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Implementation of the Digital Communication System in the F/A-18 Aircraft

Gregory D. Bigalk
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Gregory D. Bigalk entitled "Implementation of the Digital Communication System in the F/A-18 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.

Mr. R. B. Richards, Major Professor

We have read this thesis and recommend its acceptance:

Dr. George Garrison, Dr. Ralph Kimberlin

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

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

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IMPLEMENTATION OF THE DIGITAL COMMUNICATION SYSTEM IN THE F/A-18 AIRCRAFT

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Gregory D. Bigalk

August 2002

DEDICATION

This thesis is dedicated to my wife,

Brenda Marie Autobee-Bigalk,

whose support has been instrumental over the last fourteen years.

ACKNOWLEDGMENTS

My sincere appreciation goes out to all of the professional Naval Flight Officers and Naval Aviators whose input and feedback made this thesis possible. Their ideas, opinions, and knowledge assisted greatly in keeping the scope of this project within the bounds of reality.

I would also like to thank Mr. Scott Winter, Boeing Company and the instructors at the University of Tennessee Space Institute and the United States Naval Test Pilot School for their assistance in earning this degree.

Lastly, I would like to extend my gratitude to my son, Charles, and my wife Brenda for their love and support throughout the entire experience.

ABSTRACT

The F/A-18 Hornet is a Navy/Marine Corps carrier-based strike/fighter built by the Boeing Company. The Hornet is a dual role aircraft designed to have all weather intercept and ground attack capabilities. The purpose of this study was to examine the Variable Message Format (VMF) communications capability, integration compatibility and technical suitability of the RT-1824(C) ARC-210 radio as integrated into the F/A-18 aircraft. Normally, this aircraft would utilize two ARC-210 voice capable only RT-1556 radio sets designated Comm 1 and Comm 2. Comm 1 is switchable between an upper AS-4129/ARC antenna and lower AS-3557/A antenna. Comm 2 utilizes a separate lower AS-4129/ARC antenna. The RT-1824(C) provides baseline ARC-210 RT-1556 capabilities as well as embedded COMSEC capability, and digital messaging for use during the Close Air Support (CAS) mission. Tests included range performance, aircraft software integration, E^3, ECS, Carrier Suitability, TEMPEST, Reliability, Maintainability, and Supportability. Range performance and software integration testing included Air-to-Air testing using an airborne F/A-18 as a Forward Air Controller Airborne (FAC(A)) and Air to Ground testing using a ground FAC with a Target Location Designation Hand-off System (TLDHS).

The study revealed a significant reduction in aircrew workload and a tremendous improvement in aircrew and FAC situational awareness after incorporating the new VMF technology. However, the original specification requirements for this program excluded the FAC(A) mission. The author felt that the inclusion of this mission was very important and included it during the research of this thesis. This study will look into the CAS and FAC(A) roles and provide design changes to enhance this system and make it

more useful to the fleet user. The author's analysis was done on information attained during a Navy developmental test program, however all conclusions and recommendations are independent of the test program. The author's role in this test program was as lead test pilot and project officer. The identified problems are:

1. The need to redesign the touch-sensitive data entry keyboard of the Up Front Control Display to provide an alphanumeric entry capability in addition to providing secondary tactile interface with the weapons system, specifically for the FAC(A) mission.

2. Modify the aircraft software and TLDHS software to display the following commands: "Continue", "Cleared Hot" and "Abort". These messages should appear in the Pilot's HUD, FLIR display, Radar display and Joint Helmet Mounted Cueing Sight display to provide the needed situational awareness (SA) in a highly dynamic mission environment, such as CAS.

3. Design a modified CAS page to appear after the aircrew selects "USE" to facilitate gaining pertinent information faster when conducting CAS missions.

4. Redesign the NETS page to allow more than one "SEND TO" list to appear when the aircraft is serving in the FAC(A) role.

5. Modify the software to allow the "Friendly Arc" to appear on the SA display in addition to the HSI display.

6. Redesign the CAS status line function to account for total number of aircraft received versus the total number of aircraft on the "Send To" list by modifying the NETS page to incorporate color to allow quick interpretation of which aircraft received the sent messages vice which did not.

7. Relay a repeater image of the close air support aircraft's heads up display, to allow the FAC or FAC(A) to confirm the correct target is being attacked.

PREFACE

A portion of the information contained within this thesis was obtained during a Naval Air Systems Command sponsored program in conjunction with the Boeing Company and Collins Rockwell Corporation. References to F/A-18 communication integration issues were obtained during actual test flights performed by the author. Developmental test flights were performed at the Naval Air Warfare Center Aircraft and Weapon Divisions. The research, results and conclusions, and recommendations presented are the opinion of the author and should not be construed as an official position of the United States Department of Defense, the United States Navy, the Naval Air Systems Command, or the Collins Rockwell Corporation.

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LIST OF ABBREVIATIONS

A/A	Air-to-Air
A/G	Air-to-Ground
ADDR	Address
AINS	Aided Inertial Navigation System
AO	Operational Availability
BIT	Built-in Test
BDA	Battle Damage Assessment
C2	Command and Control
CAS	Close Air Support
CP	Contact Point
DASC	Direct Air Support Center
DCS	Digital Communication System
DDI	Digital Display Indicator
DPIP	Departing Initial Point
EA	Electronic Attack
ECP	Egress Control Point
E3	Electromagnetic Environmental Effects
EMC	Electronic Compatibility
EMCON	Emission Control
EP	Electronic Protection
EW	Electronic Warfare
FAC	Forward Air Controller
FAC(A)	Forward Air Controller Airborne
FCC	Flight Control Computer
FM	Frequency Modulation
FO	Forward Observer
FSCC	Fire Support Coordination Center
FTXT	Free Text

GPS	Global Positioning System
HOTAS	Hands on Throttle and Stick
HQ	Have Quick I and II
HSI	Horizontal Situation Indicator
HUD	Heads-Up-Display
IADS	Integrated Air Defense System
INFLTREP	Inflight Report (Voice only)
INS	Inertial Navigation System
IP	Initial Point
JAOC	Joint Air Operations Center
JFC	Joint Force Commander
JTAR	Joint Tactical Air Request
LINK ACK	Link Acknowledgement
LST	Laser Spot Tracker
LTD	Laser Target Designator
MACCS	Marine Air Command and Control System
MC	Mission Computer
MCDP	Marine Corps Doctrinal Publication
MCRP	Marine Corps Reference Publication
MCWP	Marine Corps Warfighting Publication
MCMTOMF	Mean Corrective Maintenance Time for Operational Mission Failure
MGRS	Military Grid Reference System
MISREP	Mission Report
MPCD	Multi Purpose Color Display
MTBOMF	Mean Time Between Operational Mission Failure
NATOPS	Naval Air Training and Operating Procedures
OFP	Operational Flight Program
OP ACK	Operator Acknowledgement

OP REP	Operator Reply
OSR	On Station Report
R&M	Reliability and Maintainability
RHC	Ruggedized Handheld Computer
ROE	Rules of Engagement
RP	Rendezvous Point
SA	Situational Awareness
SACC	Supporting Arms Coordination Center
SAR	System Anomaly Report
SATCOM	Satellite Communication
SCS	Software Configuration Set
SDC	Signal Data Computer
SEAD	Suppression of Enemy Air Defenses
SINCGARS	Single Channel
SOP	Standing Operating Procedure
TACC	Tactical Air Command Center
TACP	Tactical Air Control Party
TAD	Tactical Air Direction
TADC	Tactical Air Direction Center
TAMPS	Tactical Aircraft Mission Planning System
TLDHS	Target Locator Designation Handoff System
TOS	Time on Station
TOT	Time on Target
TTP	Tactics, Techniques, and Procedures
TTT	Time to Target
UFCD	Up Front Control Display
UHF	Ultra High Frequency
UTM	Universal Transverse Mercator
VHF	Very High Frequency
VHF-AM	Very High Frequency-Amplitude Modulation

VHF-FM	Very High Frequency-Frequency Modulation
WRA	Weapon Replaceable Assemblies

CHAPTER 1: INTRODUCTION

BACKGROUND

The F/A-18 aircraft is a twin-engine strike fighter designed for use by the U.S. Navy and Marine Corps. The F/A-18 has become the predominant tactical fixed wing aircraft in the U.S. Navy inventory. The strike fighter capabilities designed into the F/A-18 have allowed it to fulfill a variety of roles including Combat Air Patrol, Interdiction, Fighter Escort, Close Air Support and Forward Air Controller (Airborne). In all of these roles, reliable and accurate communication is essential. Another form of communication besides voice is data link, which for the F/A-18 is a somewhat new technology. The F/A-18 has been using data link to land on the carrier for several years as part of its Automated Carrier Landing System (ACLS). However, the F/A-18 platform was considered ideal for implementing Digital Communication System (DCS) data link technology due to its multi-mission capability. Normally, the F/A-18 aircraft would utilize two ARC-210 RT-1556 radio sets designated Comm 1 and Comm 2. The Comm 2 radio set has been replaced by the ARC-210 RT-1824 digital radio, which is capable of receiving data link called variable message format. The warfighter of tomorrow will be relying less upon voice transmissions and more on digital data link messages to provide target coordination and situational awareness of the battlefield.

