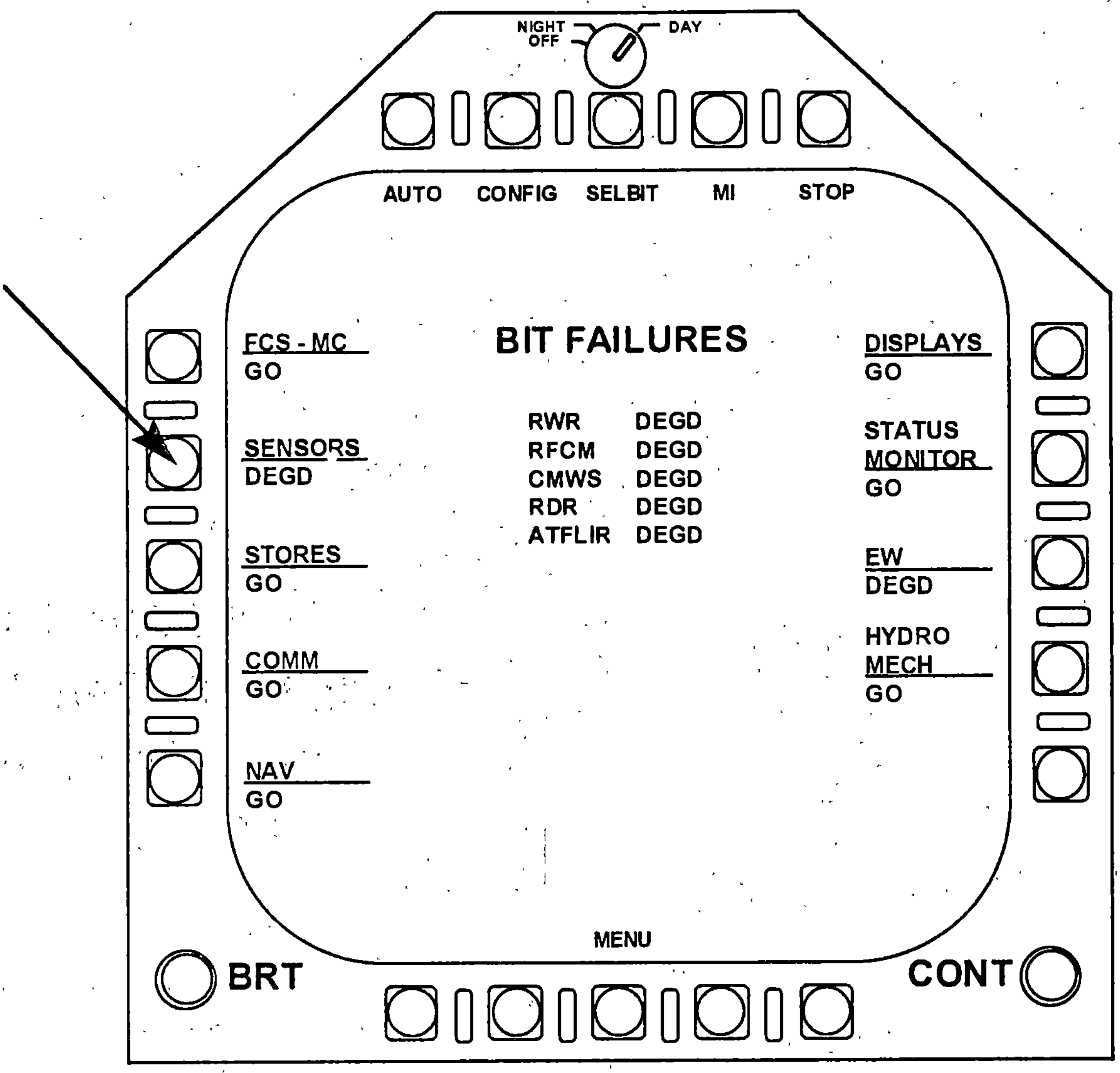

Figure 4-11. Top Level BIT Format.

Adapted from: System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set, *Boeing Aircraft, St. Louis, Missouri, 1998.*

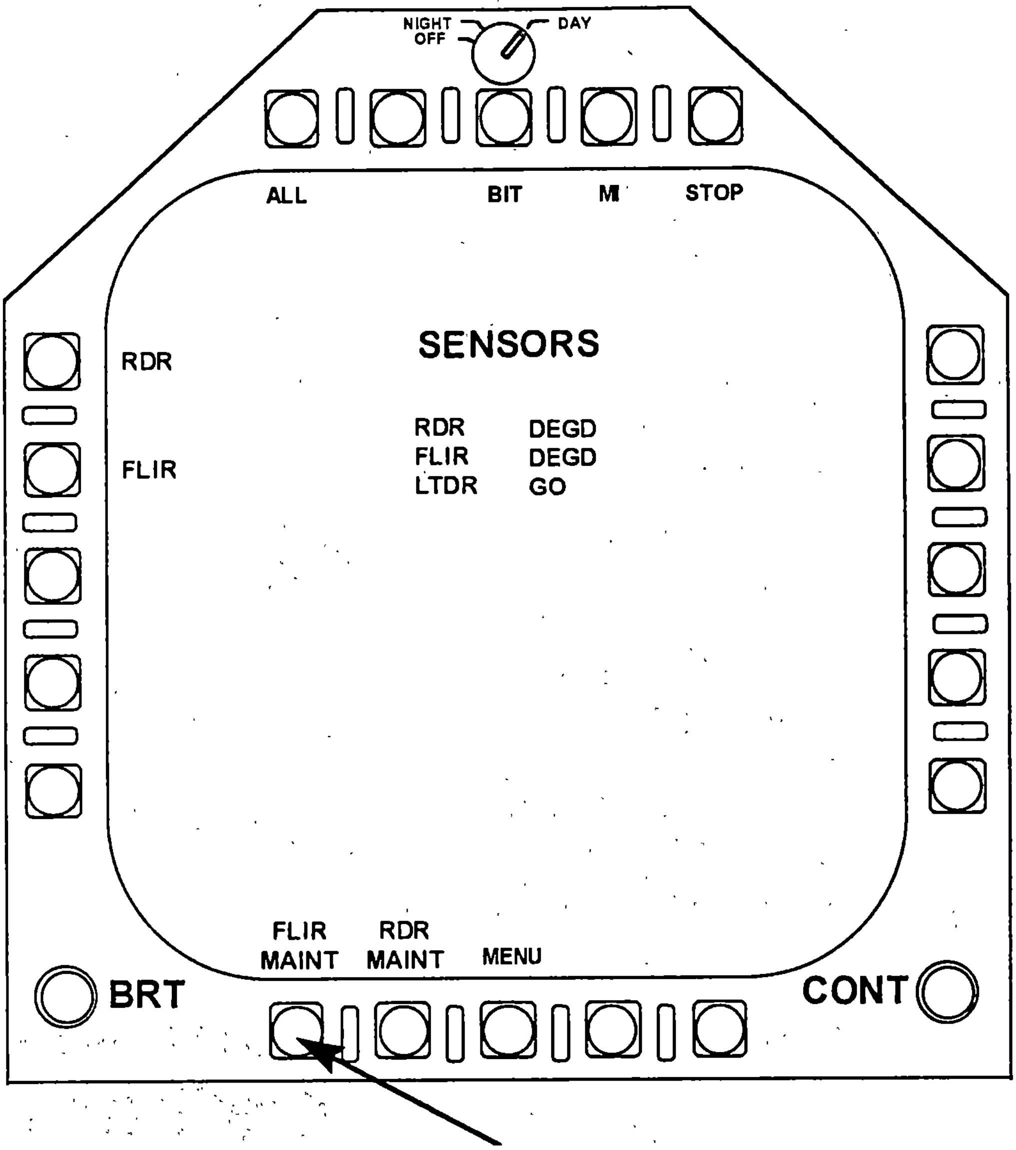

Figure 4-12. Sensors Equipment BIT Sublevel Format.

Adapted from: *Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set*, *Boeing Aircraft, St. Louis, Missouri, 1998.*

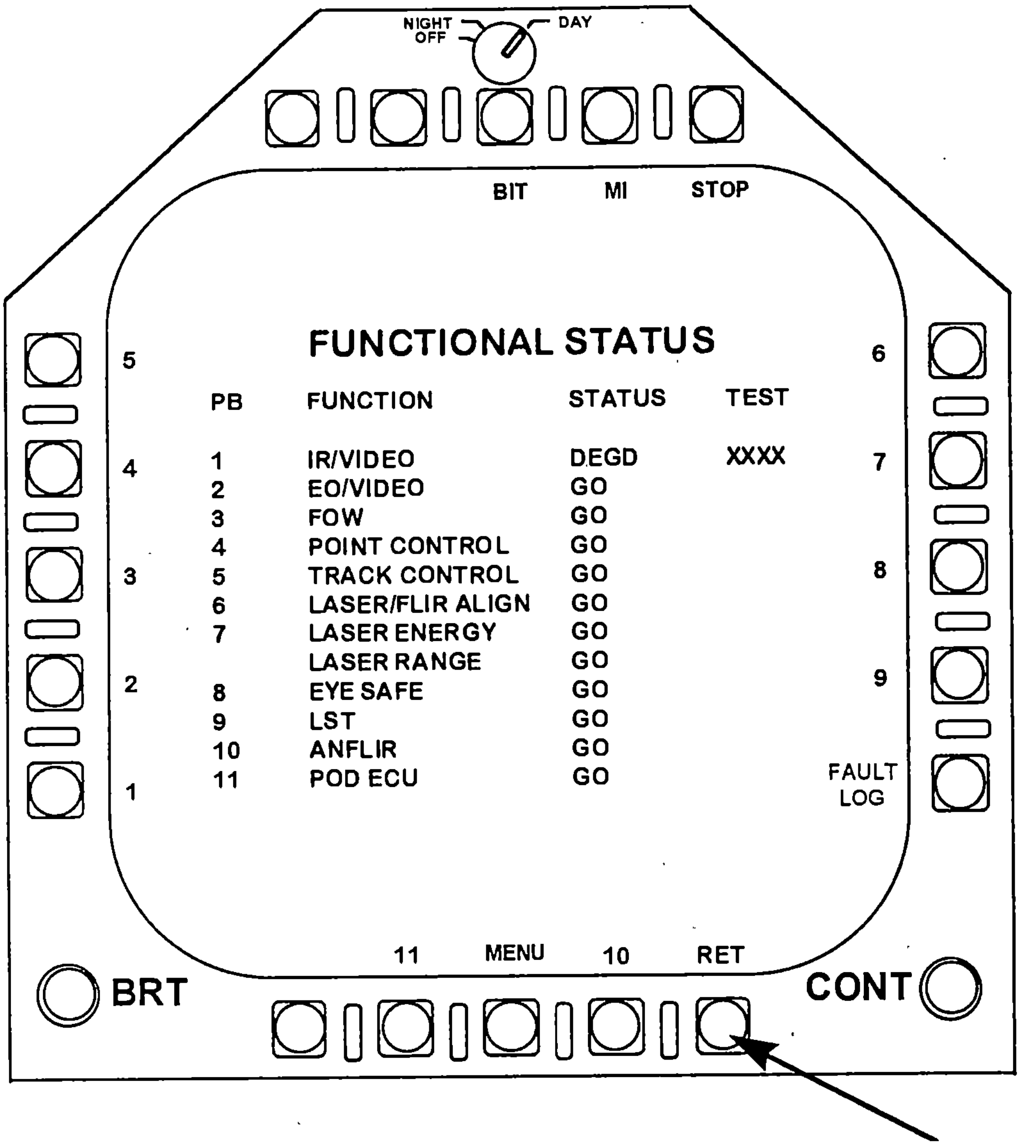

Figure 4-13. ATFLIR MAINT BIT Sublevel Format.

Adapted from: *Draft System/Segment Design Document (SSDD) for the Advanced Targeting FLIR with the 15C System Configuration Set, Boeing Aircraft, St. Louis, Missouri, June 1998.*

ATFLIR status information is also presented on the tactical ATFLIR format. Figure 4-14 represents the tactical ATFLIR format with SETUP selected. The green bar represents a gray scale that aids aircrew in adjusting the video image. SETUP provides for display of the tactical system status similar to the FLIR MAINT BIT sub-level. This is inconsistent with every other tactical format available in the F/A-18. The intent was to provide status information without aircrew having to select the BIT format [8]. If an aircrew is using the tactical ATFLIR format, however, there is no indication of a failure that requires the SETUP option to be selected other than an observed system performance degrade. The AN/APG-73 RDR/ATTK format utilizes an 'X' through mode legends to indicate failures. This technique rapidly conveys to aircrew the top-level status of the system. **The author recommends utilizing a consistent methodology to indicate system failures on tactical formats [R3].**

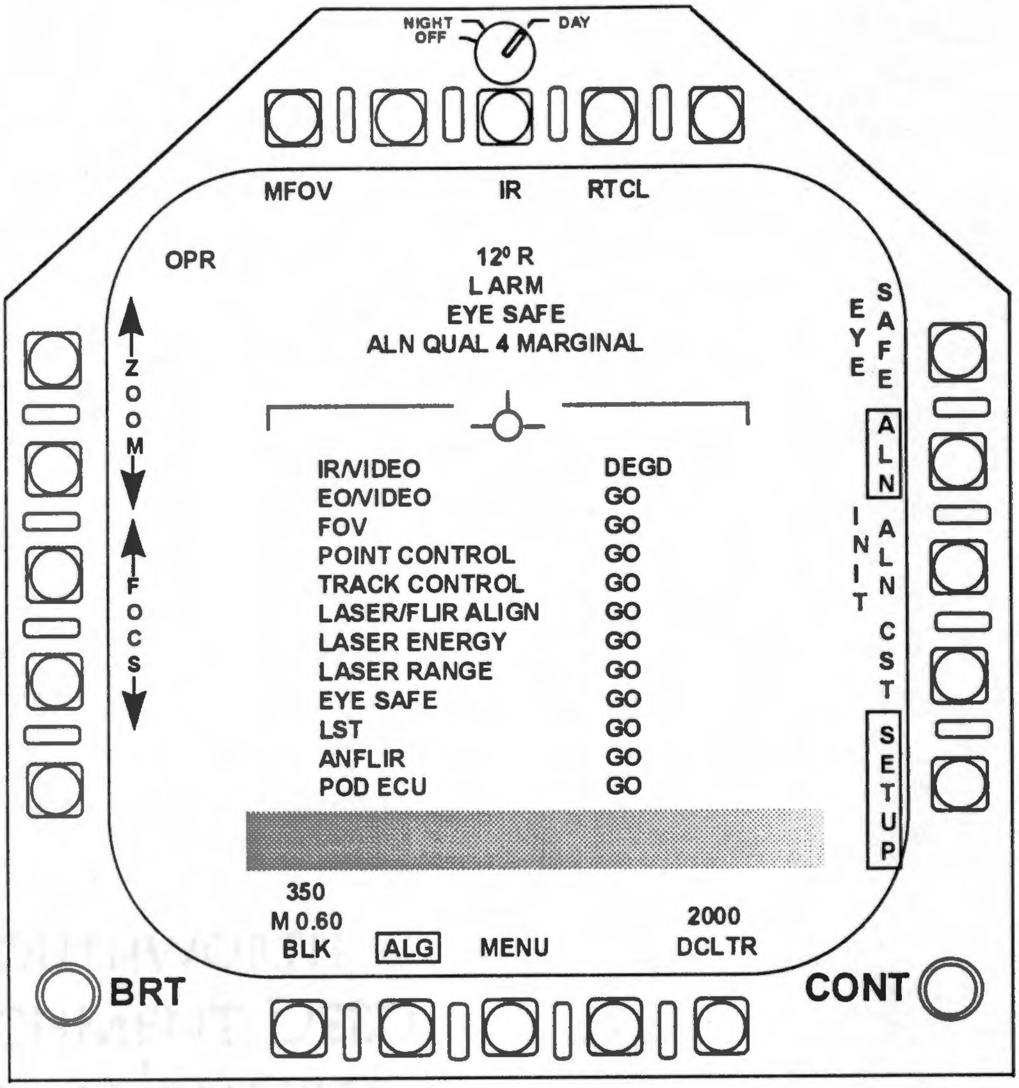

Figure 4-14. ATFLIR Tactical Format (SETUP selected).

Adapted from: Draft System/Segment Design Document (SSDD) for the Advanced Targeting FLIR with the 15C System Configuration Set, Boeing Aircraft, St. Louis, Missouri, June 1998.

ALR-67 (V) 3 BIT Format

The status of the ALR-67 (V) 3 RWR is indicated on the EW equipment group sub-level, as shown in Figure 4-16. There is no further information available on the current BIT display formats. Instead, aircrew must first select the EW format from the TAC MENU, Figure 4-17, and then select ALR67. The box around the ALR67 legend indicates the selection of the ALR-67 (V) 3 in Figure 4-18. A system failure will cause DEGD to be displayed in the lower left corner of the format. Depressing the BIT pushtile, pushbutton 1, will result in a sequence of at least six displays to be displayed at a 1.5 second interval [10]. Pushing and holding the SPCL button will temporarily suspend the sequence for detailed review until the SPCL button is released.

The top-level ALR-67 (V) 3 BIT format in Figure 4-18 details the specific sub-system failures. Subsequent pages provide 2x4 matrices of hexadecimal engineering codes pertaining to the failures. It is possible that a degraded condition can be indicated on the EW format, but a MSP code is not set. The only way for the specific BIT codes to be utilized by maintenance personnel is for them to be copied by hand from the display. This is another case where BIT information should be automatically downloaded to the aircraft memory cartridge. The information can then be stored in a maintenance computer database to provide a fault history. **The author recommends that specific fault information be stored**

in a maintenance computer database, referenced to the equipment serial number, and returned with the unit if it fails as a fault history [R12].

In this example (Figure 4-18), the ALR-67 (V) 3 BIT page indicates a Special Receiver failure. This legend not only provides very little information to the cperator, it is also a legacy from ALR-67 (V) 2 – the corresponding component in ALR-67 (V) 3 is called the Countermeasures Receiver (CR). Even if the aircrew understands the function of the CR, the mission impact of the failure is unclear. Overall, the ALR-67 BIT format is inconsistent with even the current BIT reporting scheme, and provides the operator very little useful information. **The author recommends removing the existing ALR-67 (V) 3 BIT display from the EW format and incorporating the system on the aircraft BIT format using F/A-18 BIT conventions [R5].**

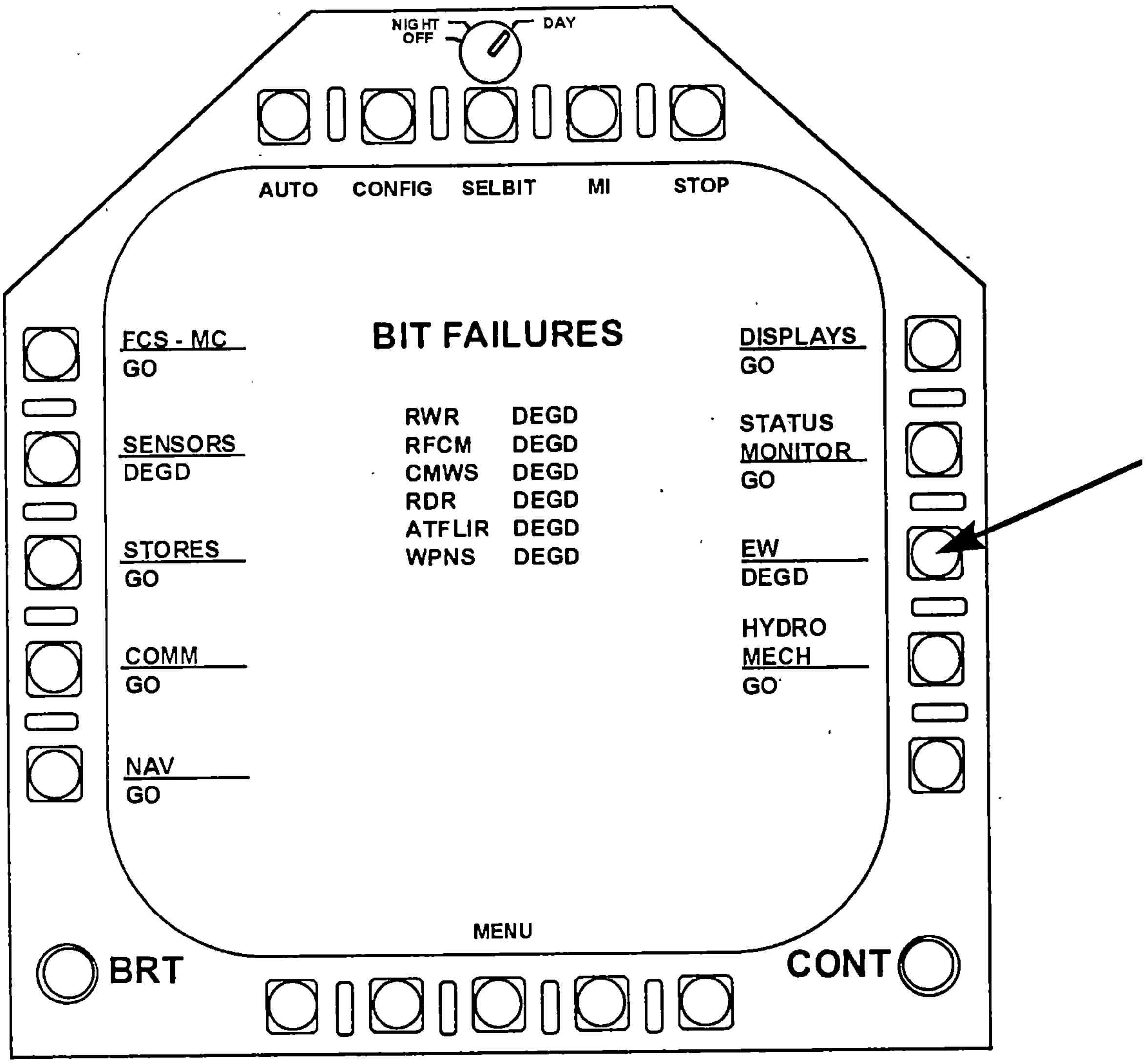

Figure 4-15. Top-Level BIT Format.