The purpose of this study was to examine the Variable Message Format (VMF) communications capability, integration compatibility and technical suitability of the RT-1824(C) ARC-210 radios as integrated into the F/A-18 aircraft. The author's analysis was done on information attained during a Navy developmental test program, however all conclusions and recommendations are independent of the test program. The author's role in this test program was as lead test pilot and project officer. The study revealed significant reduction in aircrew workload when conducting Close Air Support missions and a tremendous improvement in aircrew situational awareness. When the original requirements were set forth, the Forward Air Controller Airborne (FACA) mission was excluded. This creates a certain dilemma for the U.S. Marine Corps, as this mission makes up a very large role that the F/A-18D aircraft provides. Therefore, included in the author's analysis are problems and solutions identified to include the FAC(A) role and they are:

1. The need to redesign the touch-sensitive data entry keyboard of the Up Front Control Display to provide an alphanumeric entry capability in addition to providing secondary tactile interface with the weapons system, specifically for the FAC(A) mission.
2. Modify the aircraft software and TLDHS software to display the following commands: "Continue", "Cleared Hot" and "Abort". These messages should appear in the Pilot's HUD, FLIR display, Radar display and Joint Helmet Mounted Cueing Sight display to provide the needed situational awareness (SA) in a highly dynamic mission environment, such as CAS.
3. Designing a modified CAS page to appear after the aircrew selects "USE" to facilitate gaining pertinent information faster when conducting CAS missions.
4. Redesigning the NETS page to allow more than one "SEND TO" list to appear when the aircraft is serving in the FAC(A) role.

5. Modifying the software to allow the "Friendly Arc" to appear on the SA display in addition to the HSI display.

6. Redesigning the status line function to account for total number of aircraft received versus total number of aircraft on the send to list by modifying the NETS page to incorporate color to allow quick interpretation of who received the sent messages vice whose did not.

7. Relay a repeater image of the close air support aircraft's heads up display, to allow the FAC or FAC(A) to confirm the correct target is being attacked.

This thesis will recommend some specific software additions and modifications to the contractor's current design, which will improve mission readiness and safety, and improve the aircraft's mission effectiveness. These additions and modifications will help to eliminate the information overload problem, operational issues and integration issues associated with operating a complex modern weapons system. However, the proposed integration design currently being proposed by the prime contractor falls short in many areas relating to human factors and systems integration. Correcting this shortfall is critical since even the best-integrated weapons system will fail to live up to its full potential in combat operations unless the human operator can process the vast amount of information presented. Ultimately, the operator must have the capability to usefully employ the information presented or the system as a whole will fail to operate at its optimal capability.

This thesis will briefly describe the basic RT-1556 equipped F/A-18 aircraft and the integrated weapons system, trace the evolution of the radio frequency data link system from its beginnings, and describe the Close Air Support (CAS) mission. A review of pertinent literature and military standards discussing variable message format, data link, coupled with the author's extensive personal experience as an F/A-18 Pilot and DCS lead test pilot and project officer were used as the basis of research. Test methodology will be discussed to help understand the integration issues surrounding the DCS system.

STATEMENT OF THE PROBLEM

The implementation of the DCS variable message format (VMF) capabilities requires software modification to enhance existing cockpit displays, network data link architecture and allow easier aircrew cockpit interface to occur. The software modifications are required to allow the aircrew to operate the DCS VMF capabilities to its fullest extent during the Close Air Support (CAS) and Forward Air Controller Airborne (FAC(A)) missions.

DESCRIPTION OF THE F/A-18 DCS RADIO

The F/A-18 currently fields two voice communication radios. These are the ARC-210 RT-1556 and the ARC-210 DCS radios. The two radios are referred to as Comm 1 and Comm 2. The RT-1556 radio can be installed in either Comm 1 or Comm 2 positions in the aircraft. However, due to its physical size, the DCS radio can only be installed in the Comm 2 position. The RT-1824 (DCS) provides baseline ARC-210 RT-1556 capabilities as well as embedded COMSEC capability, and digital messaging for use during the Close Air Support (CAS) and FAC(A) missions. Baseline capabilities include operation in fixed frequency plain, plain or secure, electronic protection (EP), or EP secure. The EP mode, which provides jam resistant communications using frequency-hopping techniques in both VHF and UHF bands. These are Single Channel Ground and Airborne Radio System (SINCGARS) and HAVE QUICK I & II respectively. Both radios afford the aircrew to store presets and EP data. The presets contain the frequencies and modulation information for channels 1 through 20 as a convenience in the rapid selection of operating frequencies. The EP data is needed for the radios to operate in HQ and SINCGARS modes on these same channels. Have Quick and SINCGARS functionality of the ARC-210 (DCS) radio is unchanged from ARC-210 (RT-1556) or (RT-1556B). The DCS radio is also capable of storing cryptographic keys for its embedded communication security (COMSEC) feature. This embedded COMSEC feature takes the place of an additional control panel that provided the secure voice function. The ARC-210 and DCS radios operate in the frequency bands, as shown in Table 1, for voice communications:

Transmission and reception of AM and FM signals occur in the respective frequency bands on spaced channels of 5 kHz.

Table 1
ARC-210 OPERATING FREQUENCY BANDS

Frequency Band (MHz)	Modulation	Guard Channel
30 to 87.995	FM	
108 to 135.995 (1)	AM	121.5
136 to 155.995	AM/FM	
156 to 173.995	FM	
225 to 399.975	FM/AM	243.0 (AM)

(1) Cannot transmit in the 108 thru 117.995 MHz range.

VARIABLE MESSAGE FORMAT (VMF)

The most significant functional advance provided by ARC-210 (DCS) is the ability to perform digital data communication of Close Air Support (CAS) mission data over MIL-STD-188-220 Networks (NETS) using the Variable Message Format (VMF) communication protocol. This communication may be done in any of the following radio modes: VHF, UHF, SINCGARS, HAVE QUICK I & II (plain and cipher). There are five new F/A-18 digital display indicator (DDI) formats created to employ the data communication functions of DCS:

–Networks (NETS) Format.

–On-Station Report (OSR) Format.

–Close Air Support (CAS) Format.

–Recall (RCALL) Format.

–Free Text Format.

The cockpit's upfront control display (UFCD) is used for data input/management to support these new DDI formats. In addition to the new DDI formats, existing head up display (HUD), horizontal situation indicator (HSI), and situational awareness (SA) formats provide additional data in support of the DCS VMF functionality.

The NETS format is used to manage network interface and to select which DCS network participants, or nodes, will be the receivers of digital data communication from the sending aircraft. Each individual aircraft's particular network addressing data is also displayed on the NETS page. This information describes their hierarchical position within the flight and identifies what the DCS will receive and transmit over the MIL-STD-188-220 Network. These fields are: ID, Lead Status, Assignment to ownship's send list, and addressing data. The addressing data is broken down further to specifically identify each aircraft, which is analogous to one's home computer's modem with respect to one's Internet Service Provider and the World Wide Web. The addressing data is defined as: Internet Protocol Address (ADDR), Unit Reference Number (URN), and Data Link Number (LINK).

The OSR format, figure B-1, is used to digitally communicate with the Forward Air Controller the combat capability of the CAS Mission reporting at the Contact Point.

The CAS format is used to prepare CAS mission data for digital communication with other DCS network participants. An implied requirement was to ensure the CAS format closely resembled the "9-Line Brief", figures B-2 and B-3, being currently used by the military services today. The aircraft's mission computer software has been mechanized to automate the use of received mission data for CAS mission execution.

The Recall format, figure B-4 uses the CAS mission data that is pre-planned, edited inflight, or received via the DCS network, and may be saved and recalled for later use.

Last, the Free Text format, figure B-7, supports unformatted Free Text Messages containing alphanumeric content which must be prepared before flight, or received via the DCS network, and saved for later recall and use inflight.

CLOSE AIR SUPPORT AND FORWARD AIR CONTROLLER (AIR) MISSIONS

The definition of Close Air Support (CAS) according to Marine Corps doctrine FMFM-1 is as follows: "Air action against hostile targets in close proximity to friendly forces and which require detailed integration of each air mission with the fire and movement of those forces." There are two types of CAS Missions: Pre-planned and Immediate.

The Pre-planned CAS Missions fall into either of two categories, Scheduled Missions and On Call Missions. Scheduled missions are anticipated and requested sufficiently in advance to permit detailed mission coordination and planning or mission executed at a time specified by the supported unit against an assigned Time On Target (TOT). After launch, minor changes to mission TOTs can be made to meet Ground Combat Element requirements. On-Call Missions differ in that the aircraft are preloaded with ordnance for a particular target or type of target within a designated target area. The aircraft and aircrew are placed in an appropriate ground/air alert status and the mission is executed (launched) at the request of the supported unit. Another key difference from a scheduled mission is that detailed mission planning and briefing of pilots on all mission essential information is normally not possible prior to takeoff.

The Immediate CAS Mission is normally supported by a flight that is already airborne and is on their way to support a preplanned mission or has completed a previous CAS mission. If the request is of such urgency, it may require diverting an airborne Pre-Planned CAS flight to fill the request. This request is on such short notice that it denies detailed mission coordination or planning. This mission is performed against targets of opportunity and requires prompt execution for success. This is the most difficult form of CAS and is, generally, not an optimum combat effective response method. The reason that it may not be combat effective is that the flight may be carrying an inappropriate quantity or type of ordnance to ensure desired effect on target. To compound the aircrew's workload, a thorough map study must be accomplished prior to entering the target area to ensure the correct target is engaged. Completing all of these required duties in addition to normal cockpit duties can tax the most experienced combat aviator.

In either Pre-Planned or Immediate CAS missions, additional mission coordination briefing is accomplished enroute to the target area via the Direct Air Support Center (DASC), Tactical Air Coordination Center TACC, or by the terminal controller (FAC or FAC(A)). In today's environment, successful execution is dependent on extensive and reliable voice radio communication. This is completed through intensive training and standardized procedures required for success in a minimum communications environment. Per current CAS doctrine, if voice communications can not be established, Immediate CAS will not be done. The alternative response is to use Pre-Planned On-Call Mission. A Joint Tactical Air Strike Request (JTAR) is generated to request this kind of mission. The JTAR should be as specific as possible including: anticipated target area, type of targets likely to be engaged, time period during which mission will likely be required, and mission priority.

DCS SUPPORT OF CAS MISSION REQUIREMENTS

DCS is designed to support digital transfer of CAS mission critical information normally conveyed using voice communications with the exception of clearance to drop. The information that is passed digitally includes the Check-In/On-Station Report, the CAS Mission (receipt/negotiation/acceptance), and the Initial Point (IP) Inbound report. Under certain operational circumstances, voice communications may be needed to coordinate DCS network establishment and/or convey mission data. An example of this would be if the network participants don't have the data needed to join the network and must be given the data via voice radio (e.g. diverted strike aircraft supporting immediate CAS mission). Another example where voice would have to be used is when the equipment malfunctions and prevents transmission of mission data (e.g. FAC's or a CAS aircraft's DCS capability failed), but pre-planned data may be modified and/or used.

In the target area, Close Air Support (CAS) missions are controlled by a final controller referred to as the FAC (Forward Air Controller), or FAC(A) (Forward Air Controller (Airborne). The DCS capable FAC is equipped with a voice radio and a Target Location, Designation, and Hand-Off System (TLDHS). Whereas the DCS equipped FAC(A) is an F/A-18 equipped with an ARC-210 (DCS) radio. The FAC assigns the CAS mission, in the absence of a Airborne Forward Air Controller, to the CAS Mission Lead. The lead aircraft evaluates, accepts, and then in turn executes the Close Air Support mission. In the case where a FAC(A) is present, the FAC(A) serves as an extension of the FAC (or ground element) as needed. The Airborne Forward Air Controller coordinates the mission execution by the CAS Mission Lead assigned by the FAC (or ground element). The CAS Mission Lead (Flight Leader) controls the strike aircraft to weapon delivery. In digital Close Air Support, the wingmen equipped with the digital communication system, monitors the CAS Mission Lead and FAC or FAC(A) transmissions via the CAS format page. In case the CAS Mission Lead falls out of the formation, a wingman can assume the lead by simply modifying the NETS format page.

The TLDHS functionality provides the fire support observers and controllers the ability to observe the target area of interest, quickly and accurately locate ground targets, and designate targets for LASER guided munitions and spot trackers. The TLDHS provides the ability to digitally request and coordinate target engagements by Field Artillery, Naval Surface Fire Support (future capability), and Close Air Support. The TLDHS accomplishes this by integrating the following pieces of equipment: Lightweight LASER Designator Rangefinder (LLEADER), Target Locator Module (TLM), LASER Designator Module (LDM), Target Hand-Off Subsystem (THS), a Ruggedized Handheld Computer (RHC) and Target Handoff Software within the RHC.

VMF THEORY OF OPERATION

The VMF message format structure is comprised of the following: application header that contains the message handling instructions; addressing information which platform in network is target of message; acknowledgement requirements which is how the message receipt and response is to be handled. Next are the Data Fields, which identify message content, data of varying size, or no data (data field is retained in message and flagged to indicate no data present). The overall message length does vary.

The VMF Network Architecture replicates the current voice Tactical Air Direction (TAD) Net and it supports digital transmission of CAS Mission data in place of voice radio. The F/A-18 DCS network architecture currently allows up to ten "nodes" or participants. The following participants are supported in the F/A-18 mechanization: the CAS mission aircraft and the FAC or FAC(A). Only one FAC or FAC(A) can be defined in the NET. More than one Flight Lead can be designated via the NETS page, which is the one to communicate primarily with the FAC. The Flight Lead originates the messages from the CAS mission flight. There is no controlling node in place so communication takes place amongst all of the flight members and the FAC.

VMF Theory of Operation – Open Network

Network participation normally assumes that the participants entering the network know the addresses of the other participants before entering into the data link network. The Pre-Planned CAS mission participants will know ahead of time what network addresses will be used and who is expected to show up on the network. It is the more flexible Immediate CAS mission that is of concern, where the participants show up without prior knowledge of each other's addresses. This is depicted in figures B-10 and B-11. The DCS system was designed around this concept to allow for maximum flexibility. This allows "outsiders" (without addresses of other participants) to enter into the NET via briefed, standardized, or voice coordinated networks. The network operating characteristics must be harmonized to ensure proper data transfer occurs. In other words, the Network timing parameters must be the same. Several sets of standardized network parameters are available for use. In addition, unique protocols to handle message capability and unique operational impacts (message speed/accuracy) must be used. Simply sending a free text message to each of the participants will allow the DCS system to recognize the sender's protocol.

VMF Theory of Operation – Address Mechanization

The VMF address mechanization for each node is defined by its own Internet Protocol Address (ADDR), Unit Reference Number (URN), and the individual node's

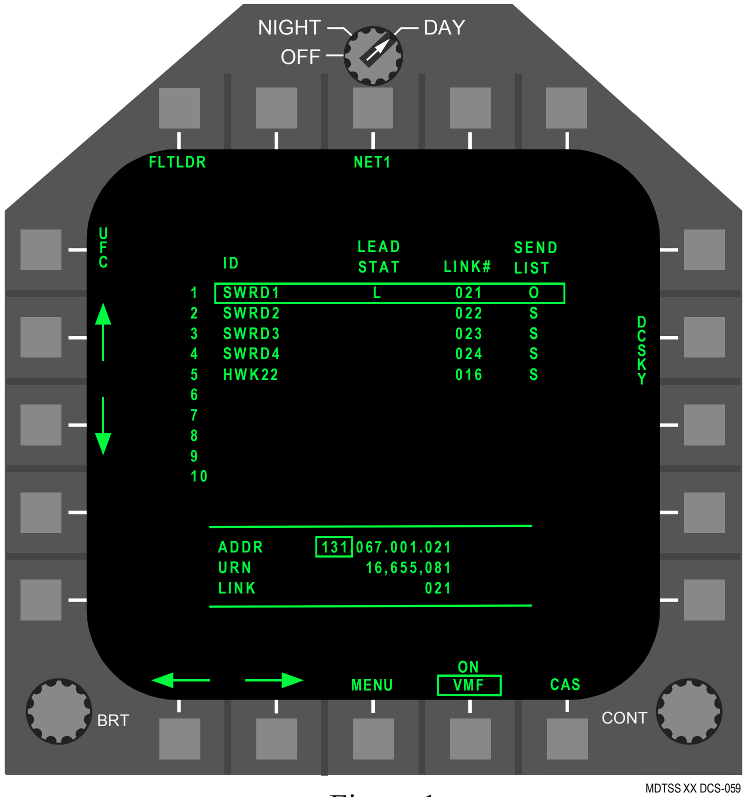

Figure 1
DCS VMF NETS DISPLAY
(Boeing Presentation Slide)

particular Link Address. This information is displayed to the aircrew as shown below on figure 1, in the lower half of the NETS page.

The Unit Reference Number, “URN”, will be assigned by blocks to services and then to units within each service. The Data Link Layer Address, “LINK”, is designed to show which particular flight a node is assigned to and his position within that flight. The LINK is used to establish network coordination and forces "serial" message exchange within flight groups. Any of the address information lines can be manually entered or edited through the aircrew’s UFCD or automatically entered as discussed previously by receiving a VMF message. The Address Edit Box is used to edit the address by positioning the box over each octet field using the Left and Right Arrows and typing the correct information into the UFCD. The DCS radio incorporates a feature that uses a look up table to correlate a Voice Call Sign (VCS) with a known node address. The VCS is then displayed to the aircrew under the ID column on the NETS page. If the VCS is unknown, a default ID will be used. Up to ten nodes can be displayed on the NETS page.

VMF Theory of Operation - Protocol

There are four VMF message types used in the F/A-18 VMF implementation: On-Station Report (OSR), CAS Mission (CAS), Departing Initial Point (DPIP), and Free Text (FTXT). Each message uses different protocols for format, addressing, and movement. The message starts out with the "Application Header", which contains addressing information and instructions to recipient(s) as to what, (if any), acknowledgement is required. Acknowledgement of message receipt is known as a Link Acknowledgement (Link Ack), which is performed automatically. An acknowledgement that the operator has seen the message is known as Operator Acknowledgement (Op Ack). An Op Ack is performed automatically when the display of the message is commanded. An Op Ack is currently used only when the FAC(A) receives an OSR. The last form of protocol used is when the operator replies to a sent message via the WILCO or CNTCO selections. This is called Operator Reply (Op Rep). Link Ack(s), Op Ack(s), and Op Reply(s) can all be heard as short electronic “hisses” or bursts in the aircrew’s headsets. A Transmit/Receive Status Line is displayed to help the aircrew keep track of all message traffic. The transmit/receive line will be addressed in the results and recommendations sections of this thesis. The ultimate goal of VMF is to operate in a communication silent mode. This presents reliability problems, as the sender and receiver need to be absolutely sure that all proper communication has taken place.