Adapted from: *System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set*, *Boeing Aircraft, St. Louis, Missouri, 1998.*

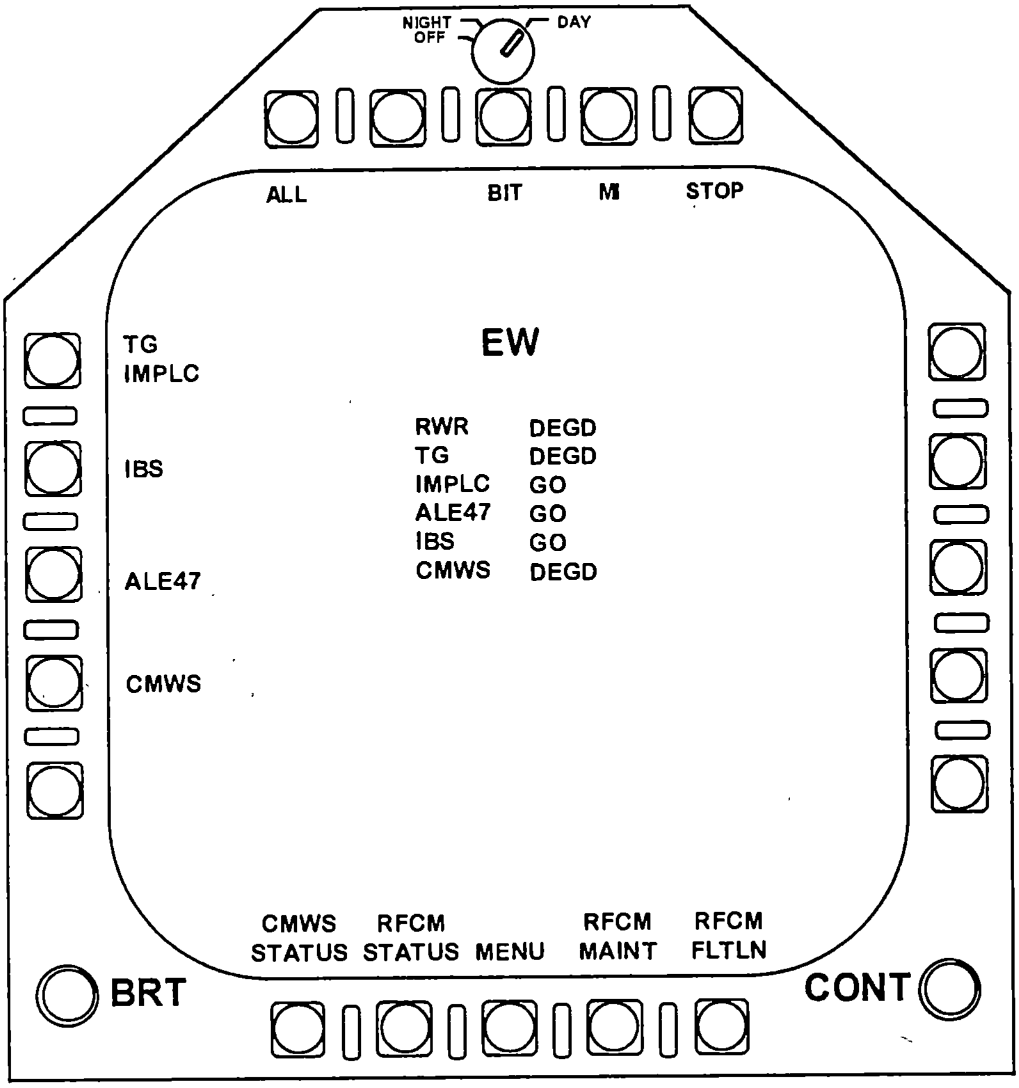

Figure 4-16. EW Equipment BIT Sublevel Format.

Adapted from: *System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.*

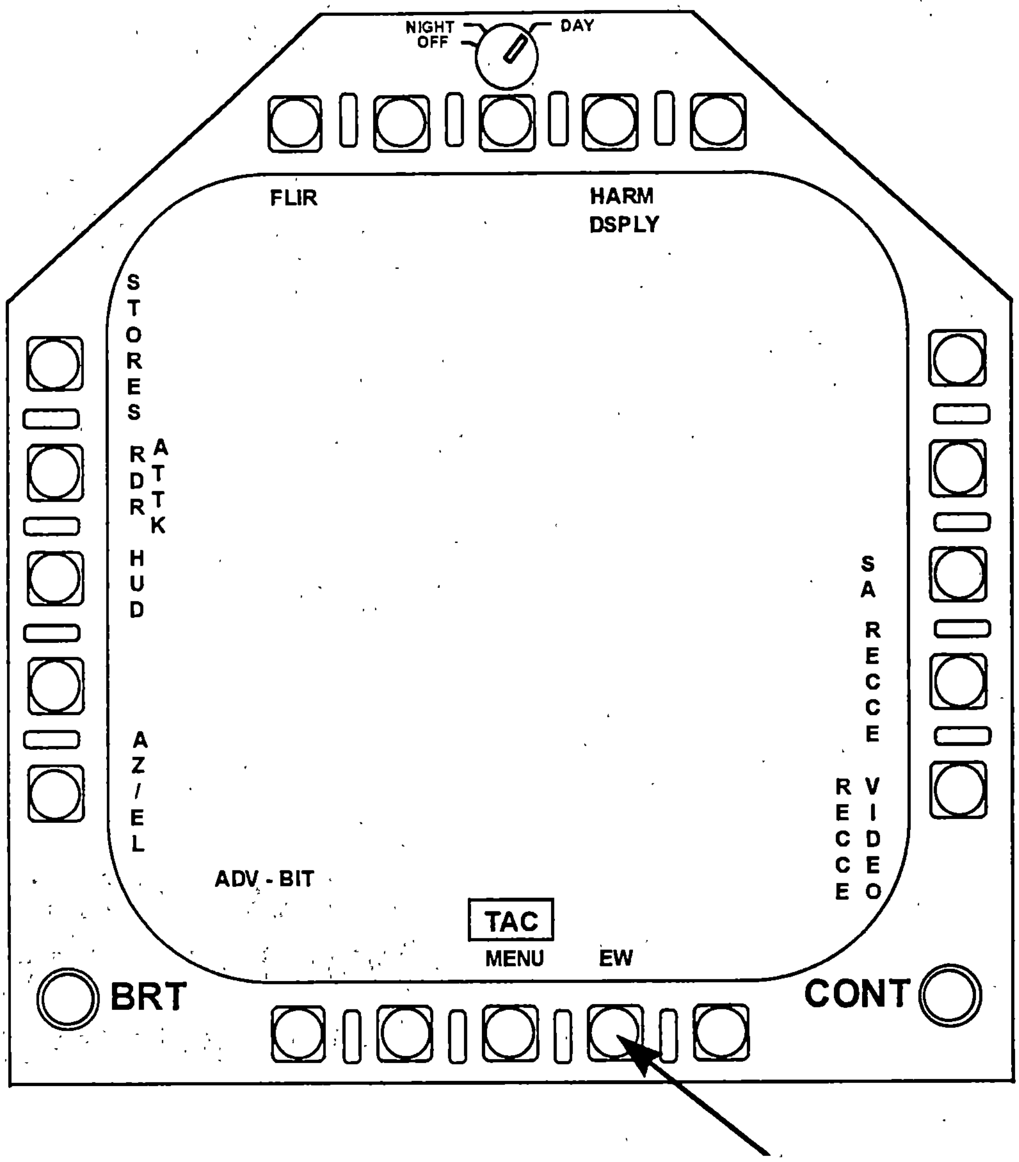

Figure 4-17. TAC Menu.

Adapted from: System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set, *Boeing Aircraft, St. Louis, Missouri, 1998.*

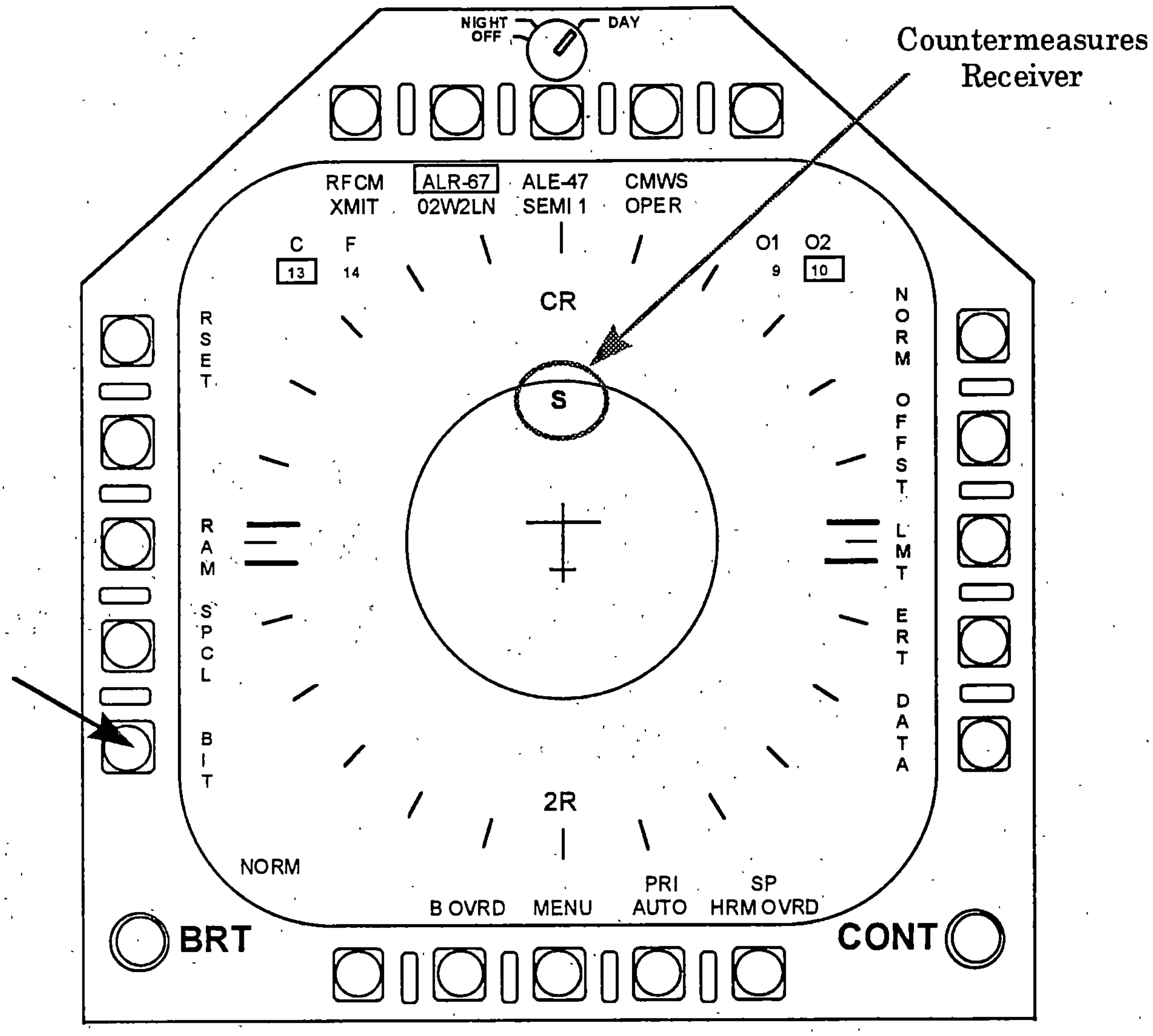

Figure 4-18. ALR-67(V)3 BIT Format.

Adapted from: *System / Segment Design Document for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set*, *Boeing Aircraft, St. Louis, Missouri, 1998.*

AIM-120 AMRAAM BIT Formats

The AIM-120 AMRAAM performs an automatic 3-second BIT on aircraft power-up, the results of which are displayed on the BIT STORES STATION sub-level and under the wing-form on the STORES format. This is shown in Figures 4-19 and 4-20. The AM TEST option on the STORES DATA sub-level performs a complete weapon IBIT on the ground, and a Data Link test in the air. This is inconsistent with other weapons that communicate on the multiplex bus, where the IBIT option is on the BIT STORES STATION sub-level. **The author recommends removing the AM TEST option from the STORES DATA sub-level and placing the weapon IBIT on the BIT STORES STATION sub-level [R14].** The status legend for a station failure with AIM-120 is FAIL, while if the weapon fails the legend is WFAIL. Given the WFAIL convention, clarity is added by substituting SFAIL for FAIL to indicate a station failure. **The author recommends replacing the station FAIL status legend with SFAIL to indicate a station failure [R15].**

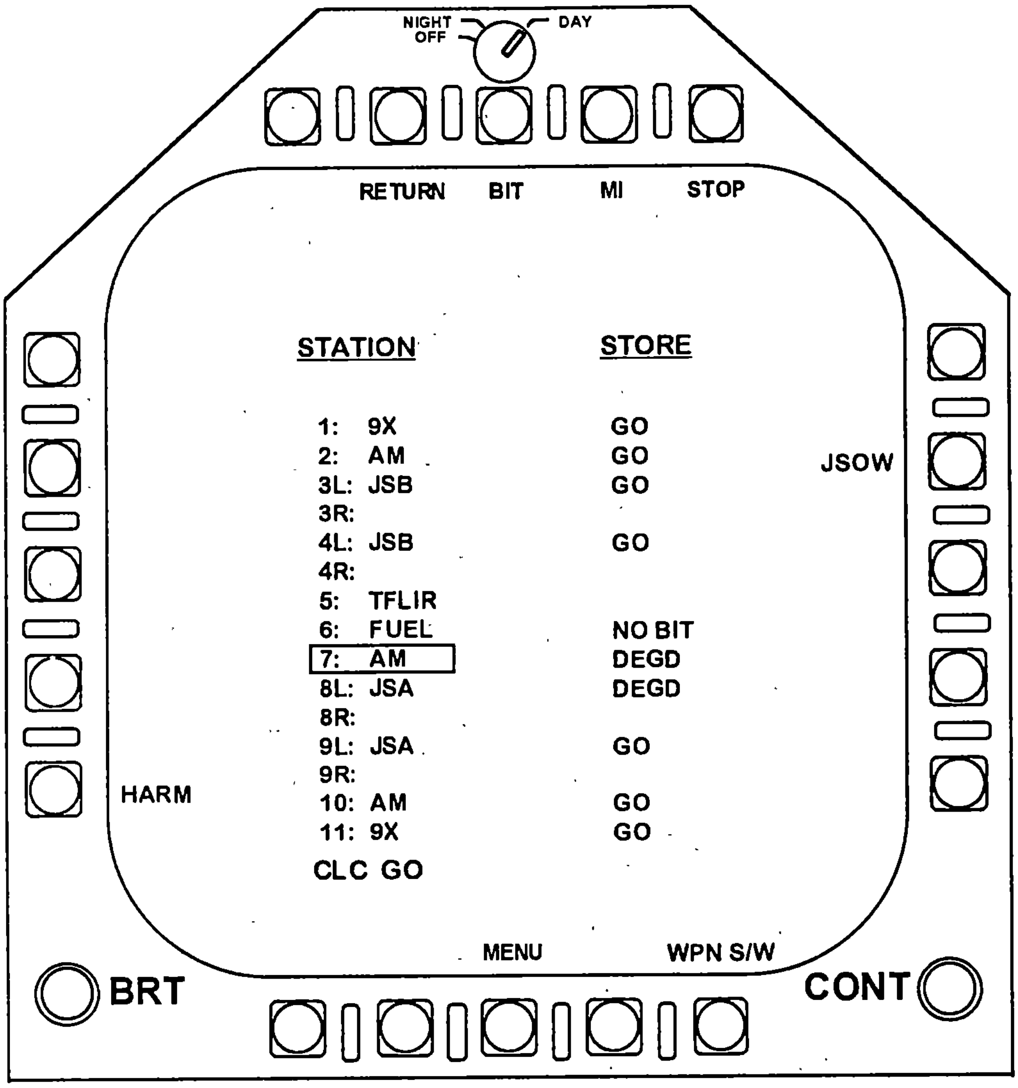

Figure 4-19. Stores Station BIT Sublevel (AMRAAM).

Adapted from: *Operation of the FA-18 Avionic Subsystem for Aircraft with the 13C System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.*

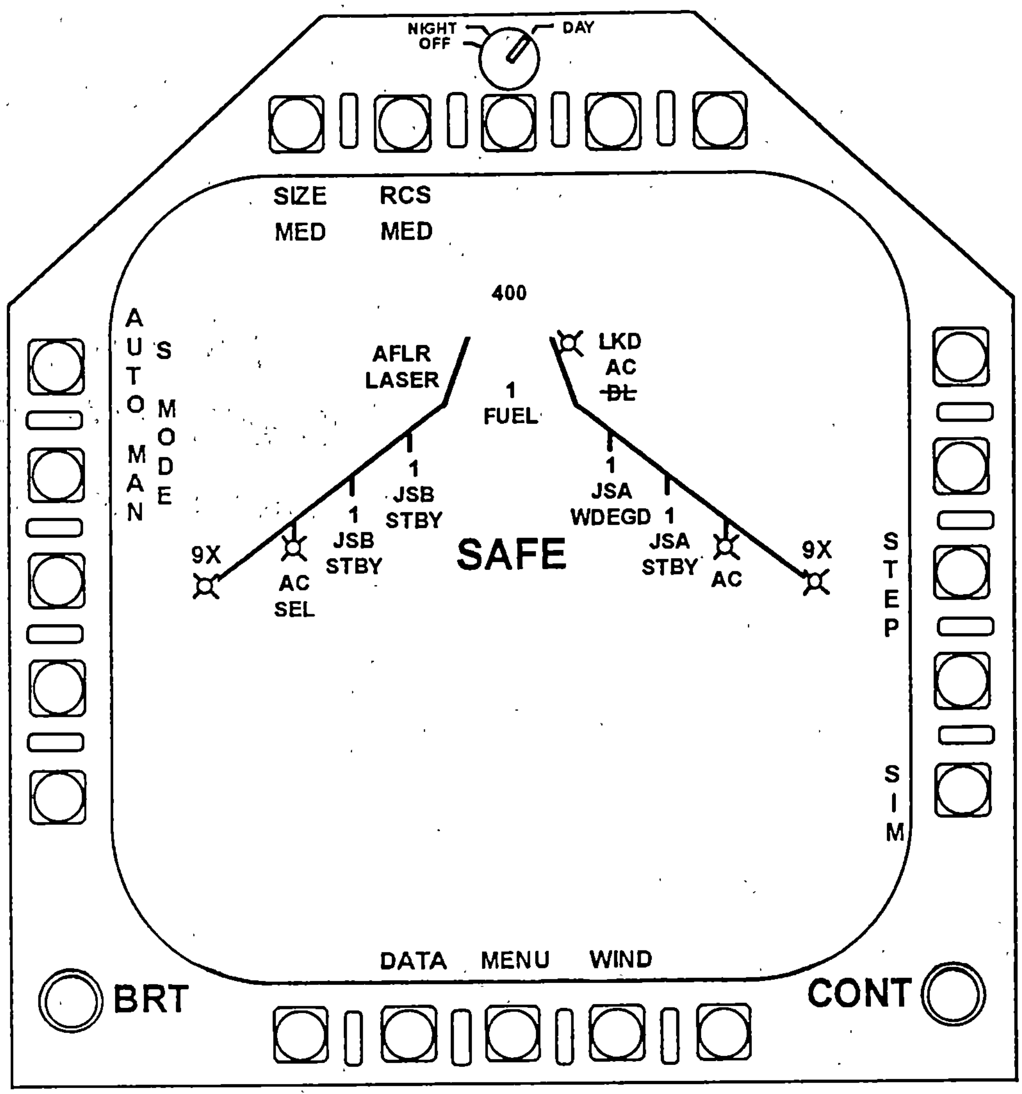

Figure 4-20. STORES Format (AMRAAM selected).