VMF Theory of Operation – Message Transmission in Network

When a message transmission is commanded, the data is transmitted when an opening is detected in the network message traffic. Voice activity on the selected communication frequency doesn't prevent data transmission, unless ownship's Comm 2 push-to-talk (PTT) button is keyed while trying to transmit a VMF message. By its nature, an open network would result in chaos as multiple nodes transmit their data simultaneously as each detects an open slot in message stream. To prevent this chaos, nodes now use a prioritization process to determine when to transmit; this evolved during developmental testing.

As discussed previously, the Link Address (Link) is broken down by the DCS network organization using a unique subscriber number (associated with position in flight/network: Lead aircraft: 1, second aircraft: 2, third aircraft: 3, fourth aircraft: 4, FAC: 5, and FAC(A): 6). This unique slot provides prioritization in message flow in which to begin transmissions. The assigned subscriber number is used to identify which node has priority to this slot in transmitting next message. When a message transmission is commanded, the transmitting node also instructs all the recipient node(s) to respond with a Link Ack message. During message traffic exchanges, Link Ack(s) are always used and indicates message receipt (no operator cues or response required).

Pending receipt of Link Ack(s), the transmitting node will "retry" transmission to the unresponding node(s) until the allotted retries are completed. The variable retries range from 1 to 5; 5 retries was determined to be the most suitable during testing. If the communication frequency is busy during the attempted retries, a possibility of no message receipt and no indications can occur. The transmit/receive status line does not operate intuitively and will be addressed in the results and discussion section of this thesis.

VMF Theory of Operation – Message Transmission Time Contributors

Message transmission time is affected by the size of message content being transmitted, the acknowledgement requirements and the number of programmable retries to transfer the message data over the network. The size of the transmissions can vary widely from: Departing Initial Point DPIP (small), On Station Report OSR (medium), Close Air Support CAS Mission (large), to the Free Text Message FTXT (variable between OSR and CAS). The acknowledgement requirements also vary from OSR (Link Ack, Op Ack), to CAS Mission (Link Ack, Op Rep), to DPIP (Link Ack) and the FTXT message (Link Ack, Op Rep). The number of "Retries" ordered in the DCS Network Timing Parameters initialization file. Until the message is delivered or until all retry attempts have been exhausted, the VMF function will tie up the Comm 2 radio. Different number of retries may be set for each network (i.e. NET1, NET2, NET3, NET4, NET5) depending on the data transfer characteristics of each.

VMF Theory of Operation – Network Types

Up to five sets of network types (or timing parameters) are selectable. The Nets consist of unique sets of optimal values for network timing and efficiency parameters determined experimentally during developmental testing. A different data set for each configuration of radio mode was found to be the most effective. A summary of all the DCS radio modes is as follows: plain, cipher, plain Have Quick, cipher Have Quick, plain SINCGARS, and cipher SINCGARS.

A selection of optimal network timing parameters for the given radio mode provided the fastest message throughput. The network timing parameter data sets are selected and preprogrammed before loaded into the aircraft. When downloaded into the aircraft, any one of up to five sets of fixed network parameters is selectable. The network timing parameters cannot be edited during flight.

CHAPTER 2: REVIEW OF THE LITERATURE

GENERAL

There really is not much in the way of a literature review due in large part that this VMF technology is so new. Therefore a review of literature was completed on the Close Air Support Mission to give the reader an appreciation of this highly orchestrated mission. Where applicable, the author has inserted where DCS VMF technology has been applied. Further research by the author to augment the necessity of this system by the operational community produced an article that appeared in *Aviation Week & Space Technology, Nov 19, 2001* issue. The article identified crucial shortcomings in prosecuting CAS in today's environment. An appreciation of this difficult mission is necessary to understand the intricacies that were required when analyzing the DCS VMF capability.

Close Air Support (CAS) is a Marine Corps innovation. Since the first dive bombing attempts in World War I and subsequent operations in Haiti, the Dominican Republic, and Nicaragua in the 1920s, Marines have realized the value of closely integrating aviation with ground combat efforts (MCWP3-23.1). World War II and the Korean War furthered the cause of performing CAS missions. During those conflicts, the fundamental tactics, techniques, and procedures for conducting CAS today were developed. Today, CAS has not only become a unique Marine aviation contribution, but it is now widely used by all services to support its integral ground forces. Marine Corps Warfighting Publication (MCWP) 3-23.1,*Close Air Support,* addresses basic CAS doctrine and procedures and is widely accepted as the CAS standard. The author will discuss CAS employment and the role CAS plays in integrated Marine, Joint, and Multinational operations. A review of standard procedures and terminology is provided which ground force personnel and pilots of fixed- and rotary-wing aircraft use to deliver aircraft ordnance in close proximity to friendly forces. Ultimately, the DCS VMF capability was designed and tested around these procedures and principles.

CAS FUNDAMENTALS

CAS is defined as an "air action by fixed- and rotary-wing aircraft against hostile targets which are in close proximity to friendly forces and which require detailed integration of each air mission with the fire and movement of those forces." (Joint Publication (Joint Pub) 1-02, *DOD Dictionary of Military and Associated Terms).* "CAS is an offensive air support (OAS) mission that is planned and executed to deliver firepower against selected enemy capabilities at a designated place and time. By using the speed and mobility of aircraft, CAS provides the commander with the means to strike the enemy swiftly and unexpectedly" (MCWP3-23.1). Applying the fundamentals of combined arms, the commander integrates CAS with other forms of fire support and the fire and movement of ground forces. In so doing, the commander takes advantage of fleeting battlefield opportunities and achieves combat objectives. CAS is a mission conducted at the tactical level that may affect operational-level objectives. CAS is conducted when and where friendly combat forces are in close proximity to enemy forces. The word "close" is situation dependent and does not imply a specific distance. "The requirement for detailed integration based on proximity, fires, or movement is the determining factor. CAS provides firepower to neutralize, destroy, or delay enemy forces in offensive and defensive operations. At times, CAS is the best firepower delivery means available to rapidly mass a lethal capability, exploit tactical opportunities, or save friendly lives" (MCWP3-23.1). Available aircraft that are capable of performing CAS are fully integrated into ground operations, thereby giving the commander flexibility in force employment. The effectiveness of CAS is proportional to the degree to which it is integrated into the planning and conduct of maneuver warfare. The supported unit commander influences the use of CAS by requesting and approving all CAS missions within his area of operations. "Proper and timely communication and control are necessary if CAS is to be successful" (MCWP3-23.1). To conduct effective CAS missions, an aircrew must: be responsive, remain flexible, be familiar with the supported unit's scheme of maneuver and understand the commander's intent, acquire the correct target and most importantly, deliver the correct ordnance accurately on the target. "Although the concept is simple, CAS requires detailed planning, coordination, and training for effective and safe execution" (MCWP3-23.1).

Fratricide

Fratricide, or casualties to friendly forces caused by friendly fire, is an unacceptable and normally avoidable circumstance in warfare. Due to the nature of CAS, fratricide is always a major concern when conducting this mission. Ensuring that target coordinates and other vital data are communicated and properly input into the aircraft's systems can mitigate this risk of fratricide. The DCS system has eliminated the possibility of the aircrew inputting the desired target's coordinates incorrectly. This is because the coordinates are part of the CAS mission message that is sent via data link and directly downloaded into the aircraft's weapons computer. It is still possible, however, to have fratricide if the sent coordinates are incorrect. Other causes of fratricide include misidentification of targets, target location errors, target locations incorrectly transmitted or received via voice, and loss of situational awareness by either terminal controllers, CAS aircrews, or fire support coordinators. Most recently in the Afghanistan Theater of operations, the FAC sent his own location coordinates vice the target's coordinates resulting in three fatalities. The Udairi Range Complex in Kuwait was the site where target misidentification took place resulting in the Observation Post being bombed vice the target. All participants in the CAS process must realize that they could possibly contribute to unintentional or inadvertent friendly fire incidents and therefore must make every effort to prevent such occurrences. Ultimately, the terminal controller issuing the "cleared hot" clearance has the responsibility of ensuring that fratricide will not occur when employing CAS.

Training

Continuous, realistic training creates a better understanding of battlefield conditions and the situations in which CAS may be employed. "Successful CAS training will result in safe and effective CAS employment and provide for synergistic fire support during operations. Advances in procedures and equipment have improved the ability of aircraft to provide close support" (MCWP3-23.1). CAS execution is complex. Aircrew and terminal controller skills have a direct influence on mission success. Maintaining a high degree of skill requires that aircrews and terminal controllers practice frequently.

With the advent of DCS VMF technology, training will be required to understand the system and to gain proficiency.

Communications and Information Systems

CAS execution requires dependable and interoperable communications. Unhindered voice or data communications between aircrews, air control agencies, terminal controllers, supported commanders, and fire support agencies greatly increase the ease by which CAS is requested and controlled. Additionally, information flow will come from the battlespace in the form of in-flight reports and mission reports (MISREPs). Information systems that can relay timely and time critical information, such as target activity after attack and additional targets, will facilitate real-time CAS decision-making as well as future CAS planning.

Command, Control and Communications

CAS requires integrated, flexible command and control (C2). C2 that facilitates an understanding of the mission and the initiative to adapt to changing battlefield situations is the foundation for creating conditions favorable for CAS employment. Basic requirements for CAS C2 are the ability to process CAS requests, assign assets, communicate taskings, deconflict fires and routing, coordinate support, establish airspace control measures, and update or warn CAS aircraft of enemy threats. Figure 2 below, from Marine Corps Publication MCWP3-23.1 shows the level of communication and

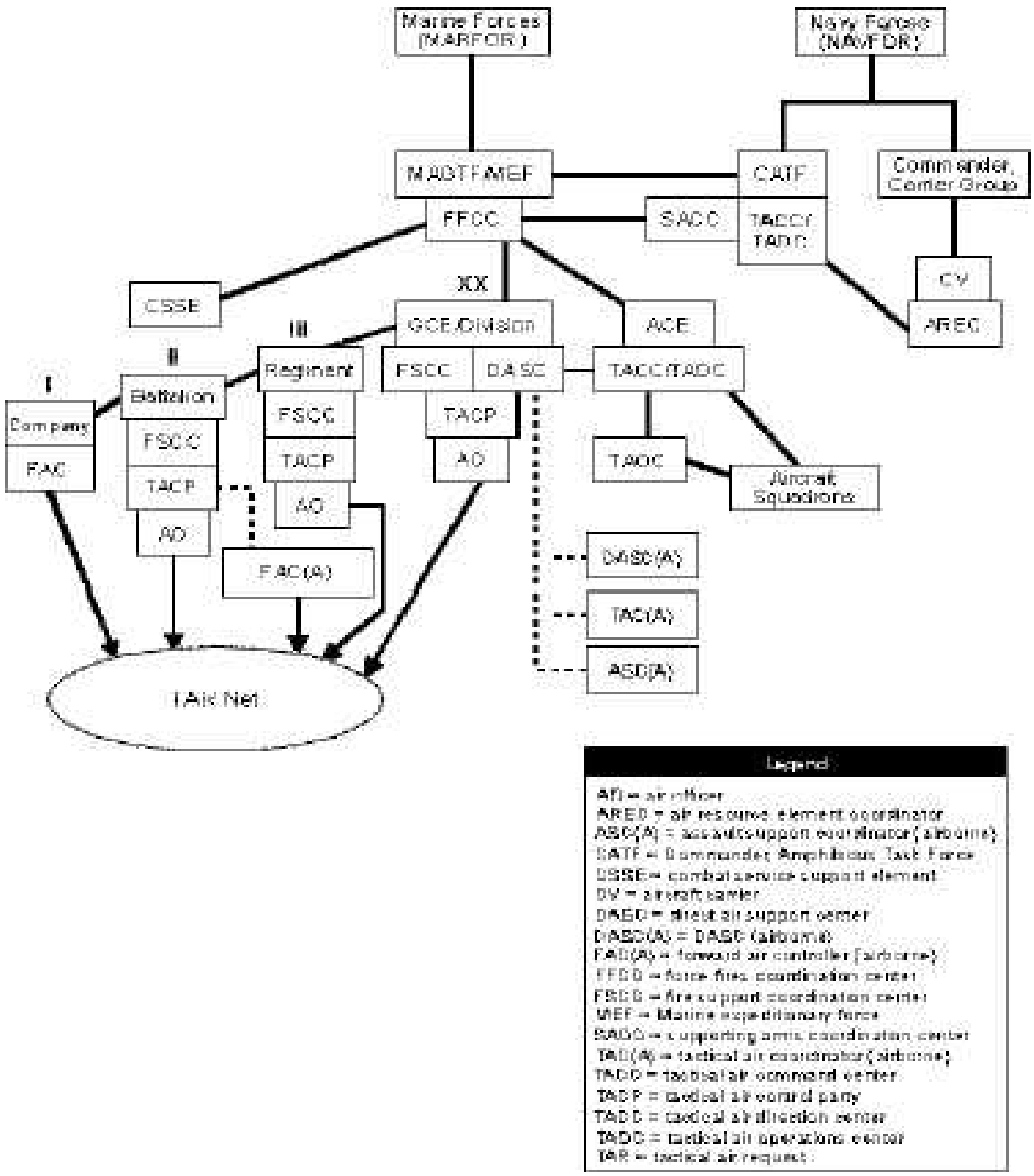

Figure 2
Navy/Marine Corps Close Air Support Connectivity (MCWP 3-23.1)

control that is involved in coordinating and controlling this complex mission. The Marine Air Command and Control System (MACCS) provides the Marine air and ground commander with the means to integrate, coordinate, and control all air operations within his area of operations and with joint or combined forces. The principal chain of command within the Marine Corps for CAS is the fire support coordination center (FSCC), the direct air support center (DASC), the tactical air command center (TACC), the tactical air operations center (TAOC), the tactical air control party, the air officer (AO), and then the FAC/FAC(A). The DASC receives current ground and air intelligence information primarily from aircrews operating within the battlespace. Aircrews can pass visual reconnaissance reports that are essential to timely battlefield targeting directly to the DASC, which then passes this information to the Marine TACC/TADC and the senior Fire Support Coordination Commander (FSCC). The FSCC uses these visual reconnaissance reports in the assessment phase of the targeting process. The forward air control parties prepare the majority of the preplanned and immediate requests for CAS and provide CAS terminal control capability.

The FAC provides terminal control for CAS aircraft and maintains radio communications with assigned CAS aircrews from a forward ground position. FAC terminal control aids in target identification and greatly reduces the potential for fratricide. The duties of the FAC include: knowing the enemy situation, selected targets and location of friendly units; knowing the supported unit's plans, position, and needs; locating targets of opportunity; advising the supported company commander on proper air employment, requesting CAS, controlling CAS aircraft and performing battle damage assessment (BDA). The FAC will now use the TLDHS to communicate with CAS aircraft for control and passing BDA while using voice communication only as a backup.

The FAC(A) is an airborne extension of the TACP. The FAC(A) can serve as another FAC for the TACP or augment and extend the acquisition range of a forward air control party. The FAC(A) provides terminal control of CAS aircraft and other duties include detecting and destroying enemy targets, coordinating or conducting target marking, providing terminal control of CAS missions, conducting air reconnaissance, providing artillery and naval gunfire air spotting, providing radio relay for the TACP and FAC, and performing BDA.

Communications

"Information exchange by tactical communication means is necessary to facilitate CAS and allow the proper control of CAS events. Communications must be mission-tailored and robust to ensure that links between aircraft and ground units are maintained and to minimize the chance of fratricide and enhance mission effectiveness" (MCWP3-23.1). With the incorporation of DCS and VMF, this allows flexibility and responsiveness of CAS communications more possible by using a variety of techniques, including secure and frequency-agile equipment countermeasures.

Per current doctrine, data link should be used whenever available is to be used as identified in MCWP3-23.1, "the standard mode for all CAS communications should be secure voice, frequency agile (e.g. HAVE QUICK or single-channel ground and airborne radio system (SINCGARS)), and/or data link whenever available". It is interesting to note that MCWP3-23.1 was revised in the year 2000 which coincided with the first testing of DCS and TLDHS systems. Enemy communications jamming, monitoring, and imitative deception interfere with the air C2 system and jeopardize the use of CAS. Prior to DCS VMF technology, the Marine FAC/FAC(A) were taught to use natural terrain masking, burn through, brevity, chattermark procedures, frequency agile radios, secure communications, authentication, and visual signals to counter these enemy measures.

Communications and control procedures in the CAS environment vary by the type of CAS, the type of threat, the support package, communication capabilities, and planned ingress tactics. A preplanned, scheduled mission may require very little communications. However, as discussed previously, an immediate mission will probably be very communications intensive. In the presence of an EW threat, communications discipline becomes more important, as effective communications may be considerably more difficult to conduct.

In either case, the aircrew must receive mission-essential information before arriving in the target area. Aircrews sometimes had to divert or abort if they were unable to receive mission-essential briefing items. At times, voice communications between the aircrew and the terminal controller can be difficult or nonexistent. If the terminal controller cannot talk to the aircrew, another air control agency had to pass mission-essential information. Using preplanned scheduled CAS missions, the aircrew could leave the CP to meet a TOT with minimal communications. The CP location may not allow communication between aircrews and terminal controllers because of radio range or line-of-sight considerations. Aircrews should still expect communication problems and plan to use other air control agencies to provide radio/datalink relay.

CHAPTER 3: METHODOLOGY

GENERAL

This section will discuss the author's methodology used to evaluate the DCS VMF system implementation and integration within the F/A-18 Hornet. The author will develop a case on how to better integrate the DCS VMF into the F/A-18 to improve mission effectiveness. Human factors and a Systems Engineering Process ideology were used to evaluate the implementation and integration of the DCS system. The evaluation consisted of Variable Message Format (VMF) communications capability, integration compatibility and technical suitability of the RT-1824 ARC-210 radios as integrated into the F/A-18 aircraft. A discussion of the systems engineering process follows which the author applied to detect problems and arrive at the required solutions to correct the problem statement. Following the discussion of the systems engineering process is an account of the test articles configurations and test methodology used during developmental test.

SYSTEMS ENGINEERING PROCESS

The systems engineering process is a methodical approach to problem-solving that attempts to break down the larger requirements of the customer into smaller identifiable pieces that can be dealt with at a subsystem level. The goal of the process is to optimize the system's components, attributes, and relationships in order for the entire system to operate at peak efficiency. During the course of this thesis, an eight step systems engineering process was developed and implemented by the author. The process consisted of the following eight steps: problem statement, requirements and constraints analysis, alternatives generation, alternatives analysis and selection, system design, system testing, system implementation, and system control.

The systems engineering process begins with identifying the problem that the system under development seeks to solve. It is important that the problem is well defined and clearly stated, allowing the problem to be bound so as to avoid the costly "unknown unknowns" that may arise later (Sheridan, 1988). If the problem is not well bounded, the system design may head in a direction other than that intended. Once identified, the problem statement should be revisited throughout the process to ensure that the focus of the process is kept on solving the problem.