Adapted from: Operation of the FA-18 Avionic Subsystem for Aircraft with the 13C System Configuration Set, Boeing Aircraft, St Louis, Missouri, 1998.

AGM-154 JSOW BIT Formats

Weapon status information for the AGM-154 JSOW is presented on the STORES, the BIT STORES STATION sub-level, and the JSOW formats. These formats are presented in Figures 4-21 and 4-22. A complete BIT is performed on each weapon loaded at aircraft power-up, and these results are displayed on all three formats. Detailed information as to the specific component failures of the priority weapon is available only in the weapon health area of the JSOW format. The JSOW weapon component fail cues are clear abbreviations, but the effects on weapon performance of any one or more failures are ambiguous. The status codes on the STORES and BIT STORES STATION formats provide an indication of whether the failure is one that has degraded weapon performance (WDEGD) or one that has resulted in a release inhibit (WFAIL). A WFAIL indication can be interpreted as a critical failure, since release has been inhibited. Combining the information on the JSOW format with that on either the STORES or BIT STORES STATION formats, however, still does not give the aircrew an indication of the mission impact of a degraded weapon. In the example in Figure 4-23, the priority JSOW has experienced an Inertial Measurement Unit failure as indicated by the IMU FAIL cue. The in-flight transfer alignment cue, which indicates the quality of the weapon IMU alignment that is "transferred" from the aircraft navigation system, displays MARGINAL. Weapon training documentation defines MARGINAL as a transfer alignment that is sufficient to enable GPS acquisition after launch, but if GPS information is denied, the weapon navigation quality is insufficient to meet accuracy specifications. It is unclear to the aircrew whether the MARGINAL cue is due to the IMU FAIL indication or whether additional aircraft maneuvers are required to enhance the transfer alignment. Additionally, this cue is available airborne only, so it is not possible to make the assessment on the ground. **The author recommends providing unambiguous cues of estimated current weapon performance, referenced to nominal weapon performance [R4].**

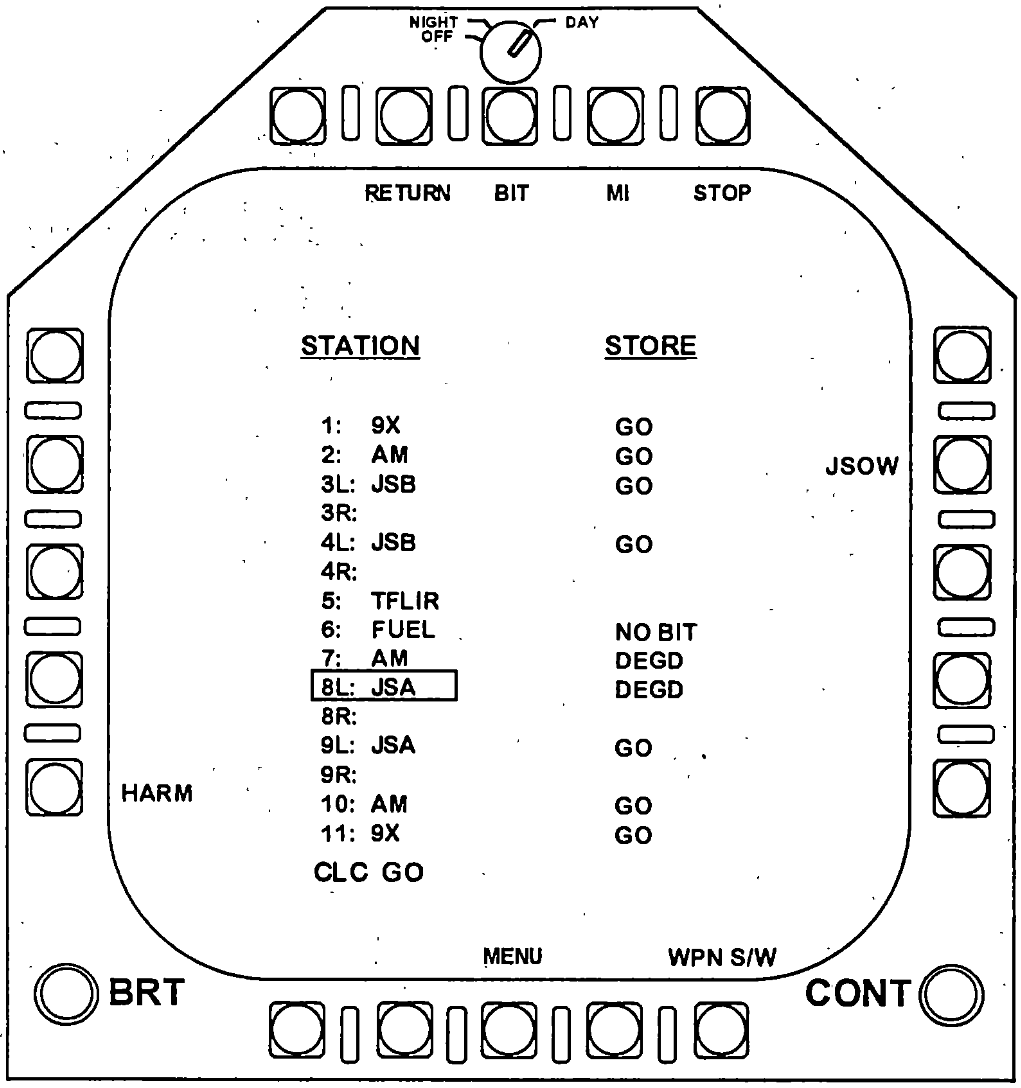

Figure 4-21. Stores Station BIT Sublevel (JSOW selected).

Adapted from: Operation of the FA-18 Avionic Subsystem for Aircraft with the 13C System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.

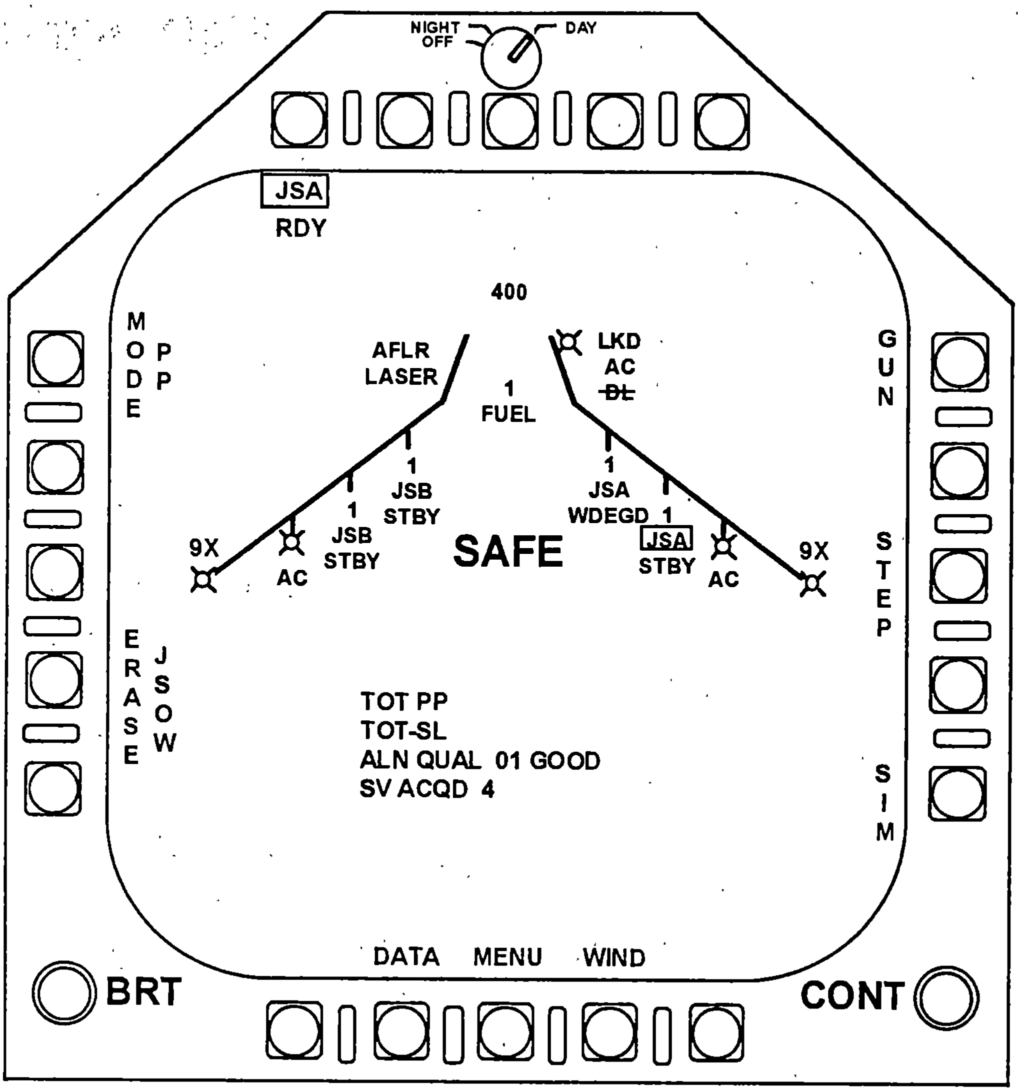

Figure 4-22. Stores Format (JSOW selected).

Adapted from: *Operation of the FA-18 Avionic Subsystem for Aircraft with the 13C System Configuration Set*, *Boeing Aircraft, St. Louis, Missouri, 1998.*

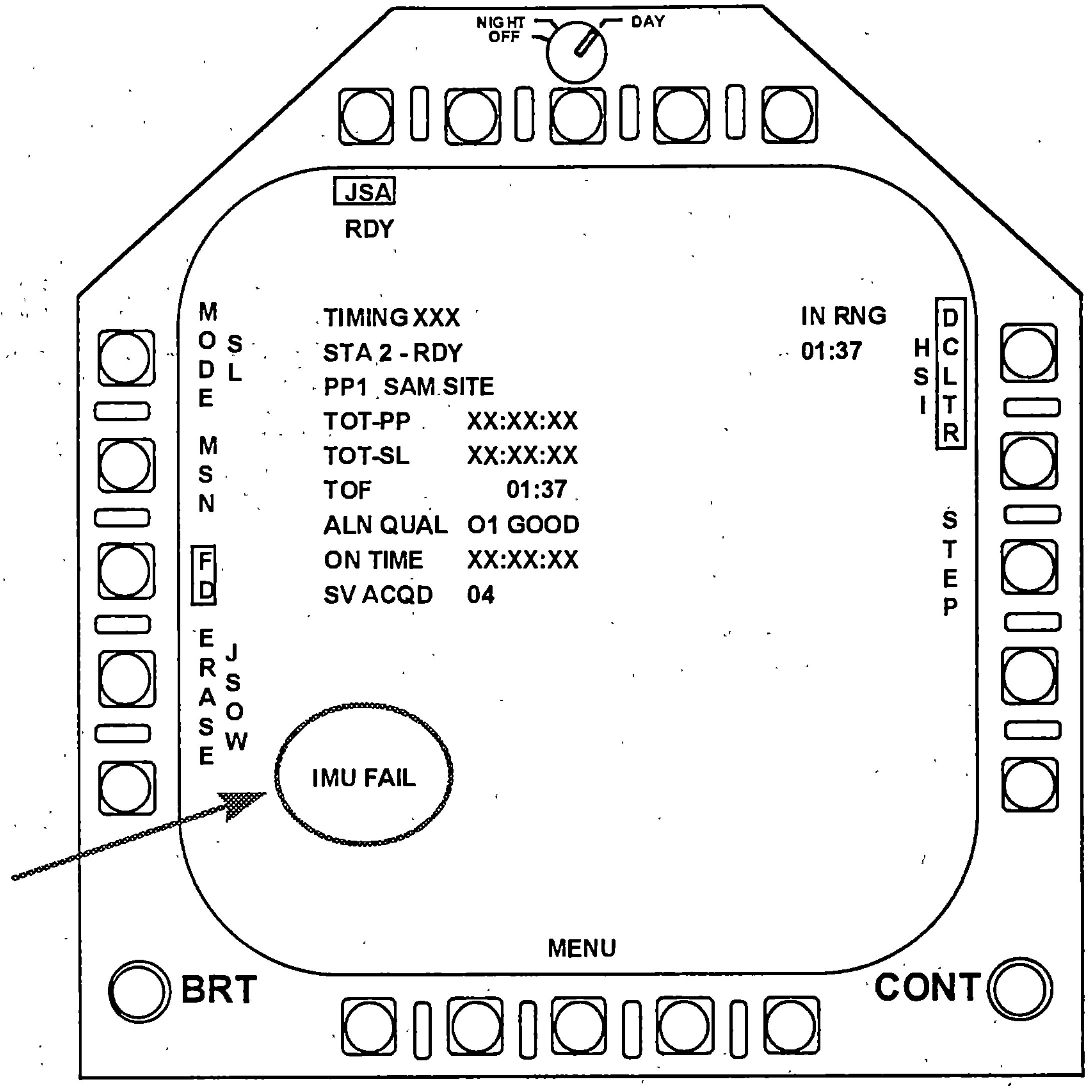

Figure 4-23. JSOW Format.

Adapted from: *Operation of the FA-18 Avionic Subsystem for Aircraft with the 13C System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.*

Status Summary – Existing Displays

The goal of presenting systems status information is to provide to the aircrew with the ability to make decisions as to the mission readiness of the aircraft. The first step in the process is to assess the mission impact of each reported failure and then synthesize this information into an overall evaluation of mission readiness.

The RFCM system reported a RFTF degrade (Figure 4-4), which alone requires an aircrew to have an extensive knowledge of electronic warfare and the RFCM system in order to assess mission impact. Assuming the aircrew does have such knowledge, the assessment would be that there could be problems operating the RADAR and RFCM in the same RF band. The extent of the impact is unclear, however, so the aircrew must assume the worst – the RADAR and RFCM operation in the RADAR band is mutually exclusive – and priority must be given to one capability. The MiG-23G Flogger air-to-air threat employs the Hi Lark 2 RADAR, which operates in the 12GHz and 16GHz bands. The SA-6 Straight Flush and SA-3 Low Blow surface-to-air systems operate in the 8.6-8.8GHz and 9.3GHz bands, respectively. These frequencies are outside the AN/APG-73 band, and the conclusion would be that the RFTF failure has no mission impact.

The CMWS status display (Figure 4-6) indicates a failure of the Electronic Control Unit (ECU). System documentation indicates that this is a critical failure, and that the system is inoperative as a result. Training and system knowledge are required to make that determination. The SES mission is to be conducted completely at high altitude, where the CMWS system is ineffective. Thus, the critical failure of the CMWS system will not impact mission accomplishment.

The AN/APG-73 RADAR (Figure 4-10) indicates degraded Air-to-Ground Ranging (AGR), Real Beam Ground Map (RBGM), and Precision Velocity Update (PVU), along with a Fixed Target Track (FTT) failure. The SES mission requires the A/A RADAR modes due to the Airborne Interceptor (AI) threat, but the JSOW mission plan uses the pre-planned modes, which do not require A/G RADAR modes. The degraded A/G RADAR modes will not have an adverse impact on mission accomplishment.

The JSOW, since it is launch-and-leave and requires no post-launch interaction from the host platform, also does not have the capability to transmit an assessment of a success or failure against the desired target. The ATFLIR offers a long range, standoff capability to image the target at weapon impact and provide a degree of bomb impact assessment. The ATFLIR status display indicates a degraded IR VIDEO mode, which limits the aircrew to use the Electro-Optic (EO), or visual spectrum, modes in this role. The SES mission is during the day, and there is briefed to be very little smoke or haze that would obscure a visual sensor. A degraded IR VIDEO mode does not prevent mission accomplishment.

The ALR-67 (V) 3 RADAR Warning Receiver is indicating degrade status on the aircraft BIT format (Figure 4-16), and an S on the ALR-67 BIT format (Figure 4-18). Training and system knowledge is required to understand that the S represents the Countermeasures Receiver, where the RF signal processing takes place. The impact of the failure on system operation, and therefore the mission, is completely unknown. The SES mission brief is that AI and S/A threats are active, which would dictate this failure be classified as NO GO.

The AMRAAM status displays (Figures 4-19 and 20) indicate a degraded data link capability with the weapon on station 7, and full capability with the remaining two weapons. A degraded data link means that missile will be automatically placed as the lowest priority weapon for a normal release, or the highest priority if an Inertial Active launch (for which there is no data link) is selected. The fighter-to-threat AI ratio, the number of fighter missiles and the ability for one fighter to target more than one threat simultaneously, leads to the assessment that the degraded AIM-120 will have little to no impact on mission accomplishment.

The weapon system status displays indicate that one of four JSOW is degraded. It is unclear from the information provided whether the IMU FAIL will result in the weapon failing to impact the intended target, particularly if GPS dropouts or jamming is encountered. Pre-flight, the aircrew must assume that the weapon will be unsuccessful. In this case, a GO/NO GO decision would be based on target priority. The SES mission in this example has no target redundancy (i.e. multiple weapons are directed against the same target), which would force the aircrew to either abort or retarget one of the remaining weapons from a lower priority target.

The overall system status is sufficiently ambiguous that the aircrew would most likely make a NO GO decision. There is insufficient plain-language, tactical information to adequately assess the mission readiness of the aircraft. Aircrew must view a large number of displays to gather status information for the assessment, which is time-consuming and increases the risk that critical information will be missed. **The author recommends incorporating a TAC INFO format which summarizes, in plain-language, the status of all tactical systems on the aircraft [R2].**

Assessment of Mission Readiness - Proposed Displays

Menu Format

The advisory line on the SUPT MENU format of the proposed displays in Figure 4-24 conveys that the weapons, RWR, RFCM, ATFLIR, and RDR are operating in a degraded state. This is indicated by the presence of the advisory and the yellow color text. The red CMWS advisory indicates the system has detected a critical failure. The color-coding gives the aircrew a cue as to the seriousness of the failures without unnecessary caution displays or having to select the BIT format.

Top-Level BIT Format

The proposed top-level BIT format in Figure 4-25 includes a color-coding scheme and two additional options – DCS DWNLD and TAC INFO. The status displayed under the individual equipment groups reflects the status of the entire group. Adding a color-coding scheme aids in rapid status assessment of the equipment groups. A yellow degrade indicates that one or all of the functions performed by that subsystem are degraded. An individual function within that subsystem may be either degraded or failed. A red weapon system advisory indicates a complete subsystem failure. Color-coding the equipment failures displayed in the center of the format provides a visual prioritization of the failures without having to read the legends.

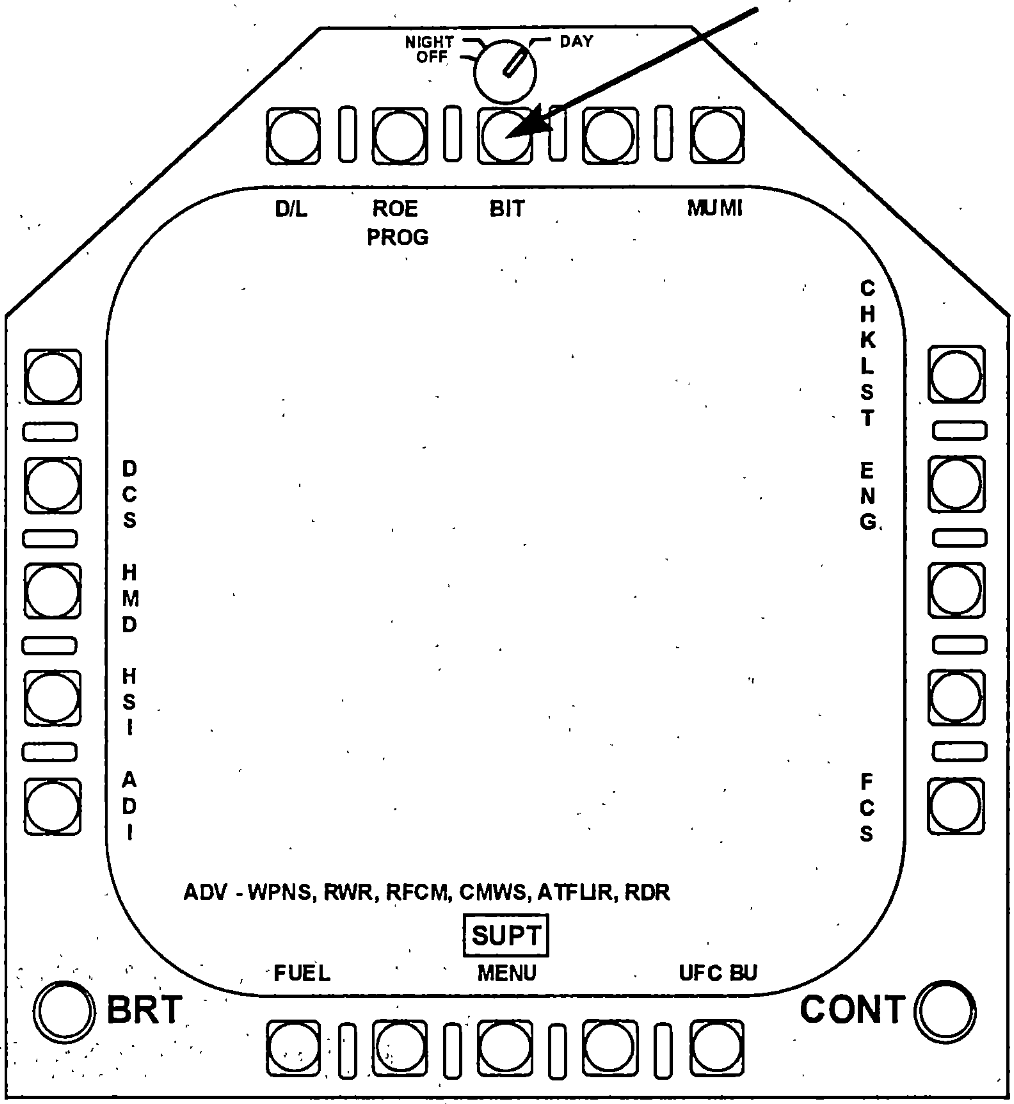

Figure 4-24. TAC Menu (Proposed).

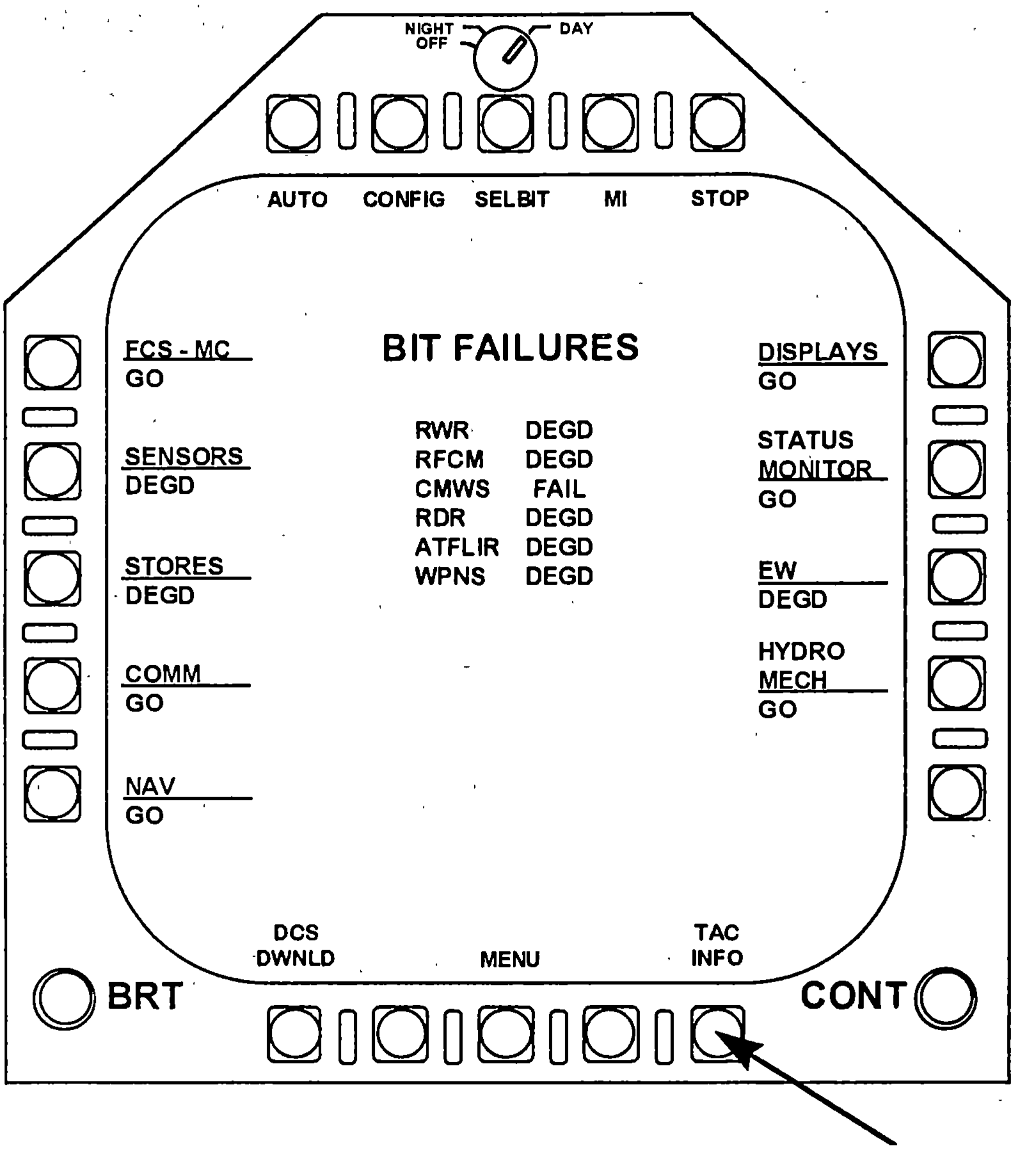

Figure 4-25. Top-Level BIT Format (Proposed).

The DCS DWNLD option introduces an interface between the system status monitoring and reporting system and the Digital Communication Suite (DCS) in the F/A-18. The DCS utilizes one of the ARC-210 radios in the F/A-18 to provide a digital air-to-air and air-to-ground communication link. The proposed DCS DWNLD function would transmit specific maintenance information, such as maintenance status panel (MSP) codes, from the aircraft to maintenance personnel on the ground. This function is similar to those used in the commercial aircraft industry, and would allow maintenance to be prepared to return the aircraft to FMC status as rapidly as possible after aircraft landing.

The most significant change in the proposed displays is the addition of the TAC INFO option. Selecting this option brings the aircrew to the TAC INFO page, shown in Figure 4-26, which provides a summary of the status of all detected weapon and sensor failures. The mission impact of each failure can be rapidly assessed because the fault description is translated into the effects on operational capability of the system. These failures are color-coded, and the term FAIL is added to indicate a total loss of capability of the specific mode or system. The affected WRA and associated MSP code are also listed to provide the complete picture on one display.

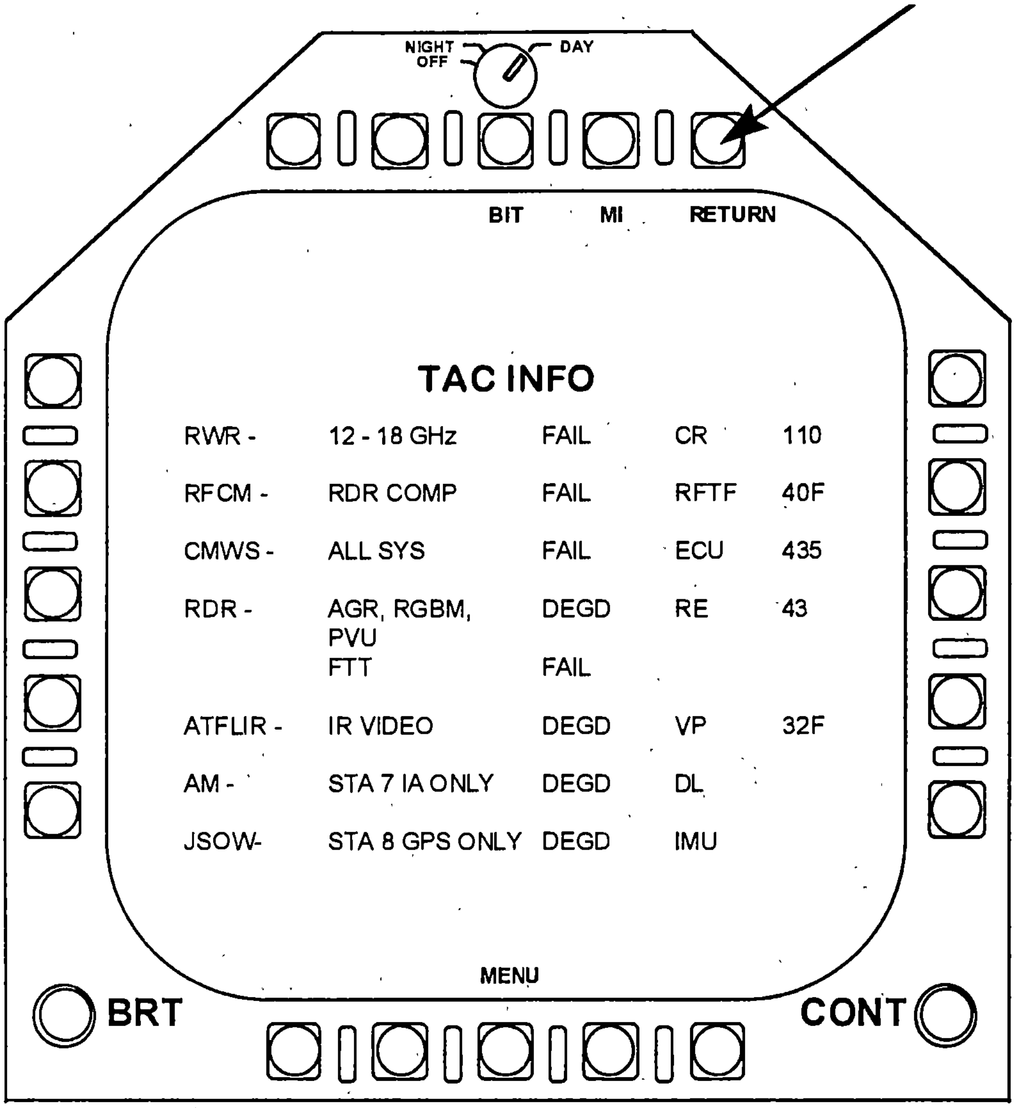

Figure 4-26. TAC INFO BIT Format (Proposed).

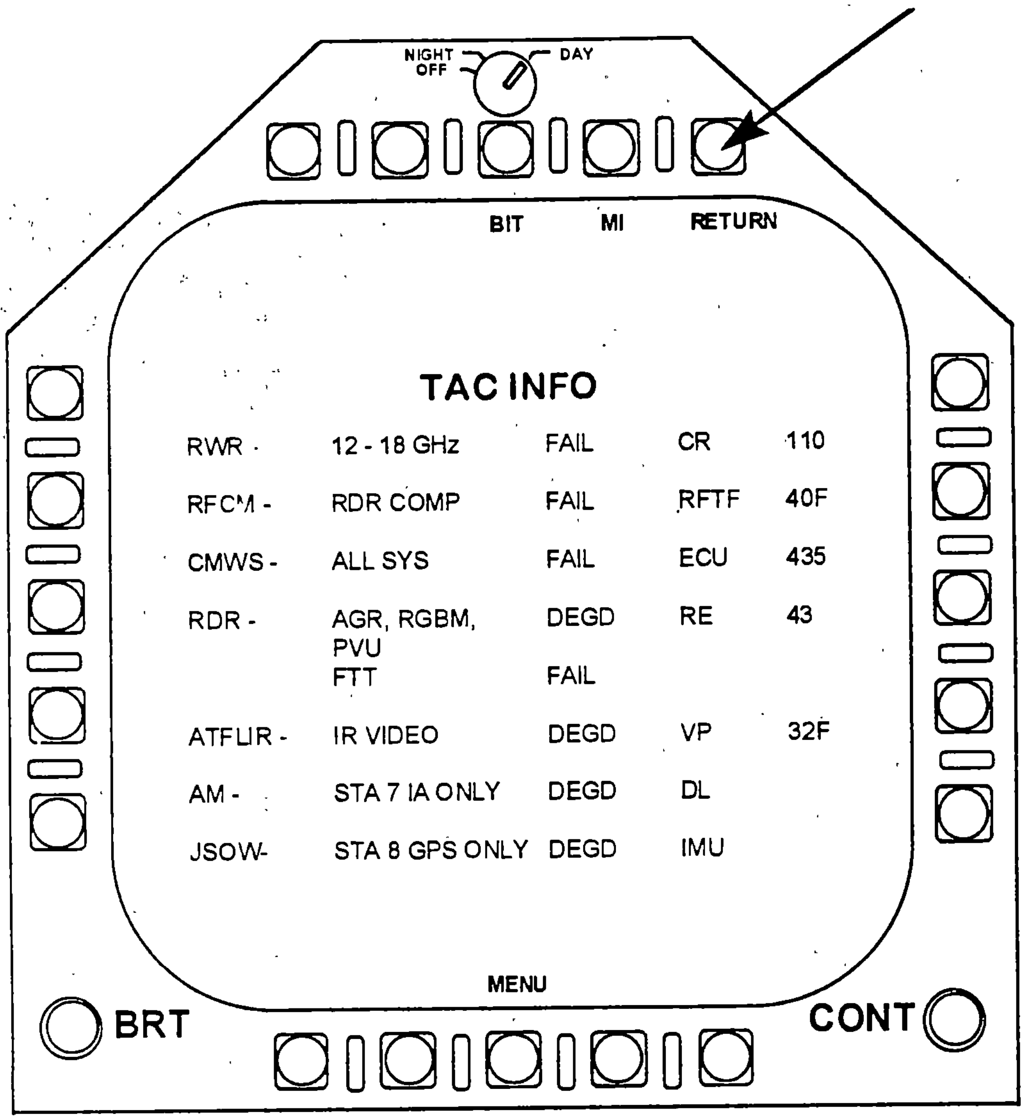

Figure 4-26. TAC INFO BIT Format (Proposed).

Equipment Group BIT Format

The proposed equipment group BIT displays reflect an effort to code using location, legend, and color. As an example, the EW equipment group BIT sub-level, shown in Figure 4-27, locates normal IBIT options at push buttons 1 through 5, additional IBIT options at push buttons 16 through 20, and status options at push buttons 11 through 15. The FAIL legend is added to the current scheme, and is used to indicate a total loss of sub-system capability. The color coding methodology is shown in Table 4-1, and is uniform across all formats.

System Status Displays

Individual system status displays continue the effort toward coding using location, legend, and color. The display looks very similar to the TAC INFO display, except that failures shown refer to the individual system only. In the absence of failures, the format displays the legend "ALL SYSTEMS GO". Examples of individual systems status displays are shown in Figures 4-27, 29, 31, and 33.

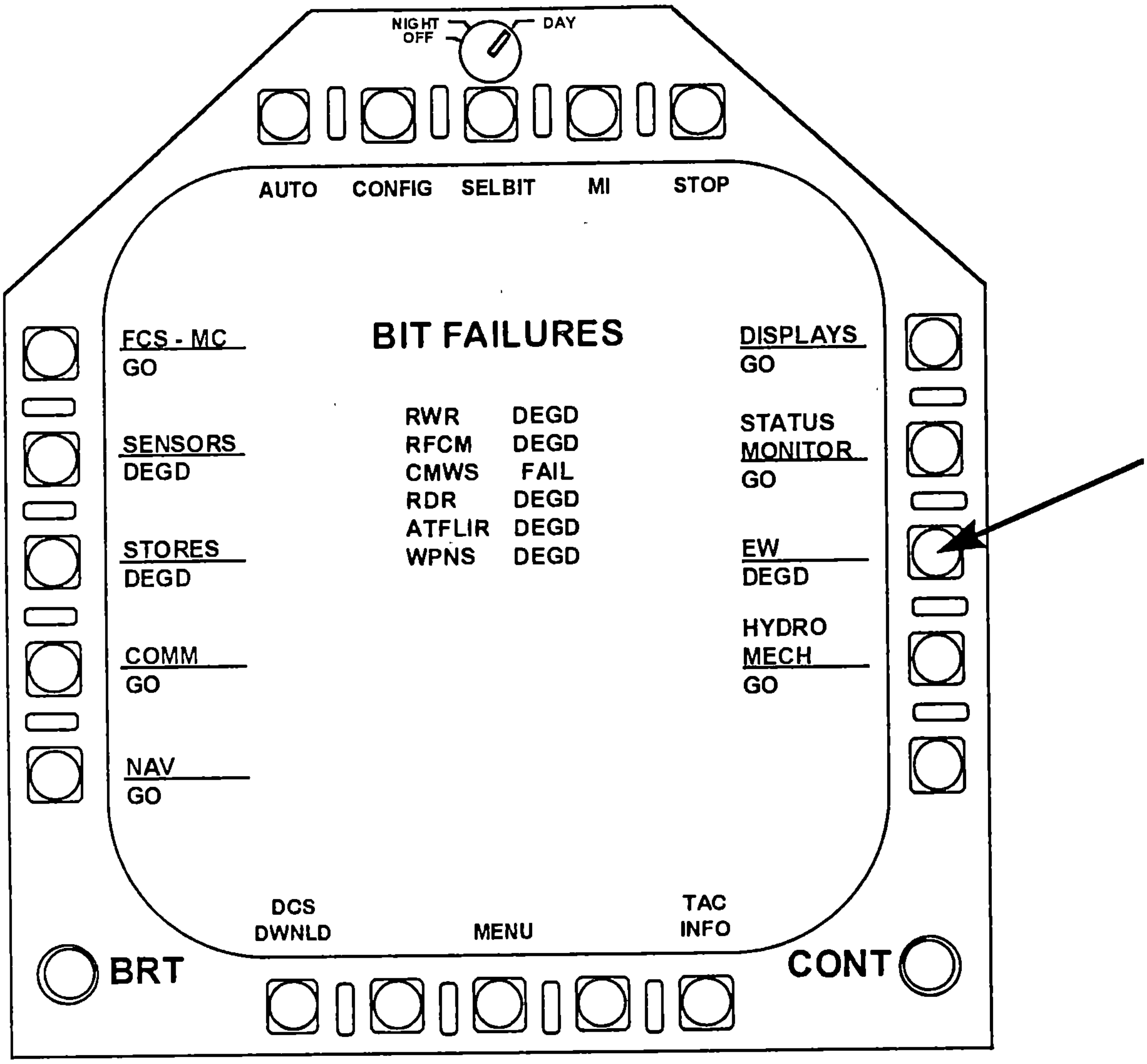

Figure 4-27. Top-Level BIT Format (Proposed).