An analysis of the requirements and constraints of the system under design is performed in order to ensure that the needs of the customer will be met. Areas to be analyzed include mission, cost, schedule, performance, and programmatic requirements. Additionally, constraints imposed by the customer, military standards and specifications, and technology must be analyzed for their impact on the system. The requirements and constraints analysis step takes place at the beginning of the process but is continuous throughout the systems engineering process. Each following sequential step should be traceable back to a stated requirement and should not violate any of the constraints deemed pertinent during this step. Continuously performing the requirements traceability and constraints analysis will ensure that the system focus will be maintained throughout the design.

Alternatives generation involves developing all of the alternatives that may potentially solve the problem statement. The focus during this step is to generate as many alternatives as possible. At this stage, no possible alternative is discarded. Extensive research and study is performed to explore alternatives that have been used in similar systems. Additionally, advanced concepts are researched to determine if they may be applicable to the system under design. All alternatives are recorded for possible future use.

The alternatives analysis and selection stage is where all of the previously generated alternatives are weighed for possible use in the design. The advantages and disadvantages of each are investigated and weighed. Important factors to analyze include technological risk, life cycle costs, availability, and compatibility with other system components, producibility, supportability, and performance. If necessary, studies may be conducted to select the best solution among many possible solutions. During this stage, the systems engineering perspective must be maintained. The intent is to optimize the performance of the overall system, even if that means some individual components of the system operate at less than their optimal performance.

The system design stage is where all of the individual alternatives previously selected are formulated into a system. It is at this point that the physical architecture of the system is defined. The physical architecture must be constructed so that each component will satisfy at least one or more of the requirements stated for the system. If it does not satisfy one or more of the requirements, it should be eliminated from the design. Additionally, each component must be capable of operating within the constraints analyzed previously.

Once designed, the system must be tested to ensure that it can meet the stated requirements and that it can operate within the imposed constraints. System testing will take place at many levels. Subsystem testing should be performed to ensure that the subsystem has met its requirements and can operate within the specified environment. Environmental, stress, vibration, electromagnetic compatibility, electromagnetic vulnerability, and performance are some of the tests to be completed. Full system testing must also take place. Early testing may involve modeling, simulations, mock-ups, demonstrations, and analysis. Finally, testing of the full-integrated system in the operational environment must be conducted.

Weaknesses in a system's design are often identified during the system test phase. Any deficiencies identified during test will return the design to the alternatives analysis and selection step. A new alternative may need to be selected and passed to the system design step for modifications in the design. The concept of test, analyze, and fix ensures that the final system design will meet all of the requirements and design constraints placed on the system. A system should never be allowed to proceed to the implementation stage with deficiencies found in the test stage still outstanding. Failure to fix known deficiencies guarantees that the system will operate at less than an optimal condition.

Manufacturing and fielding of the system takes place during the system implementation phase. If the systems engineering approach has been properly employed, the system fielded will satisfy the stated requirements, operate within the design constraints, and perform at an optimal level.

System control is a concurrent activity that takes place throughout the systems engineering process. The purpose of system control is to provide balance to the process. It provides the program manager with a tool to track progress and identifies problems early. Areas monitored include risk management, configuration management, interface management, and data management. Effectiveness analyses, trade studies, and performance based progress measurements are developed and tracked to ensure that the system design will satisfy performance requirements while staying within the cost and schedule mandated by the customer.

TEST METHODOLOGY AND TEST ARTICLE CONFIGURATIONS

This thesis will concentrate on the VMF software integration testing and interoperability with the TLDHS, which included Air-to-Air testing using an airborne F/A-18 as a Forward Air Controller Airborne (FAC(A)) and Air to Ground testing using a ground FAC with a TLDHS. Integration data were gathered on all DCS flights and included verifying the DCS interface and interoperability with related systems and support equipment, successfully verifying the controls and displays, verifying the functionality of the DCS and the performance of related systems that would be affected by the DCS. Ground and Laboratory testing was performed throughout the duration of the program.

The F/A-18 DCS testing consisted of a series of integration tests to evaluate the integration of the DCS radio into the latest aircraft OFP's. The developmental flight test phase was conducted from March 2000 to December 2001 and consisted of approximately 270 laboratory hours, 89 ground test hours, and 50 dedicated DCS flights for approximately 80 flight hours. The first series of flights were for risk reduction testing to ensure that the anticipated throughput timing and displays mechanization were acceptable. When the final aircraft OFP software version was available for test, a series of laboratory and ground testing was conducted to validate throughput timing matched the expected results. The next and final series of tests were conducted to simulate the CAS flight environment with a FAC or a FAC(A) controlling a section, division, and two sections for attacking multiple targets.

The DCS VMF testing performed was conducted on an F/A-18E, an F/A-18F, and an F/A-18D. For this evaluation, the test aircraft was configured with Software Configuration Set (SCS) 15C-255U/256U or higher, the test radio was configured with software versions 15C–D03 or higher, and the CSC was configured with 15C-002 or higher. All aircraft were upgraded with Engineering Change Proposal (ECP)-576. This ECP installed an ARC-210 DCS radio in place of the existing Comm 2 RT-1556 ARC-210 radio. The MIDS amplifier-control, intercommunication (ACI) panels were also installed to reflect an operational F/A-18 aircraft configuration. See figures A-1, 2.

During the VMF software integration testing, the ground station used was the Target Location, Designation and Hand-off System (TLDHS). The TLDHS consisted of a Lightweight Laser Designator Rangefinder, which was comprised of a Target Location Module (TLM) and a Laser Designator Module (LDM), and the Target Handoff System, which was comprised of the Ruggedized Handheld Computer (RHC) with the Target handoff Software (THS). The RHC was connected to either the PRC-113 (RT-1319B) or the PRC-119 (RT-1523(C)) radios during testing. During the range performance testing only the RHC and a radio were used.

Message Error Rate (MER) was determined during single channel and Have Quick data communications. MER was determined by monitoring messages at the receiving radio to determine completeness and accuracy of the messages sent. Aircraft avionics bus data was also analyzed for message error.

During all of these tests, a sample CAS 9-Line VMF message was transmitted, received, edited and then retransmitted to verify proper logical operations. Simulated CAS missions were performed out at NAWCWD China Lake by the author and his test team to assess the operational capabilities of the DCS VMF system. It was through this process that most of the integration and implementation issues were discovered. The Air to Ground tests used the TLDHS when it was available and operational; otherwise a normal PRC-113 manpack radio was used to provide an operational assessment. The PRC-113 is the most common field radio employed by the fleet today.

Air-to-Ground Low-Band VHF Data

The Low-Band VHF data communications performance/maximum range of the F/A-18 DCS ARC-210 radio set was evaluated at NAWCAD Patuxent River during air-to-ground communications between the test aircraft and the Communications, Navigation, Identification (CNI) ground station. Prior to takeoff, the aircrew established normal VHF, and SINCGARS voice and data communications with the CNI ground station. The aircraft then proceeded out to the test area flying racetrack patterns with 30 nmi legs at max endurance airspeeds and altitudes ranging from 5,000 feet to 15,000 feet MSL. Actual range from the ground station varied from 10 to 40 nmi.

While flying in the racetrack pattern, the aircrew established plain and secure VHF non-ECCM data communications on single channel frequencies 36.85 and 49.95 MHz, and plain and secure SINCGARS data communications with the CNI ground station using the

Comm 2 DCS ARC-210. The aircrew recorded accuracy and completeness of messages received every 5 nmi from the ground station on data cards. Orbits were also conducted short of max range to determine azimuth performance. While flying an orbit pattern, the aircrew established data communications with the CNI ground station every 20 degrees of heading by calling out heading. The aircrew then recorded accuracy and completeness of messages received on data cards. The test aircraft also used an onboard data bus recording system to record data bus traffic during all flight test maneuvers. Cockpit video and audio was recorded using the cockpit recording system.

The automatic relay capability of the F/A-18 in the single channel and SINCGARS modes was also functionally tested with two external ground stations communicating through the F/A-18 automatic relay system. These two ground stations included a DCS ARC-210 ground station and a PRC-119A manpack radio both located at the CNI ground station. Completeness and accuracy of messages at the ground station were recorded manually.

Air-to-Ground UHF/VHF Data

UHF/VHF data communications performance/maximum range of the F/A-18 was evaluated at NAWCAD Patuxent River during air-to-ground communications between the test aircraft and the CNI ground station. Prior to takeoff, the aircrew established non-ECCM UHF, and HAVE QUICK voice and data communications with the CNI ground station using the Comm 2 DCS ARC-210. Flight testing consisted of the test aircraft flying outbound runs to approximately 200 nmi and inbound runs to approximately 150 nmi along the PXT 150°-170° radial at max endurance airspeeds and altitudes of 28,000-32,000 feet.

During outbound runs, the test aircrew established plain data communications on VHF frequencies 123.35 and 167.5 MHz, plain and secure data communications on 262.8 MHz, 383.4 MHz, HQI and HQII with CNI ground station every 10 nmi of flight to a range of 200 nmi or where communications are lost on all frequencies. The aircrew recorded accuracy and completeness of messages received from the ground station at each contact on data cards to be provided by the CNI station. In addition, the test aircrew noted ranges where communications were lost/re-established. At 200 nmi, the test aircraft will turn inbound and attempt communications with the CNI ground station every 10 nmi of flight to a range of 150 nmi or where communications are re-established on all frequencies. The aircrew recorded accuracy and completeness of messages received from the ground station at each contact on data cards in addition to videotape and data bus recordings. In addition, the test aircrew also noted ranges where communications were lost/re-established and environmental conditions.