Table 4-1. Status Messages

STATUS MESSAGE	COLOR	MESSAGE DEFINITION
NOT RDY	**Green**	Equipment OFF, not installed, or initializing.
IN TEST	**Green**	Initiated BIT in progress.
SF TEST	**Green**	Self-test in progress - cannot be operator terminated.
GO	**Green**	Initiated BIT complete without failure.
DEGD	**Yellow**	Failure detected - equipment operation degraded.
NO GO	**Yellow**	Equipment ON but not communicating.
FAIL	**Red**	Failure detected; total loss of sub-system or system functionality.
OVRHT	**Red**	Overheat.
DEGD + OVRHT	**Red**	Detected failure and overheat.
RESTRT	**Green**	Reinitiate BIT; equipment did not respond to BIT command, remained in BIT too long and was terminated by MC.
OP GO	**Green**	Non-critical BIT failure detected.
PBIT GO	**Green**	Initiated BIT has not been run since ground power-up and periodic BIT is not reporting any failures.
MUX FAIL	**Yellow**	Equipment is ON and not communicating on the AVMUX.

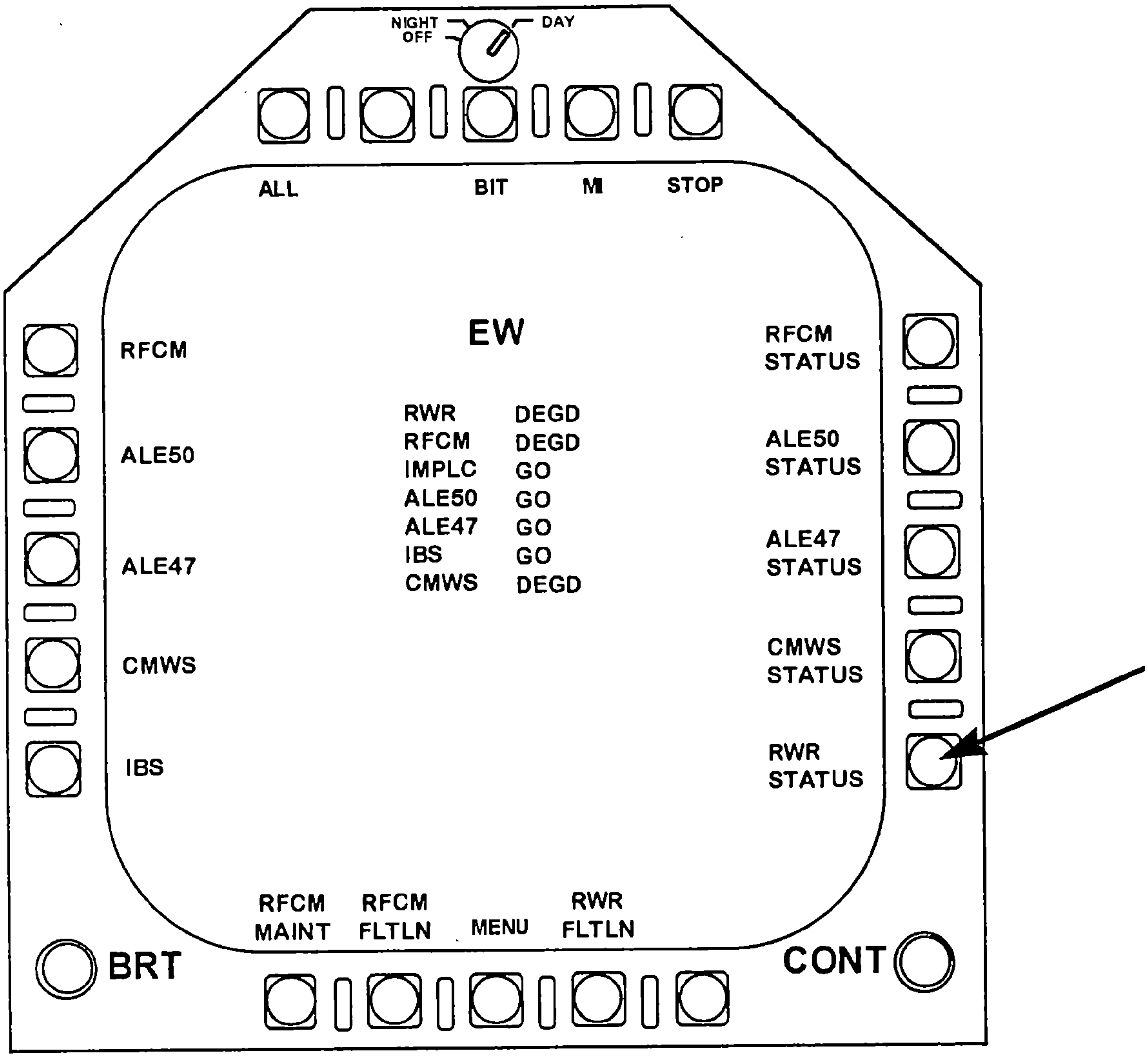

Figure 4-28. EW Equipment BIT Sublevel (Proposed).

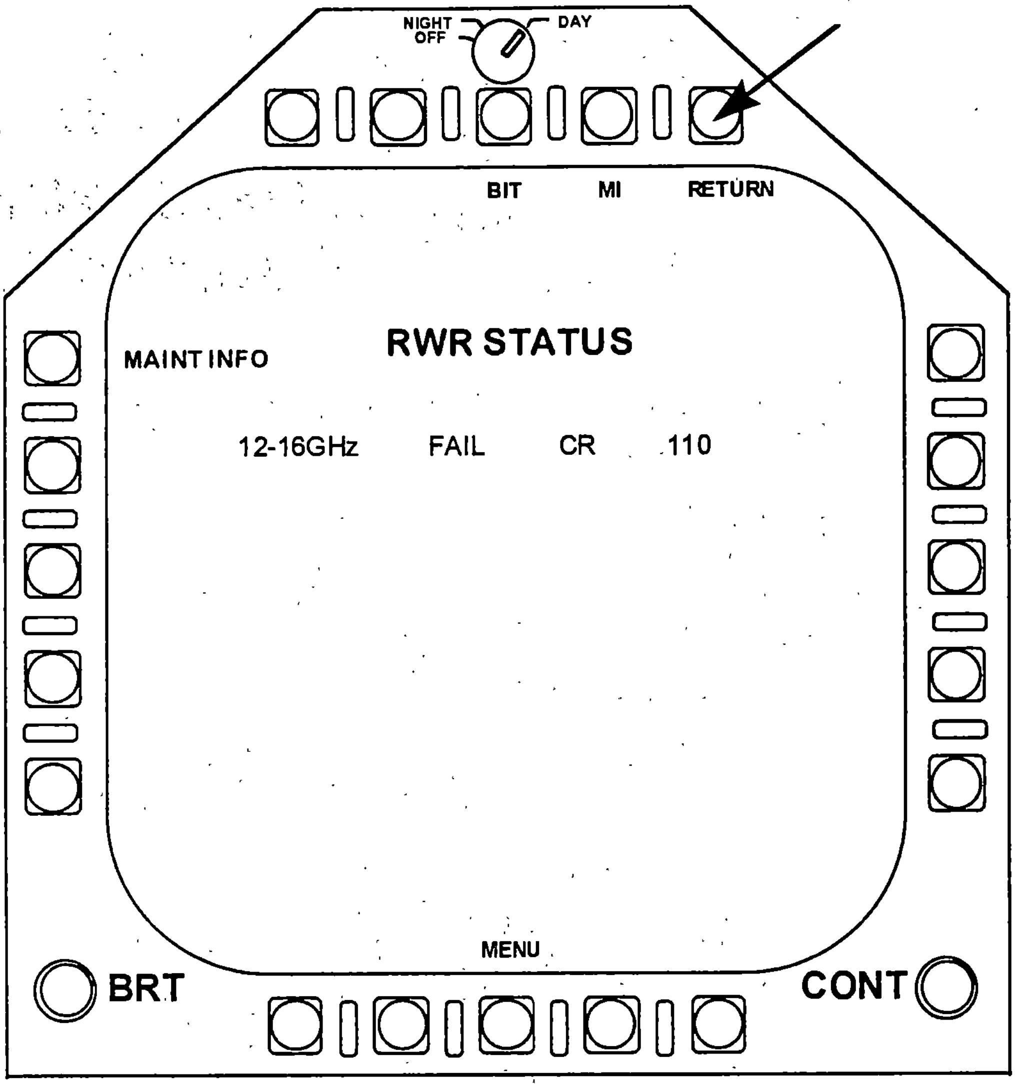

Figure 4-29. RWR Status BIT Sublevel (Proposed).

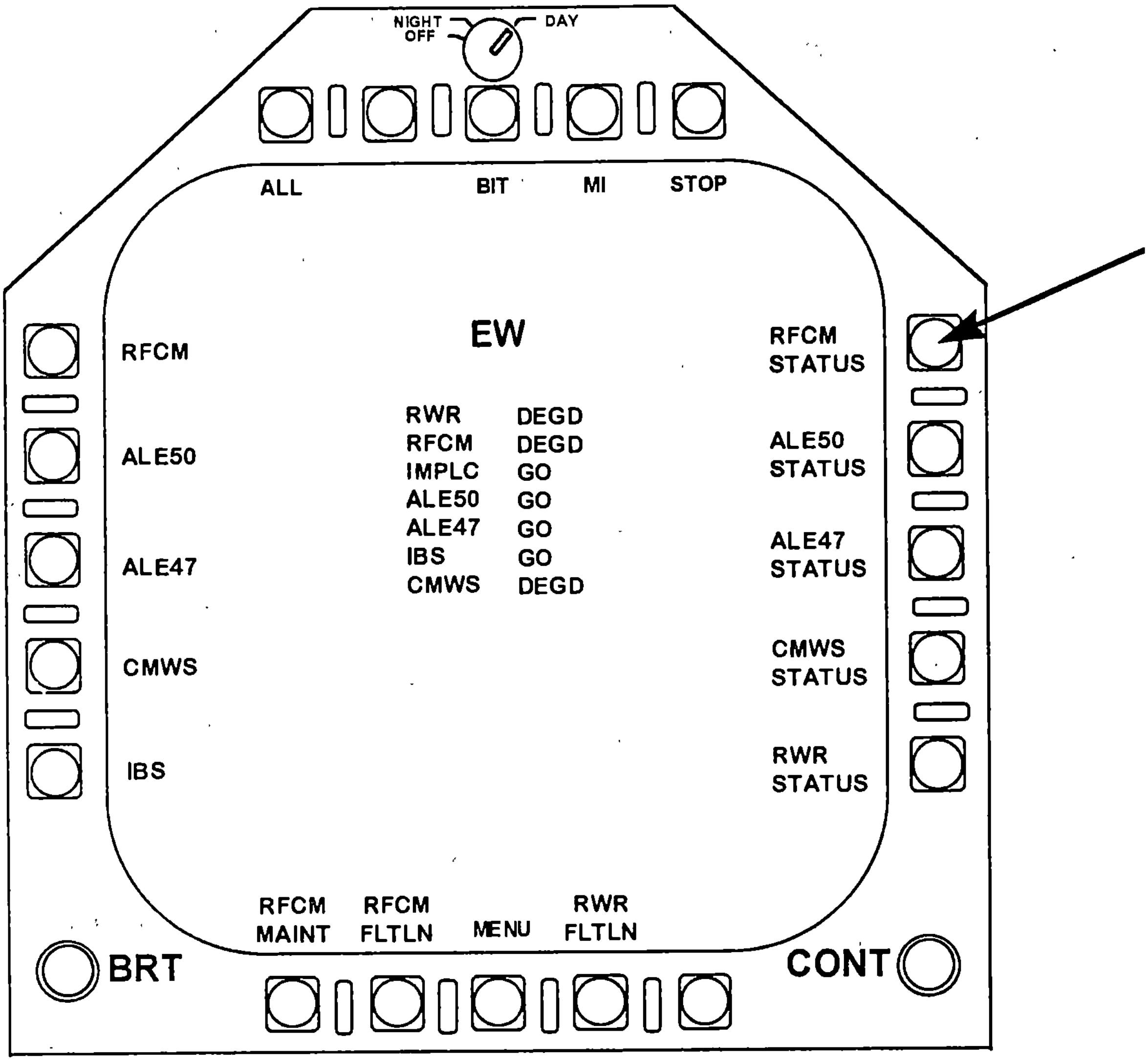

Figure 4-30. EW Equipment BIT Sublevel (Proposed).

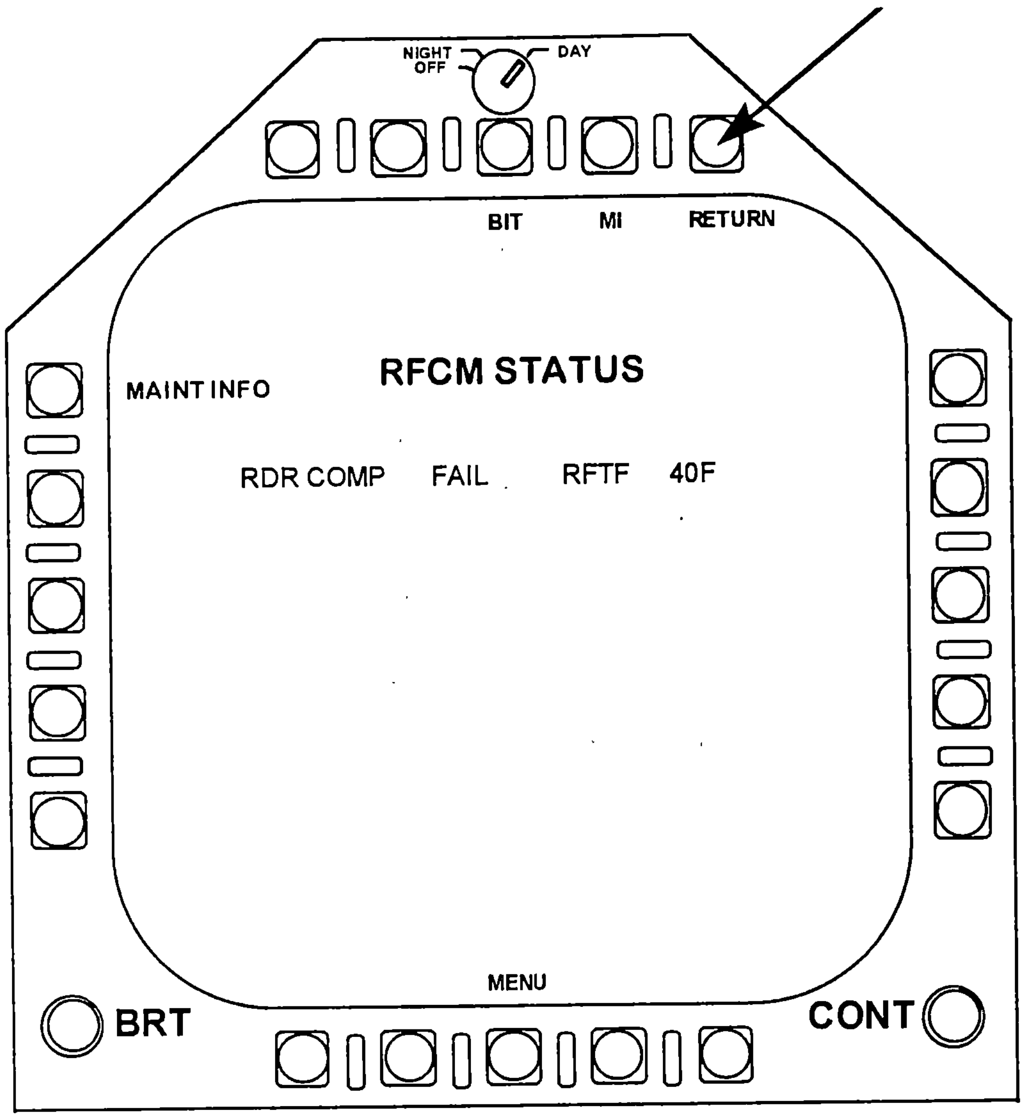

Figure 4-31. RFCM Status BIT Sublevel (Proposed).

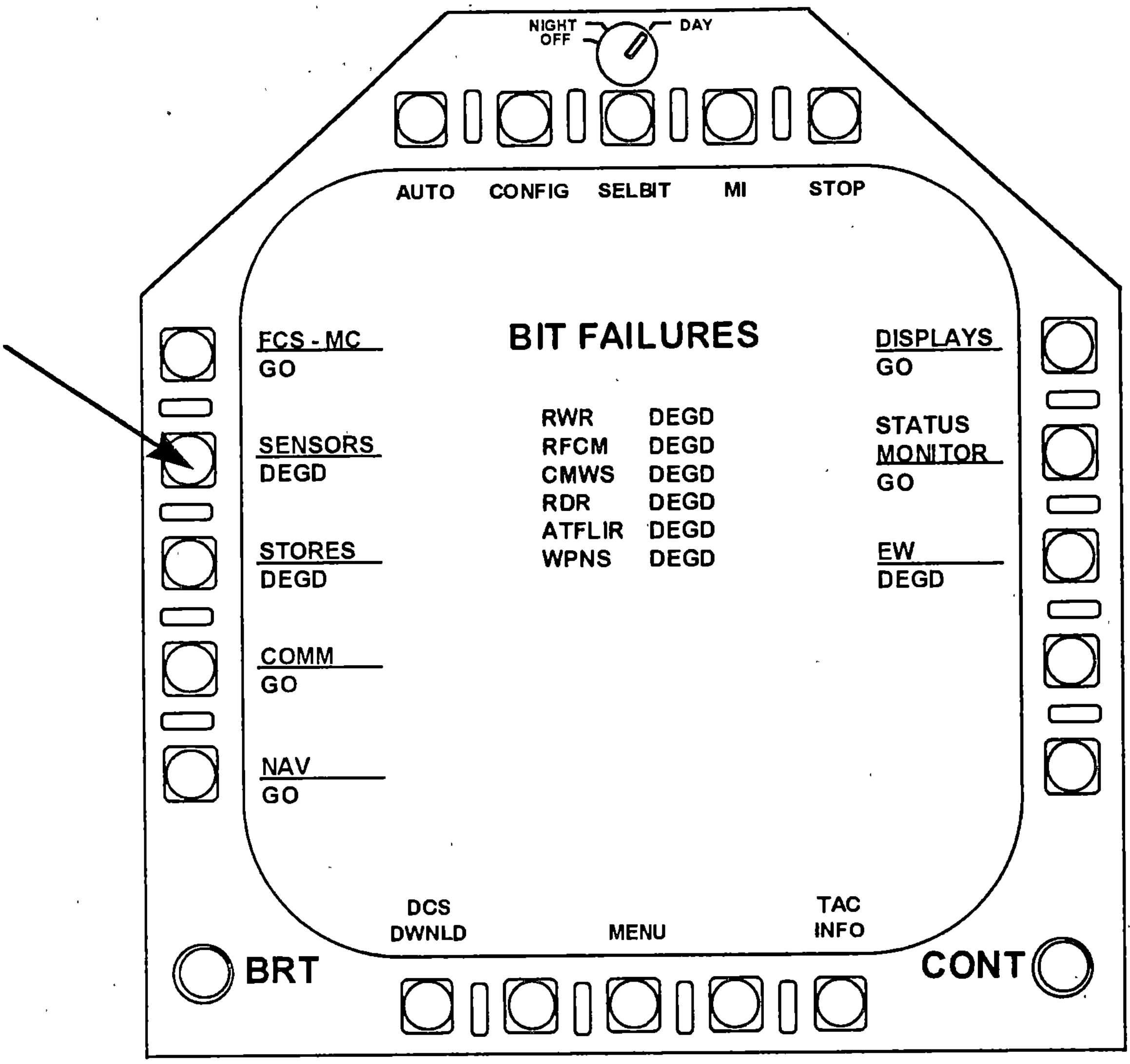

Figure 4-32. Top-Level BIT Format (Proposed).

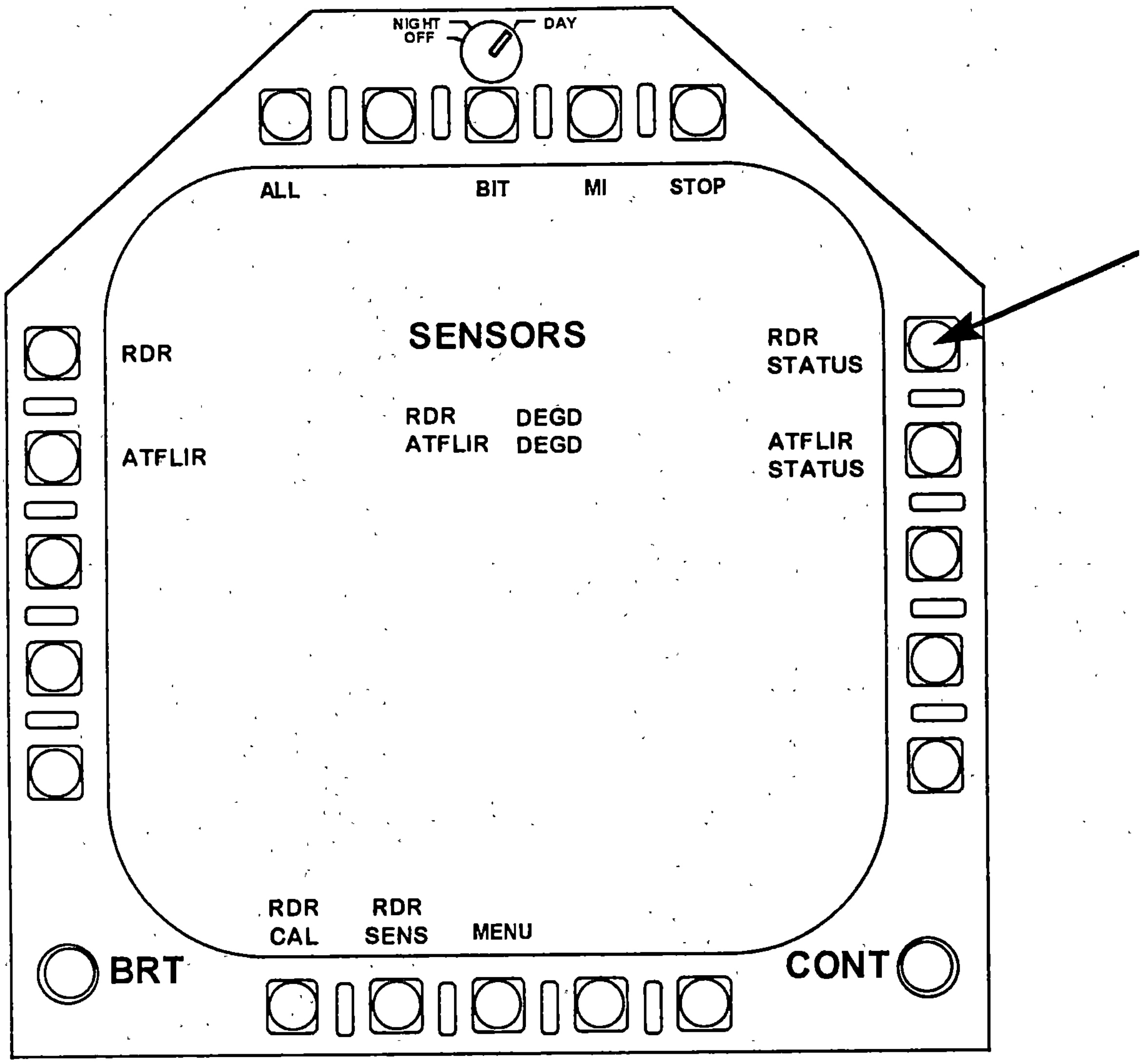

Figure 4-33. Sensors Equipment BIT Sublevel (Proposed).

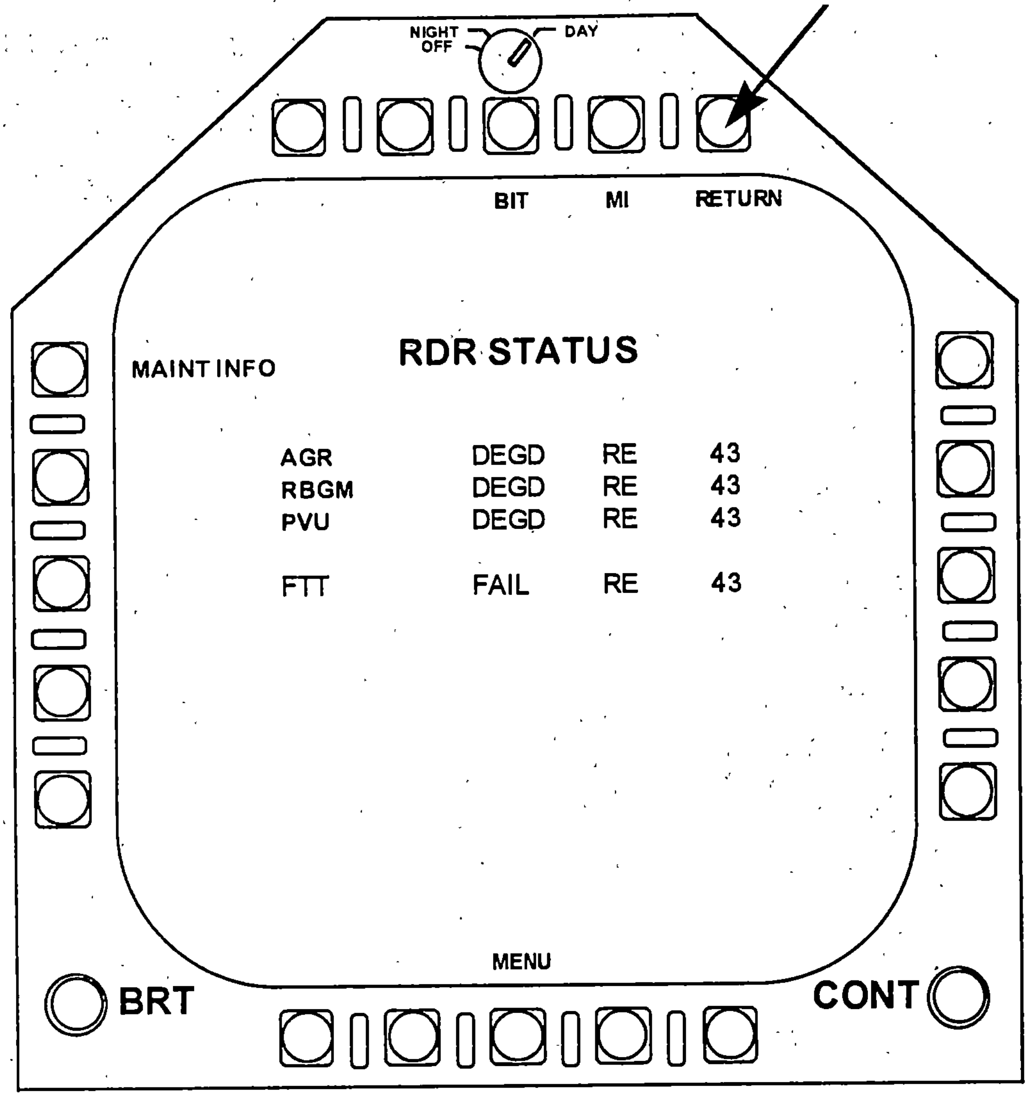

Figure 4-34. RADAR STATUS BIT Sublevel (Proposed).

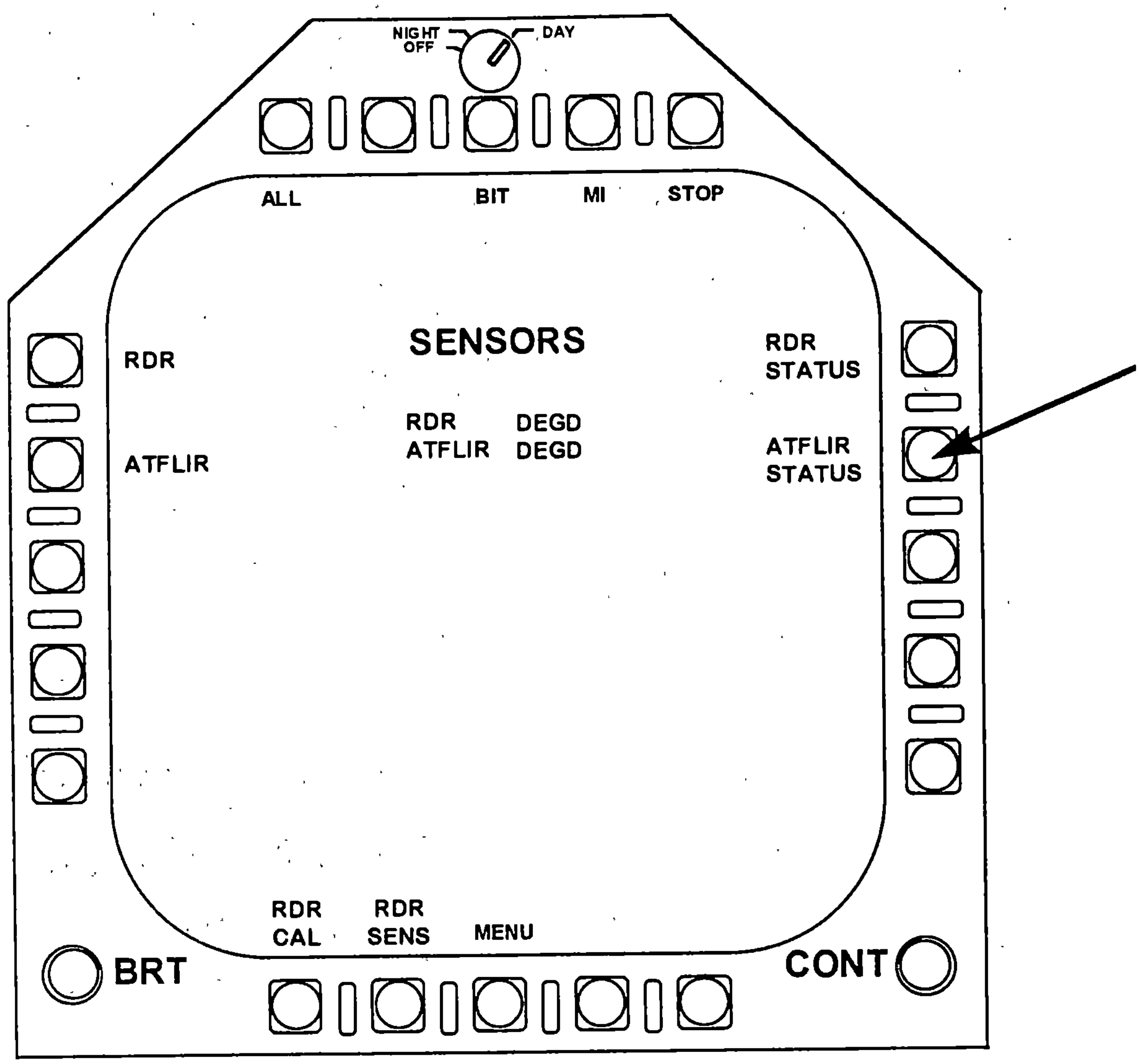

Figure 4-35. Sensors Equipment BIT Sublevel (Proposed).

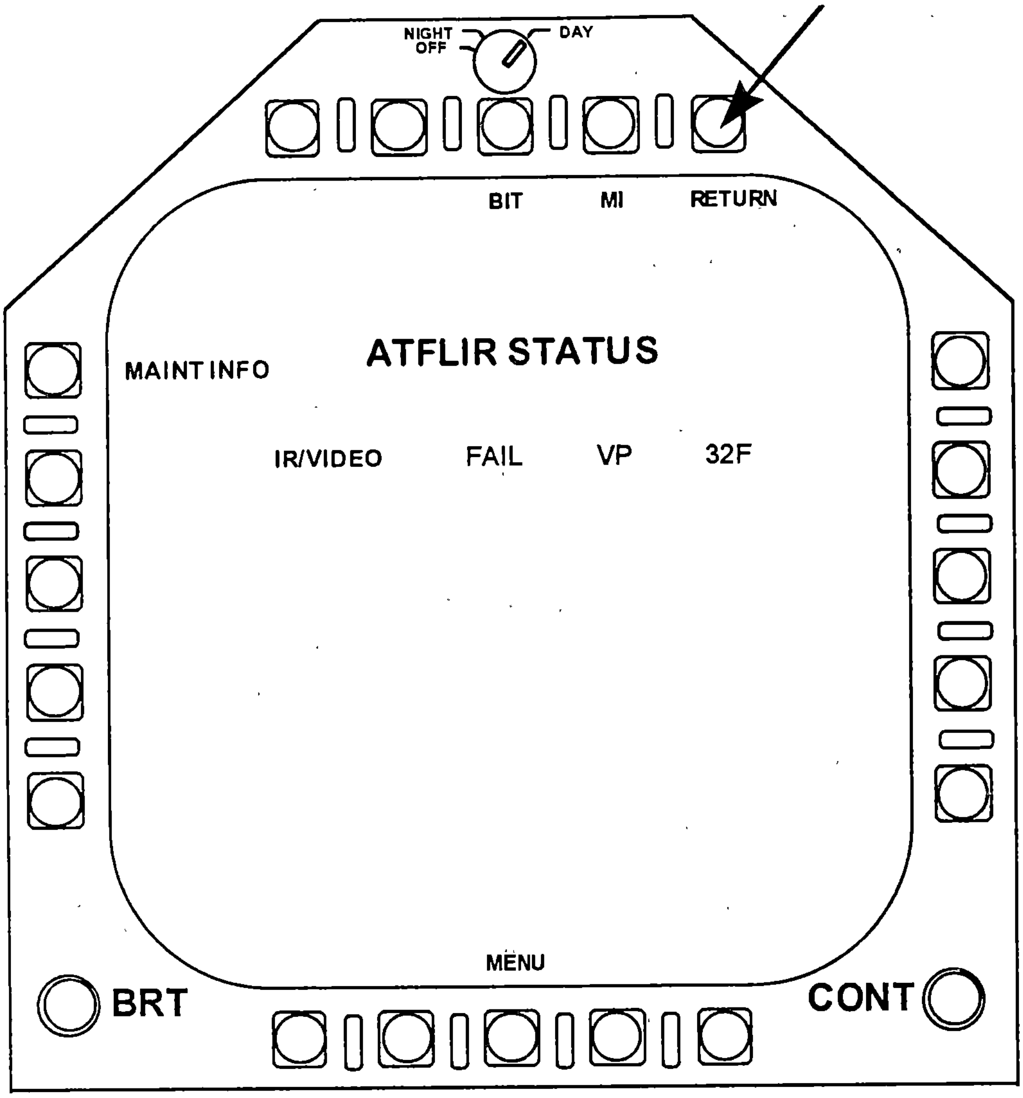

Figure 4-36. ATFLIR Status BIT Sublevel (Proposed).

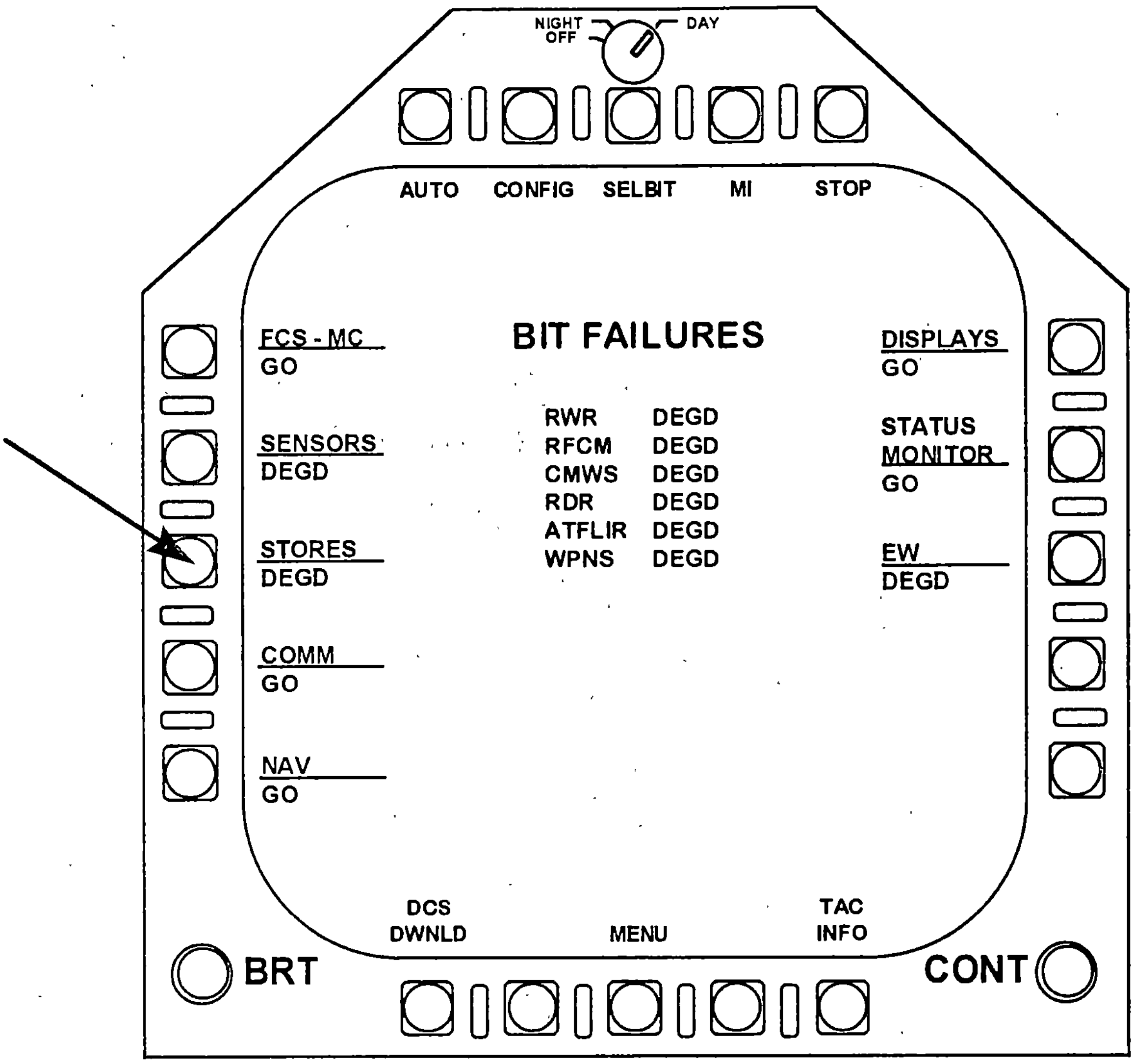

Figure 4-37. Top-Level BIT Format (Proposed).