Orbits were conducted short of max range to determine azimuth performance. During the orbits, the aircrew established data communications with the ground station every 20 degrees of heading. The aircrew recorded accuracy and completeness of messages received from the ground station at each contact.

The automatic relay capability in the single channel and HAVE QUICK data modes were functionally tested with two external ground stations communicating through the automatic relay system just as previously tested for Low Band VHF.

Air-to-Air UHF/VHF Data

The UHF/VHF data communications performance/maximum range of the F/A-18 was evaluated at NAWCWD China Lake during air-to-air communications between two F/A-18s namely, aircraft #1 and aircraft #2. Aircraft #1 was designated the FAC on the NETS page, or sender, while aircraft #2 served as the CAS player. Prior to takeoff, both aircraft established UHF and HAVE QUICK communications with each other and with the ground station. Flight tests consisted of aircraft #2 flying racetrack patterns with approximately 20 nmi legs at max endurance airspeeds at altitudes ranging from 23,000 to 25,000 feet while aircraft #1 conducted outbound runs to approximately 200 nmi and inbound runs at maximum endurance airspeeds and altitudes of 28,000-32,000 feet. Aircrew #1 established plain and secure data communications on single channel frequencies provided and HAVE QUICK nets with aircrew #2 and with the ground station every 10 nmi of flight out to 200 nmi separation. Both aircrew noted completeness and accuracy of messages received. At 200 nmi, aircraft #1 then turned inbound and attempted communications with aircrew #2 and the ground station every 10 nmi of flight to a range where communications were re-established on all frequencies. Both aircrews noted aircraft heading and ranges where communications were lost/re-established.

Orbits were conducted by aircraft #1 to determine azimuth performance. During orbits, aircrew #1 established data communications with aircraft #2 every 20 degrees of heading. Both aircrew noted completeness and accuracy of messages received at each contact.

Human Factors

Human Factors Military Standard, MIL-STD 1472D, was used as a guideline to assess the system's compliance with human engineering principles. MIL-STD-1472D Human Engineering Design Criteria for Military Systems, Equipment and Facilities is a document that presents human engineering principles, design criteria, and practices to integrate humans (their requirements) into systems and facilities. This is desired to achieve effectiveness, simplicity, efficiency, reliability, and safety of the system operation, training, and maintenance. This document contains information on items with which humans commonly interface including data and illustrations on visual fields, controls and displays (manual, visual, and audio), physical dimensions and strengths of humans, ground workspace design requirements, environments, design for maintainability, design for remote handling, hazards, and safety considerations. In addition, aircrew interviews were utilized to evaluate the usability and functionality of the DCS system, particularly VMF.

SUMMARY

Systems engineering and human factors formed the method ideologies used in this study while evaluating and improving the implementation and integration of DCS VMF within the F/A-18 Hornet. Systems engineering process was used to cite several integration problems of the DCS VMF capability.

CHAPTER 4: RESULTS AND DISCUSSION

The author's analysis was done on information attained during a Navy developmental test program, however all conclusions and recommendations are independent of the test program. The author's role in this test program was as lead test pilot and project officer. Overall, the DCS radio provided the F/A-18 with voice and VMF communications capability in all modes (UHF, VHF, SINCGARS, HQI, and HQII), embedded COMSEC capability and digital messaging for use during the CAS mission. The greatest improvement in mission capability was provided by VMF. The DCS system required extensive preflight planning and required extensive preflight coordination with all participants to send and receive data. If the system was not fully understood or the operator did not follow procedures, confusion developed requiring voice communication to receive all required information to conduct a CAS mission.

DCS will provide the fleet with a significant increase in capability to perform the CAS mission. Executing CAS missions currently requires an extensive amount of "heads-down" time while the 9-Line brief is copied and the data is input to the mission computer. DCS brings the 9-Line into the cockpit automatically and displays the information to the aircrew in a familiar format. The selection of "USE" loads all pertinent mission information into the mission computer and displays it to the aircrew in a useful manner. DCS allows effortless completion of the administrative tasks of a CAS mission, which will allow aircrew to concentrate on executing the tactical portion of the mission placing bombs on target, on time, in support of ground forces. The situational awareness provided by a HUD cue to indicate friendly positions is remarkable and will reduce the incidence of friendly fire mishaps.

The current DCS implementation that is being proposed by the prime contractor for the F/A-18 aircraft is inadequate in several areas and will not fully solve the previously defined problem statement. Using the systems engineering approach, the overall problem statement was further broken down to seven separate sub-areas where the current proposed design is inadequate.

When the DCS system was originally designed, the mission and utility of the FAC(A) was limited but in recent years this capability has been exploited. The result is that the DCS VMF system is inadequate for this mission because there is no way for a FAC(A) to type free-text messages or include remarks in the CAS 9-Line. Efficient and accurate entry of alphanumeric character entry into the weapons system is required during combat operations. The F/A-18E/F employs a touch screen Up Front Control Display (UFCD) that could be redesigned to allow alphanumeric entry through the use of an alpha matrix and scratch pad. In the current design, a 9-Line can be developed real-time with default selections and by use of the numeric keypad provided by the UFCD. However if there are any amplifying remarks to be included real-time, the only way to currently communicate those is by voice. The DCS VMF system allows free-text messages to be sent and received, however those must be pre-programmed prior to flight. This system limitation is undesirable and defeats the purpose of incorporating a non-voice communication system.

As discussed in the CAS mission background, Chapter 2, there are currently three mandatory voice communication calls that must be made by the CAS aircraft prior to weapons release. They are “Continue”, “Cleared Hot” and “Abort”. The importance of these three calls can’t be overemphasized as failure to adhere to these procedures often results in catastrophic events and fratricide. In the current DCS system, none of those messages were incorporated into the F/A-18 DCS VMF message standard. All three of these messages should be included on the aircrew’s radar, forward looking infrared, situational awareness, and helmet mounted sight displays.

Currently the CAS page, see figure B-3, is very cluttered and is difficult to quickly scan for needed information while executing a CAS 9-Line mission. Upon initial inspection in a laboratory environment, the CAS page did not appear to be an issue. However, when using the page inflight during CAS missions, it was very apparent that too much unnecessary information was being displayed to the aircrew after “USE” was selected. Once “USE” is selected, the aircrew has thoroughly reviewed the 9-Line and is ready to execute the mission that was sent. A task was presented to the test aircrew in order to find out how quickly they could find certain key pieces of information. On average, aircrews were spending between 3 to 5 seconds searching the display for the information. The Modified Cooper Harper scale, Reference 5 was used to standardize and quantify aircrew’s evaluation of the desired task. The test aircrew all agreed that the CAS display page was too cluttered with a resulting workload scale rating of WL7 was assigned. This meant that the aircrew had very little spare mental capacity to accomplish other tasks, but maintenance of effort in the primary task were not in question. The resulting recommendation by the author was to design a second CAS page that should replace the existing CAS page after “USE” is selected. This page is presented in figure B-13.

The current NETS design only allows for one SEND TO list, which is inadequate for the F/A-18 FAC(A) aircraft mission. The FAC(A) role was not originally included in the design of DCS, however fleet operators are intending on using the radio for this very important mission. In the current design up to 10 aircraft or nodes can be identified on the NETS page. The problem with the current design is all 10 nodes will be receiving information that may pertain to only a certain flight of CAS aircraft. With multiple SEND TO lists, the FAC and FAC(A) can send specific information to the appropriate aircraft without tying up all of the participating aircraft's COMM 2 radio. During flight test, some aircraft COMM 2 radios were unavailable to their operators while performing unnecessary VMF transmissions and receptions. This unavailability is highly undesirable. The author proposes that the DCS VMF NETS page be redesigned to allow up to four lists, which would include four participants per each list. This redesign would allow for necessary flexibility for both the Airborne Forward Air Controller and ground Forward Air Controller.

A friendly arc is depicted on the aircraft's Horizontal Situation Indicator (HSI) display, which shows where friendly troops are to prevent fratricide. This arc was shown to be very useful, for human factors reasons, and gave aircrew terrific situational awareness. The friendly arc only appears on this one display. The issue raised is that additional datalink (Link 16) that is being incorporated into all F/A-18 Hornets under the Multi Functional Information Distribution System program which uses the Situational Awareness (SA) page not the HSI page. The HSI display was designed for navigational purposes only, not for employment of tactics. A change to the aircraft's mission computer software will be required to change the display.

The status line located at the bottom of the CAS and FTXT pages, example shown in figure B-7, was designed to inform aircrew that their messages were being sent and received by all pertinent CAS aircraft and the FAC. Several times during flight test, a VMF message was sent but not received for several different reasons, but the problem was the sending aircraft did not know who received the message and who did not. The workaround for this was to resend the message to everyone on the SEND TO list, which again unnecessarily ties up the COMM 2 radio for those who received the message. The status line as designed shows the number of aircraft that received the message over the total number of participants on the SEND TO list. The current VMF datalink architecture uses Link Acks to verify when aircraft have received and transmitted messages in a serial process. Sometimes not all aircraft received the message and in a flight of four aircraft the result see on the status line was "¾", i.e. one flight member did not receive the message. This result hampered and delayed prosecuting CAS 9-Line missions until the missing aircraft could be identified and then successful message exchanges take place. As a result, the test team agreed the best solution would be to use a color change on the SEND TO list to identify who received the message, thereby giving the sender an accurate accounting of message exchange.