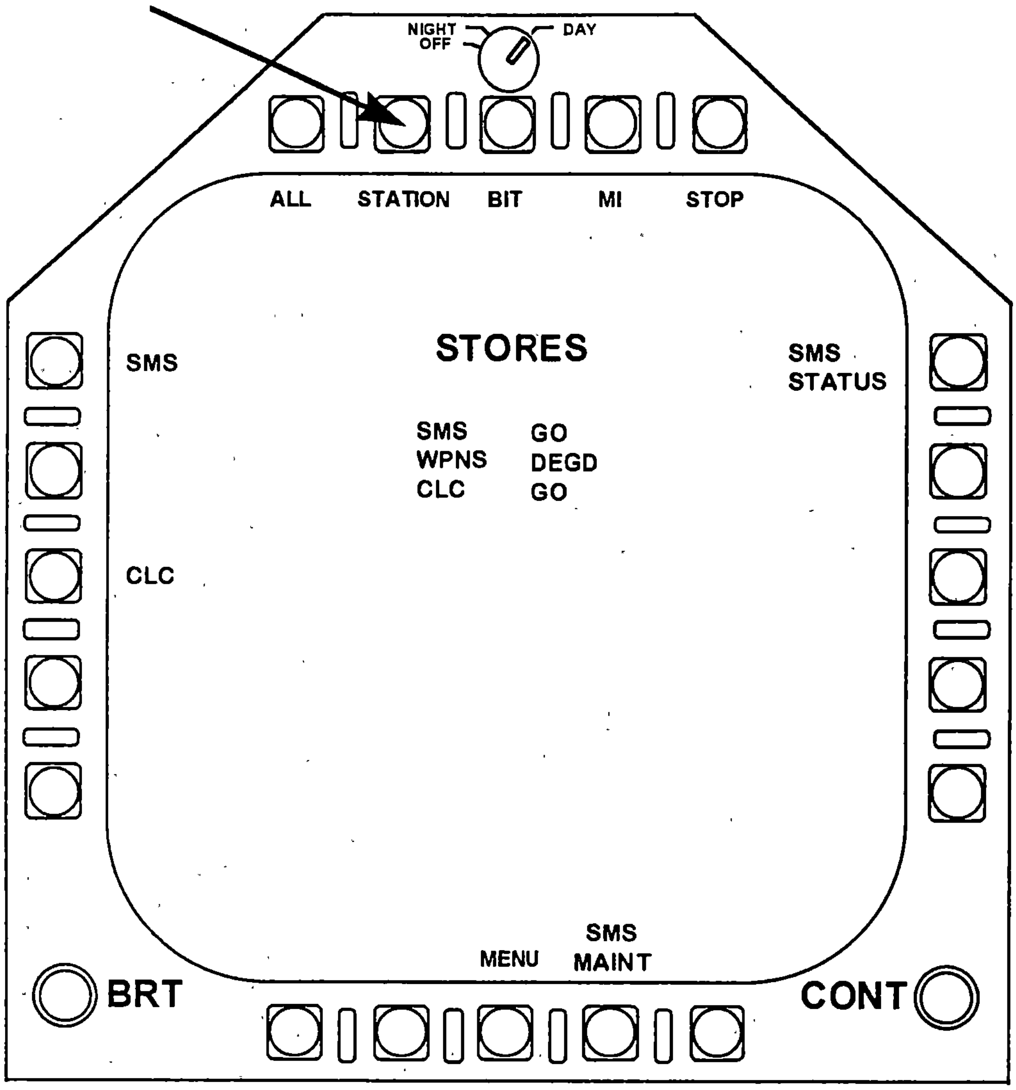

Figure 4-38. Stores BIT Sublevel Format (Proposed).

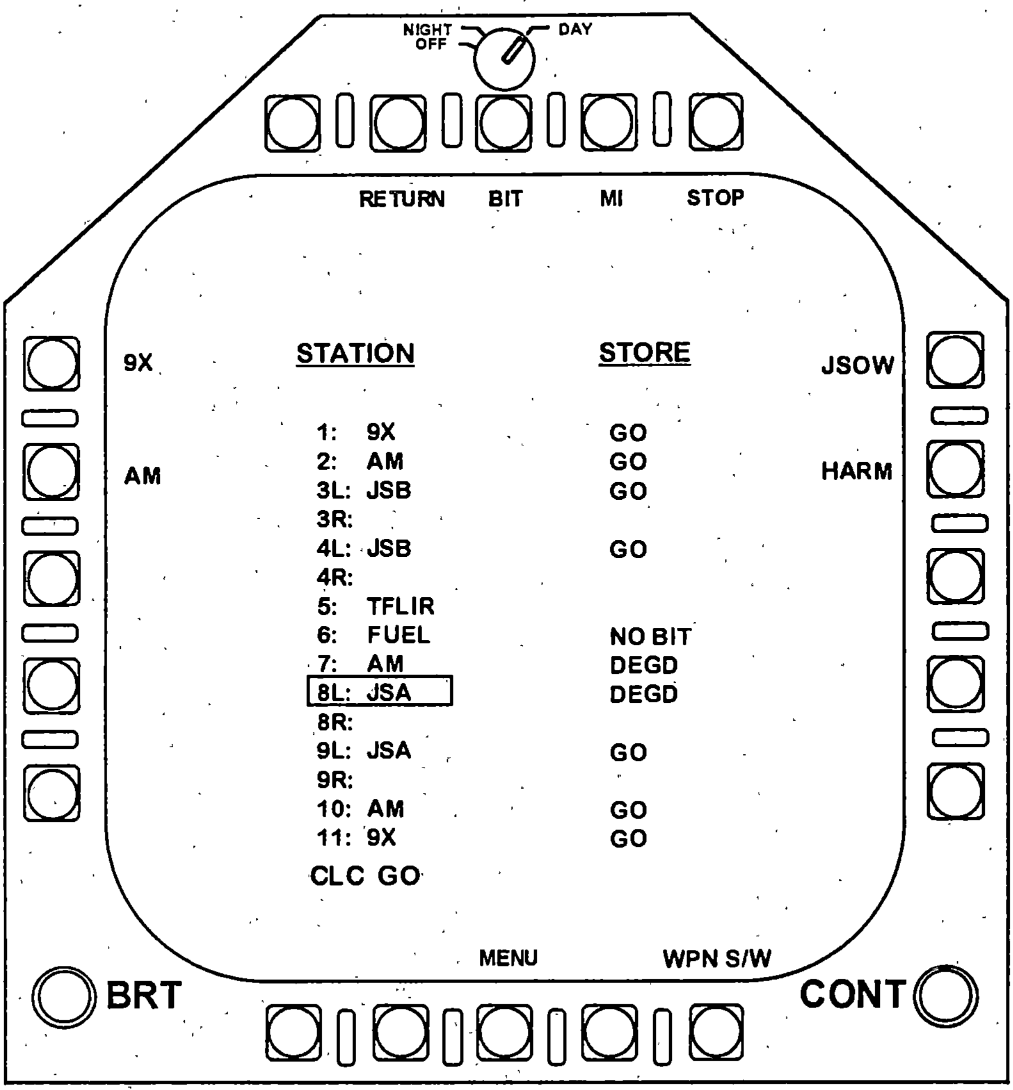

Figure 4-39. Stores Station BIT Sublevel (Proposed).

Tactical Display Formats

In flight, one way to communicate a critical fault within a sensor to the operator is on the tactical format for the sensor itself. The ATFLIR format in Figure 4-40 is an example of a proposed, consistent approach to display of status information on tactical formats. Failed modes legends have an 'X' through them, indicating a loss of functionality. The X through the IR sensor mode of the ATFLIR indicates that function is failed. The use of color on tactical formats, with the exception of the advisory line, should be limited to conveying threat information – red for hostile, yellow for ambiguous or unknown, and green for friendly. Adding color to the legends around the tactical display formats could cause confusion and detract from the utility of color-coding.

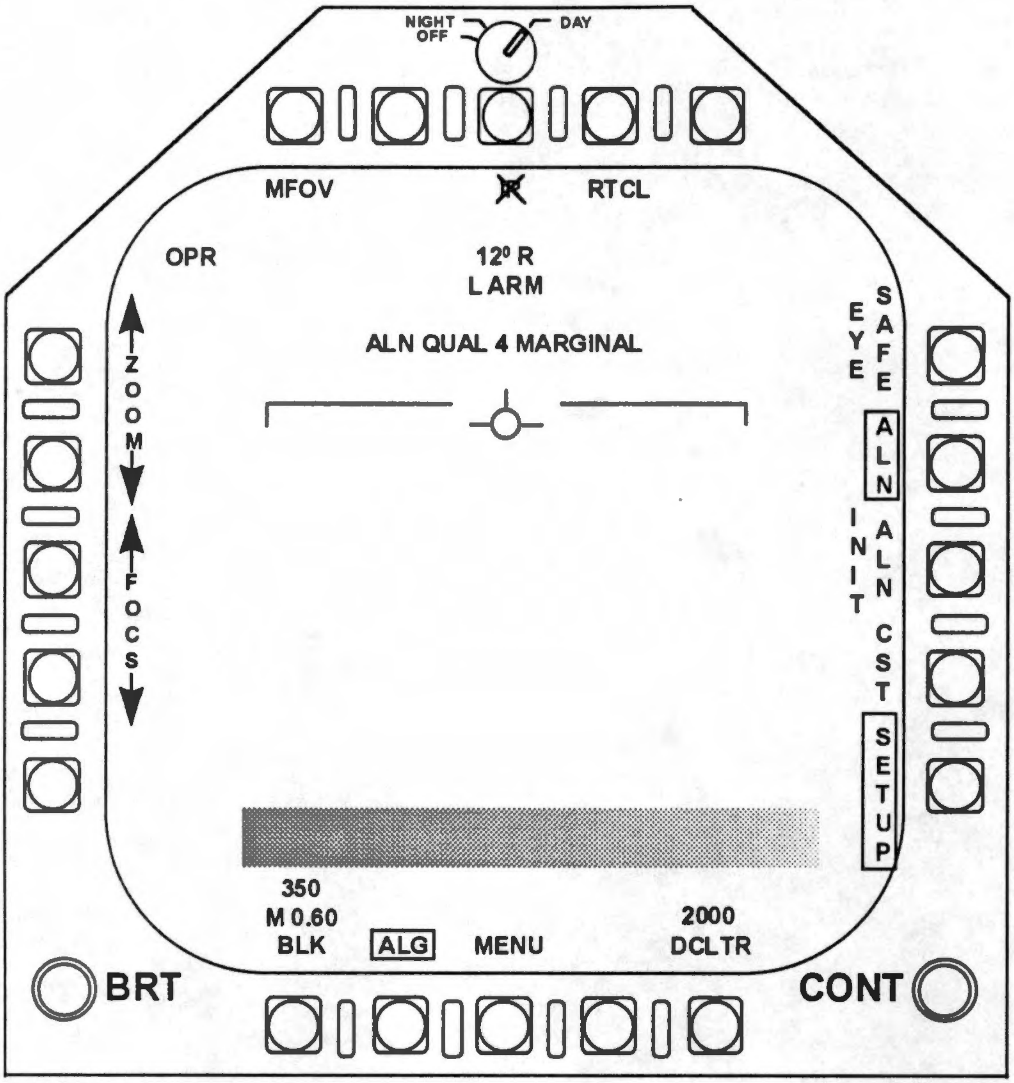

Figure 4-40. ATFLIR Tactical Format (Proposed).

Status Summary – Proposed Displays

The mission impact of the system failures can begin to be assessed from the advisory line on the proposed displays, as in Figure 4-24. Degraded system advisories appear as status legends, color-coded based on the severity of the failure. The conclusion from the advisory line is that the weapons, RWR, RFCM, ATFLIR, and RADAR are degraded, and the CMWS has a critical failure.

The advisories cue the aircrew to look at the BIT format for more information. From the top-level BIT format shown in Figure 4-25 the aircrew can select the TAC INFO format. All the status information required for a GO / NO GO decision is available on the TAC INFO format in Figure 4-26. Failure data is presented in plain language with regard to system functionality, and aircrew can easily compare aircraft capabilities with mission tasking.

Specific RWR failure information provided on the TAC INFO format indicates a failure in the Countermeasures Receiver that has resulted in the inability to process RF in the 12-18GHz band. The SES mission brief included threats in that band, such as the MiG-23 Flogger and the SA-8 Gecko. Of those threats, only the MiG-23 is a concern because the high-altitude profile for the strike will keep the fighters out of the SA-8 envelope. The conclusion is that the RWR failure would be a NO GO item.

A failure of the RF Tunable Filter (RFTF) in the RFCM system, according to the plain-language information provided on the TAC INFO format, results in a failure of RFCM and RADAR compatibility. This failure is not critical to the mission since the threats are outside the AN/APG-73 RADAR band. The CMWS ECU failure translates into a plain-language "ALL SYS FAIL", which is not mission critical due to the high-altitude nature of the strike. Degrades and failures in the A/G functions of the RADAR are also not mission critical, because JSOW is a bomb-on-coordinates weapon system. The degraded ATFLIR IR video has no mission impact because the EO sensor is still functioning normally. The TAC INFO format indicates the degraded AIM-120 is capable of an Inertial Active (IA) launch only. The fighter-to-threat aircraft ratio, the multi-targeting capability of the F/A-18, and the number of remaining missiles with full capability implies that the data link failure on the station seven weapon is non-mission critical. Similarly, the IMU failure on the station eight JSOW will not result in mission abort because the weapon is still able to guide with GPS-only. The conclusion that can be drawn from the information presented with the proposed displays is that the aircraft should abort the mission due to the RWR failure.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The systems status information provided in the F/A-18E/F does not allow aircrew to make sound assessments of the mission capability of their aircraft. The status displays have been oriented toward maintenance rather than the operator. They are inconsistent from format to format, and do not present system health in a manner that allows aircrew to easily synthesize the information in order to make an accurate mission readiness assessment. This was demonstrated using a representative SES mission scenario, for which the current systems status displays lead the aircrew to an unnecessary ground abort. The opposite case is when an aircraft is launched with a mission critical failure, but the aircrew is unaware because the information was either presented in an unusable fashion or not presented at all. The existing systems status displays in the F/A-18 are **unsatisfactory**.

For the aircrew to make a GO / NO GO decision, the aircraft status information must be synthesized and evaluated against the specific mission tasking. Select systems such as the AN/APG-73 RADAR can provide the necessary information, but most systems do not provide such features.

The human factors issues with the current BIT display formats should be addressed immediately. Incorporation of improved display formats will not only improve the man-machine interface but also increase aircraft availability and decrease the probability of sending partial or non-mission capable aircraft into combat.

The proposed display formats incorporate the recommendations to mitigate the deficiencies with current displays found during the evaluation in Section 4.0. Table 5-1 is a summary of those recommendations, listed in priority order.

Table 5-1. Summary of Recommendations

Priority	Recommendation	Page
1	BIT information on all tactical systems should be provided in terms of system capability and functionality lost due to the equipment failure.	31
2	Incorporate a TAC INFO format which summarizes, in plain-language, the status of all tactical systems on the aircraft.	40
3	Utilize a consistent methodology to indicate system failures on tactical formats.	33
4	Provide unambiguous cues of estimated current weapon performance, referenced to nominal weapon performance.	37
5	Remove the existing ALR-67 (V) 3 BIT display from the EW format and incorporate the system on the aircraft BIT format using F/A-18 BIT conventions.	35
6	Use color coding to convey more detailed status information.	30
7	Incorporate the term FAIL into the list of system status descriptors to indicate a total loss of system capability.	32
8	The Advisory line should be used to provide a top-level indication of all system degrades.	29

9	Automatically record all fault information to the aircraft maintenance memory cartridge, and delete fault log displays.	32
10	Use plain-language system references to the maximum extent practical.	30
11	Equipment status sub-levels should list only the components that are in a degraded status.	30
12	Specific fault information should be stored in a maintenance computer database, referenced to the equipment serial number, and returned with the unit if it fails as a fault history.	34
13	IBIT options for specific systems should be arranged in a consistent fashion on BIT sub-levels.	31
14	Remove the AM TEST option from the STORES DATA sub-level and place the weapon IBIT on the BIT STORES STATION sub-level.	35
15	Replace the FAIL status legend with SFAIL to indicate a station failure.	35

OTHER AREAS OF INVESTIGATION

The series of displays that were presented offer a significant improvement in the area of aircraft mission readiness assessment. The design, however, still relies on the operator to synthesize mission tasking, threat type and level, and displayed system status to make an appropriate decision. The next logical step is the development of a true 'expert system', where the mission computers perform the information synthesis and present a GO / NO GO condition to the operator. The key elements in the decision process, such as mission tasking, threat type and level, are already incorporated in the mission planning system. Provisions exist in the current interface to download those elements from the mission planning system to the mission computers. Results of aircraft system BIT could be synthesized with mission information to present the aircrew with a GO / NO GO indication.

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6. Rollinger, M.G. "An Evaluation of the Man-Machine Interface with the Advanced Tactical Airborne Reconnaissance System Installed in the F/A-18D Aircraft" M.S. Thesis, The University of Tennessee, Knoxville, Tennessee, 1998.

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8. Draft System/Segment Design Document (SSDD) for the Advanced Targeting FLIR with the 15C System Configuration Set, Boeing Aircraft, St. Louis, Missouri, June 1998.

9. System/Segment Design Document (SSDD) for the Integrated Defensive Counter-Measures system with the 16E System Configuration Set, Boeing Aircraft, St. Louis, Missouri, 1998.

10. Huffman, G. and Johnson, S., Functional Requirements Document for the AN/ALR-67(V)3 RADAR Warning Receiver, Naval Air Warfare Center, China Lake, California, 1999.

APPENDICES

APPENDIX A

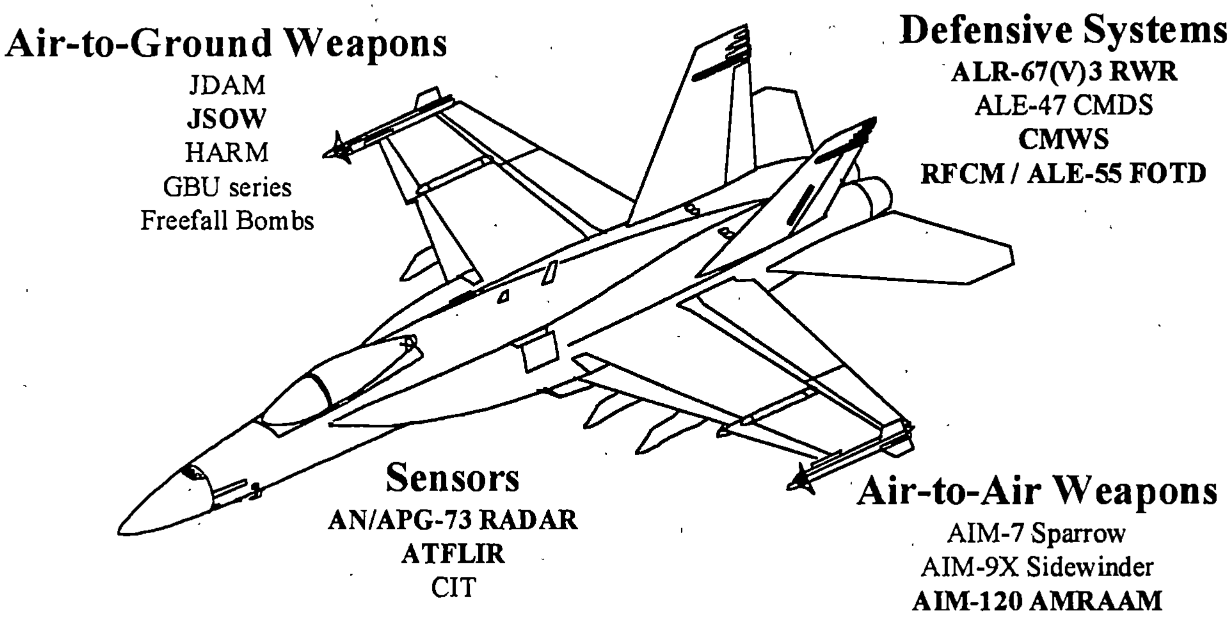

Figure A-1. F/A-18 Super Hornet

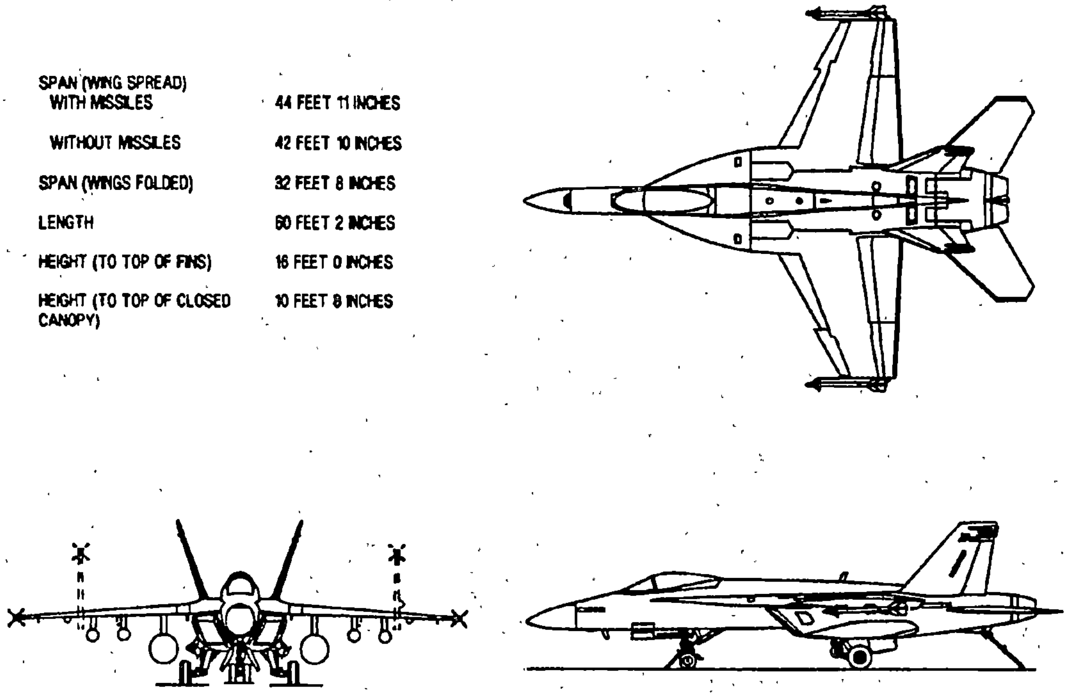

Figure A-2. F/A-18 Super Hornet

Source: NAVAIR A1-F18EA-NFM-000, F/A-18E/F NATOPS Flight Manual, Philadelphia, Pennsylvania, Naval Air Technical Services Facility, 1999

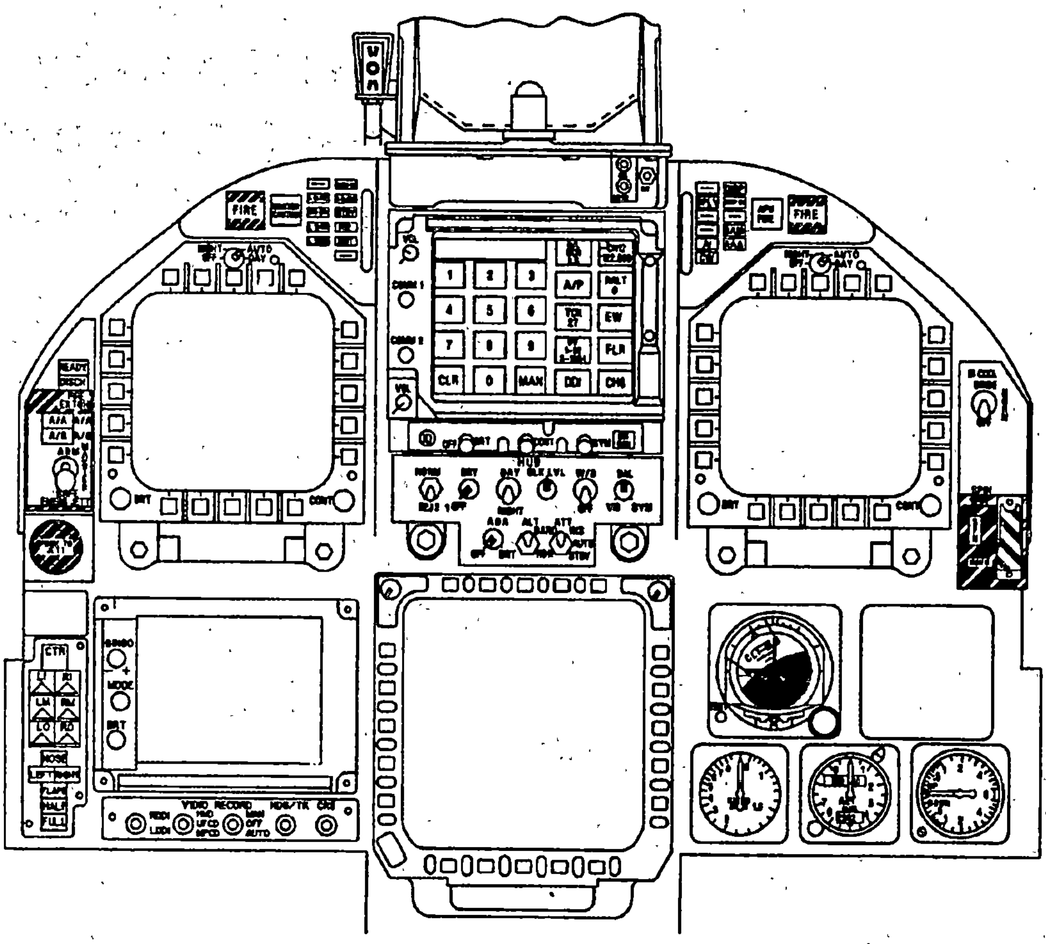

Figure A-3. F/A-18E/F Forward Crew Station Instrument Panel

Source: *Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set*, *Naval Air Warfare Center, China Lake, California, 1999.*

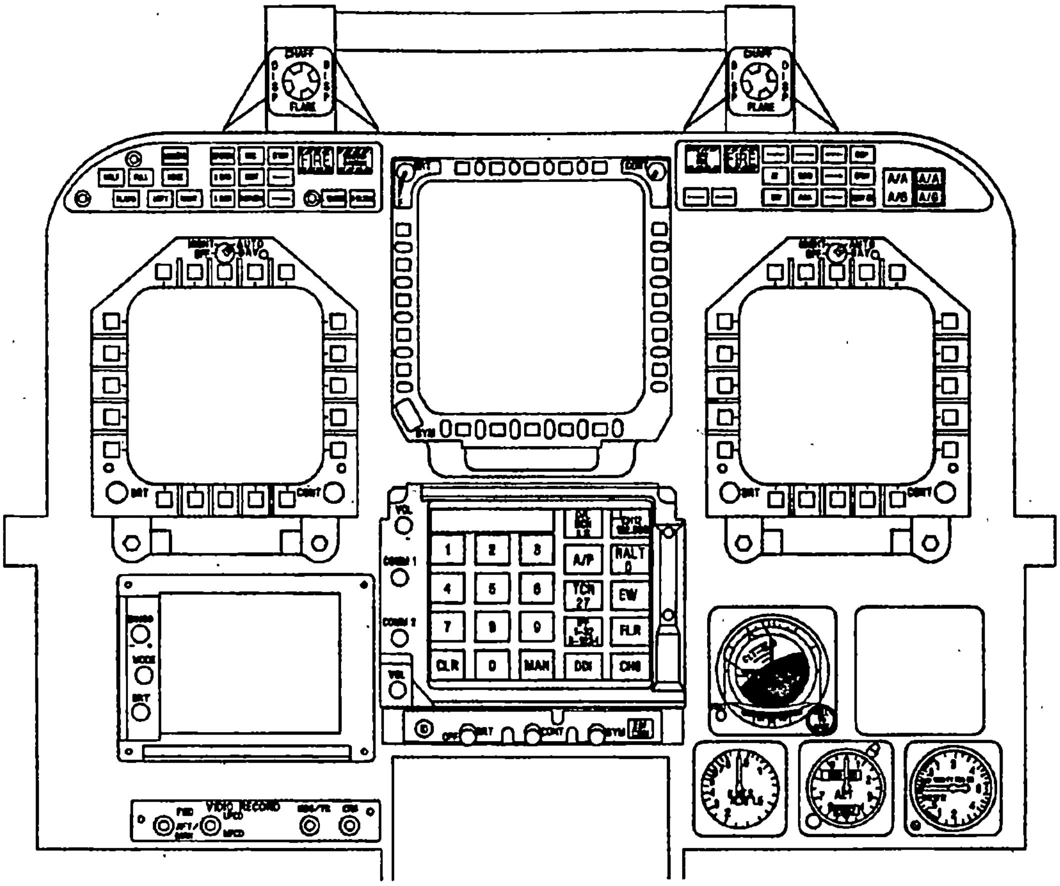

Figure A-4. F/A-18F Aft Crew Station Instrument Panel

Source: *Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set*, *Naval Air Warfare Center, China Lake, California, 1999.*

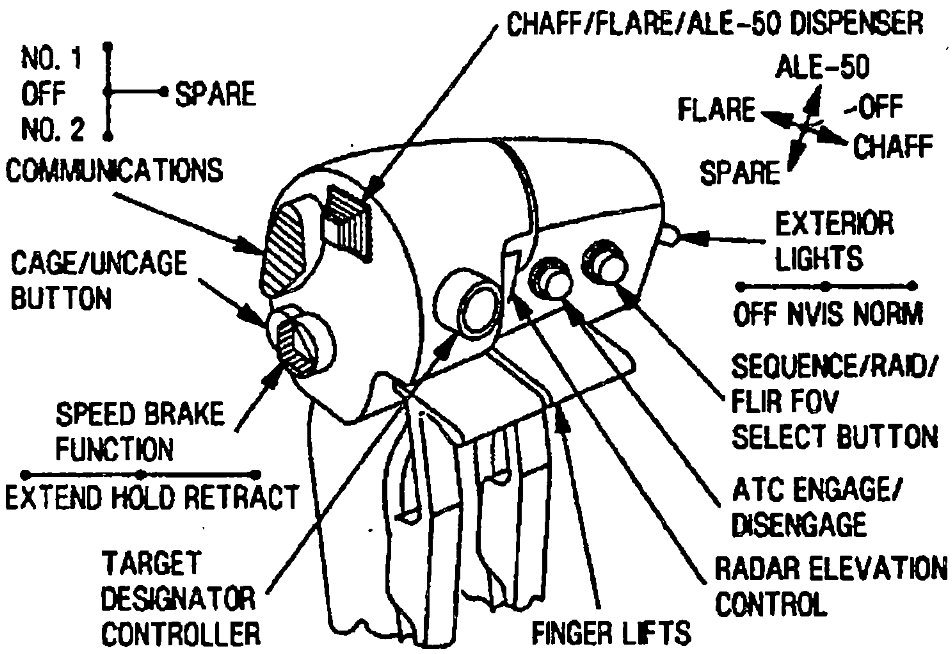

Figure A-5. F/A-18E/F Throttles

Source: *Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set*, *Naval Air Warfare Center, China Lake, California, 1999.*

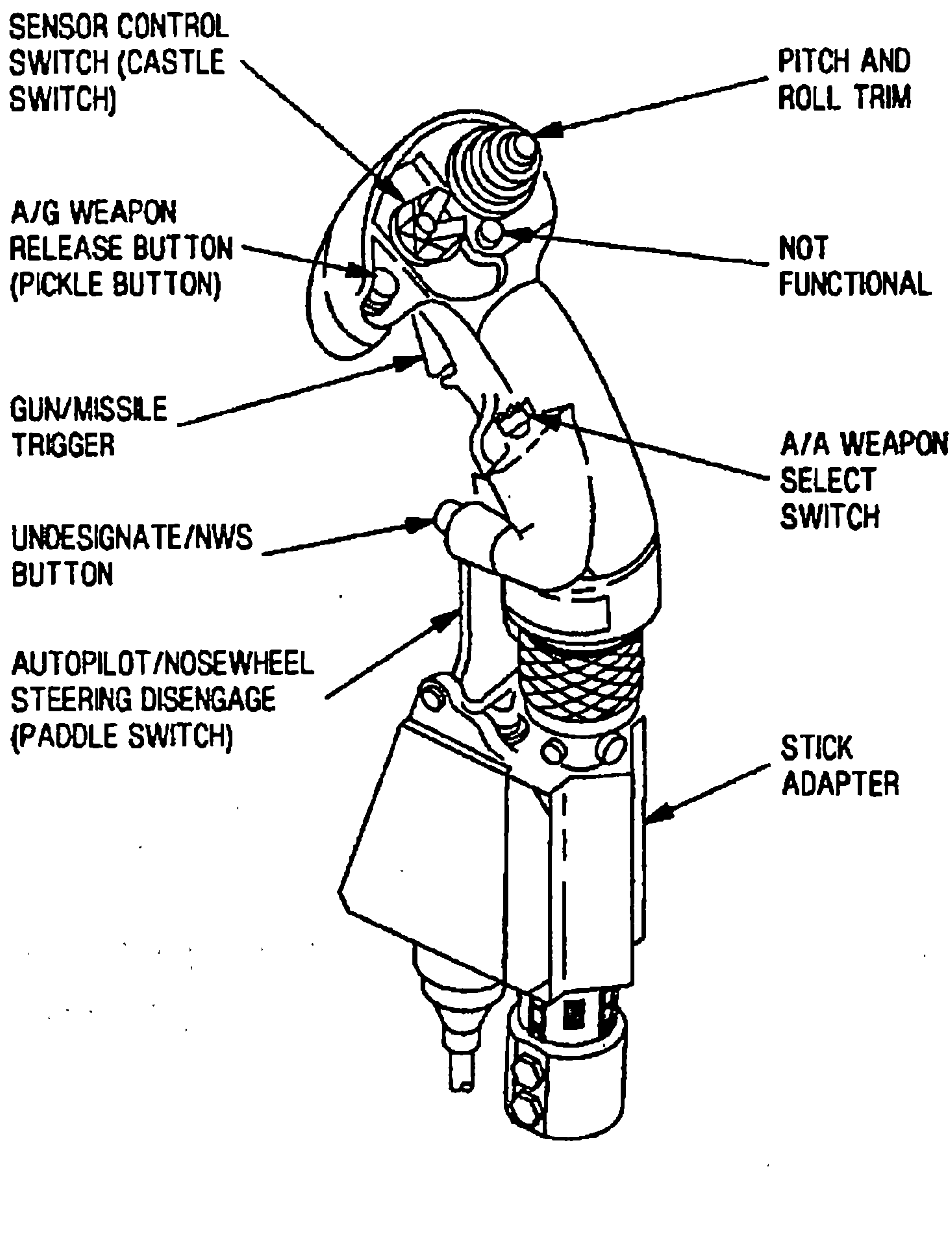

Figure A-6. F/A-18E/F Control Stick.

Source: Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set, Naval Air Warfare Center, China Lake, California, 1999.

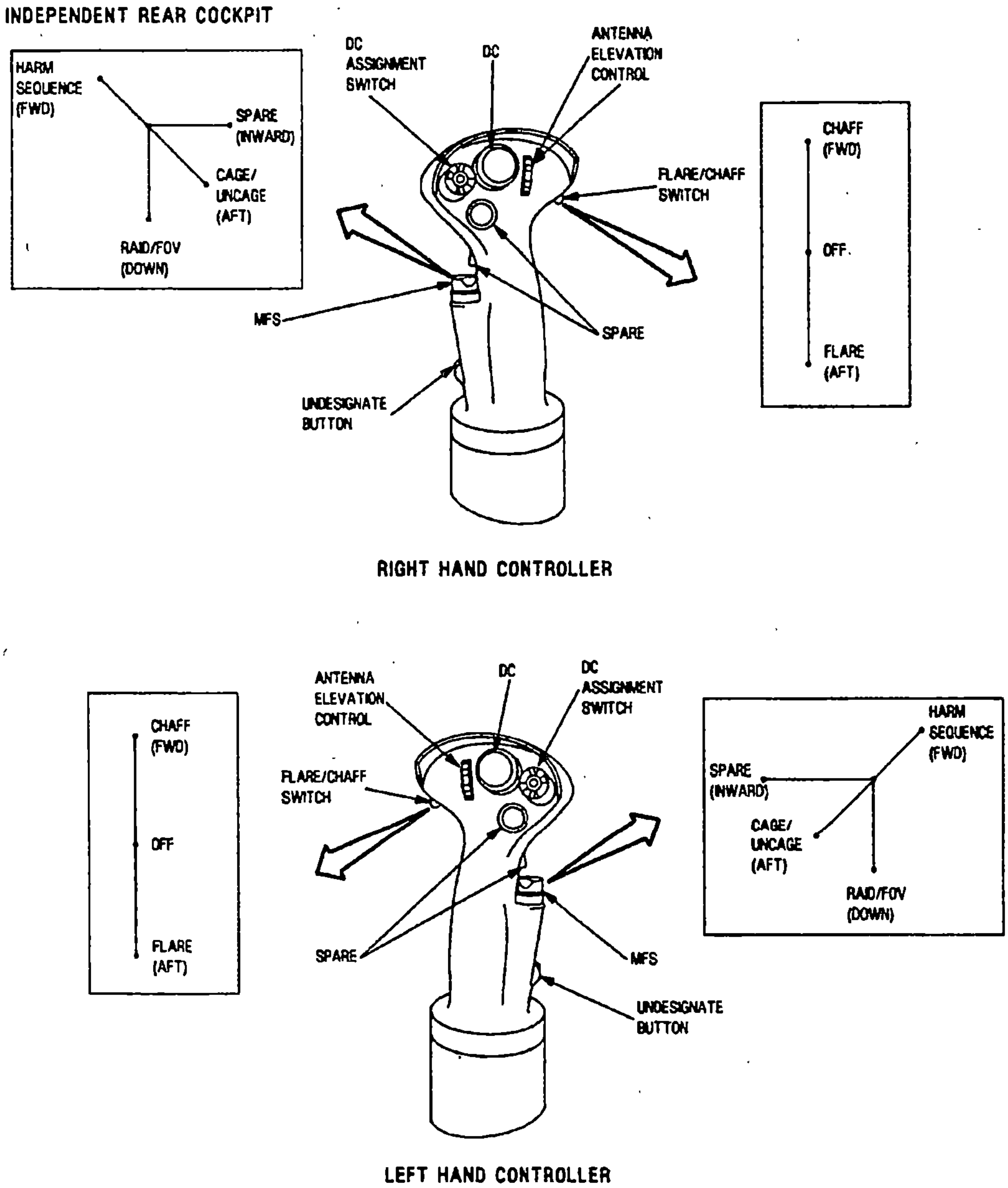

Figure A-7. F/A-18E/F Hand Controllers

Source: *Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set, Naval Air Warfare Center, China Lake, California, 1999.*

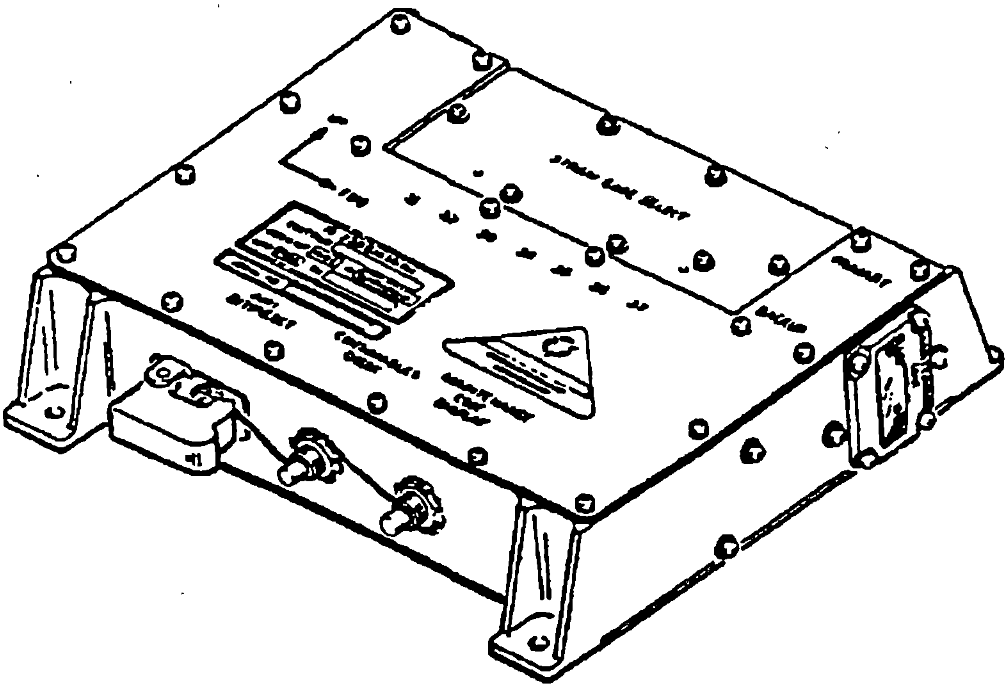

Figure A-8. F/A-18 Maintenance Status Panel

Source: Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13E System Configuration Set, Naval Air Warfare Center, China Lake, California, 1999.

VITA

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