Earlier in Chapter 2, fratricide was discussed at great lengths and is always a major concern when live ordnance is being used near friendly troops. The DCS VMF system has simplified the aircrew's job by not having to input the coordinates into the aircraft's weapon computer system. However, there is still the possibility of human error. This can occur if the FAC or FAC(A) input and send the incorrect target coordinates. A way to close this loophole is to incorporate a heads up display (HUD) repeater. This repeater would display to the FAC or FAC(A) what the close air support aircraft is seeing through their own aircraft's HUD. This repeated image can then be used to verify that the correct target has been designated thereby increasing the confidence amongst all participants and greatly reducing the possibility of fratricide. Currently the F-16 is developing a similar system called Situational Awareness Data Link (SADL).

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The author's analysis was done on information attained during a Navy developmental test program, however all conclusions and recommendations are independent of the test program. The author's role in this test program was as lead test pilot and project officer. The DCS radio provides several enhancing characteristics to the F/A-18, specifically the incorporation of Variable Message Format messages for use during CAS operations. The DCS system is required for current and future battlefield operations, but this will require some software modifications to the existing system within the F/A-18 to ensure its operational success. Based upon the research performed during the course of this thesis from the information gathered during the test program and from extensive personal F/A-18 Close Air Support flight experience of the author, the software integration and implementation changes proposed in Chapter 4 are recommended for inclusion in the F/A-18 DCS design. The conclusions are summarized below:

1. The DCS system lacks an alphanumeric entry capability to compose messages and 9-line missions.
2. The DCS system does not display crucial time critical commands to aircrew.
3. Once aircrew has accepted a CAS mission, the resulting CAS display is too cluttered to allow for quick access of vital information.
4. The DCS system NETS page does not adequately partition flight groups from receiving messages, resulting in everyone receiving everyone's messages.

5. The DCS system does not display the friendly arc on the Situational Awareness display.

6. The status line does not address who received and more importantly who did not receive a message.

7. The DCS system does not provide feedback to the FAC that the correct target has been designated.

Specific recommendations are summarized below:

1. The need to redesign the touch-sensitive data entry keyboard of the Up Front Control Display to provide an alphanumeric entry capability in addition to providing secondary tactile interface with the weapons system, specifically for the FAC(A) mission.

2. Modify the aircraft software and TLDHS software to display the following commands: “Continue”, “Cleared Hot” and “Abort”. These messages should appear in the Pilot’s HUD, FLIR display, Radar display and Joint Helmet Mounted Cueing Sight display to provide the needed situational awareness (SA) in a highly dynamic mission environment, such as CAS.

3. Designing a modified CAS page to appear after the aircrew selects “USE” to facilitate gaining pertinent information faster when conducting CAS missions.

4. Redesigning the NETS page to allow more than one “SEND TO” list to appear when the aircraft is serving in the FAC(A) role.

5. Modifying the software to allow the “Friendly Arc” to appear on the SA display in addition to the HSI display.

6. Redesigning the status line function to account for total number of aircraft received versus total number of aircraft on the send to list by modifying the NETS page to

incorporate color to allow quick interpretation of who received the sent messages vice whose did not.

7. Relay a repeater image of the close air support aircraft's heads up display, to allow the FAC or FAC(A) to confirm the correct target is being attacked.

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REFERENCES

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APPENDICES

DESCRIPTION OF THE DIGITAL CONTROL SYSTEM

GENERAL

The F/A-18, depicted in figure A-1, is a single or two-seat, twin-engine, all weather, fighter attack airplane manufactured by The Boeing Company which incorporates a variety of avionics and weapons systems.

Figure A-1
F/A-18C Hornet over Kuwait
Aviation Week & Space Technology

F/A-18 DCS SYSTEM INTERFACE COMPONENTS

Figure A-2
FRONT COCKPIT MIDS ACI VOLUME PANEL
(Boeing Presentation Slide)

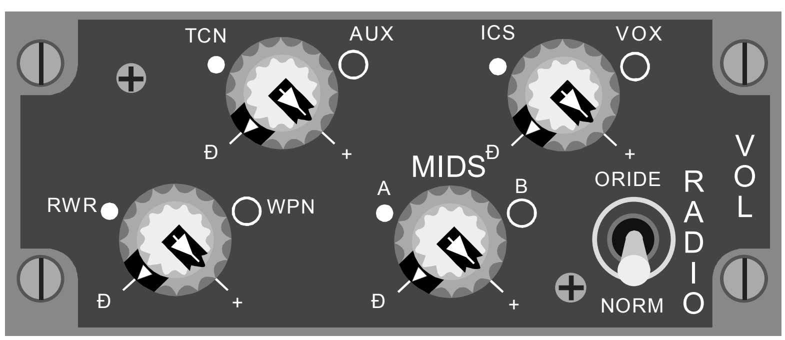


Figure A-3
AFT COCKPIT MIDS ACI VOLUME PANEL
(Boeing Presentation Slide)

BASIC CAS DEFINITIONS & VMF DISPLAYS

On Station Report (OSR) An OSR is the first step of check-in procedures and is essential for establishing the required flow of information between CAS aircrews and control agencies. Control agencies should update all en route CAS aircrews on the current intelligence situation in the target area and on any changes to preplanned missions. The CAS OSR check-in VMF format, below in figure B-1, is used on check-in with terminal controllers.

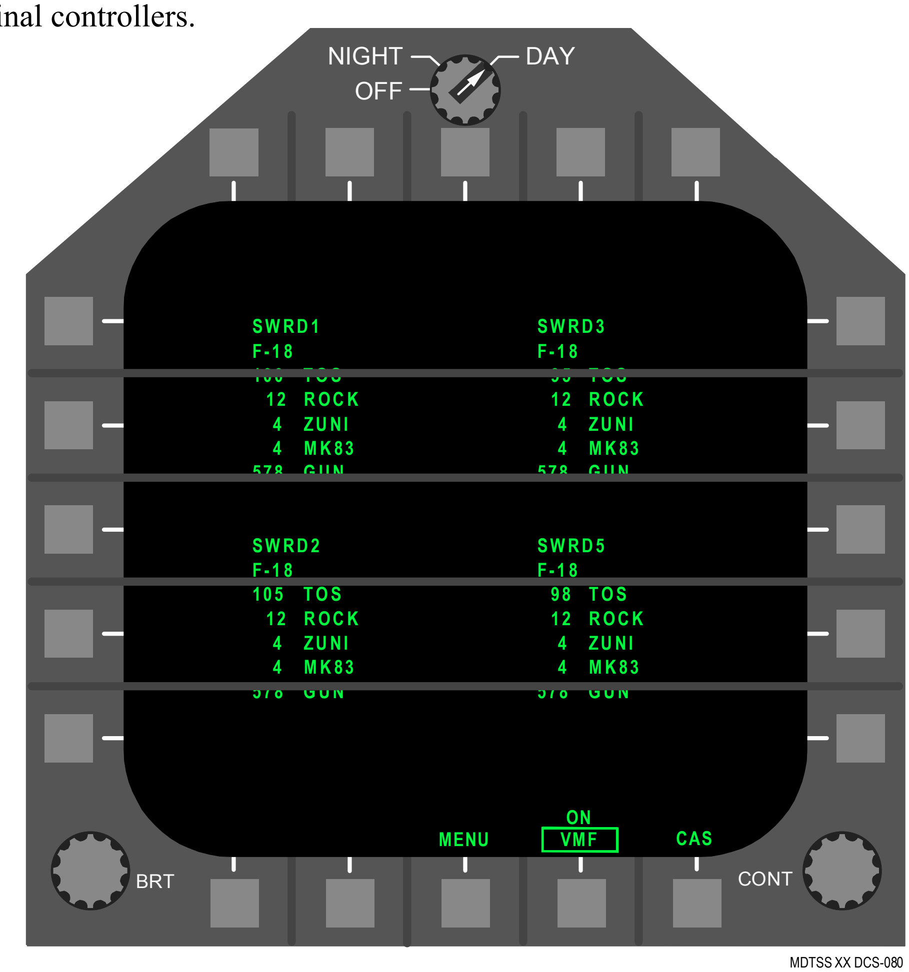


Figure B-1
VMF On Station Report (OSR)
(Boeing Presentation Slide)

Close Air Support Brief Form (9-Line) The CAS 9-Line provides the aircrew all of the essential information required to perform a CAS mission. The Pre-VMF CAS 9-Line is shown below in figure B-2 and the VMF 9-Line in figure B-3. A discussion of what each line represents follows.

Omit data not required; do not transmit line numbers. Units of measure are standard unless otherwise specified.
* Denotes minimum essential information required in a limited-communication environment. Bold denotes readback items when requested.

Terminal controller: ____________, this is ____________
(aircraft call sign) (terminal controller)

*1. IP/BP: ____________

*2. Heading: ____________ Offset ________ (left/right)

*3. Distance: ____________

*4. Target elevation: ____________ (in feet above MSL)

*5. Target description: ____________

*6. Target location: ____________
(latitude/longitude, grid coordinates, offsets or visual)

7. Type mark: ____________ Code: ____________
(WP/laser/IR/beacon) (actual code)

Laser-to-target line: ____________ degrees

*8. Location of friendlies: ____________

Position marked by: ____________

9. Egress ____________

- -

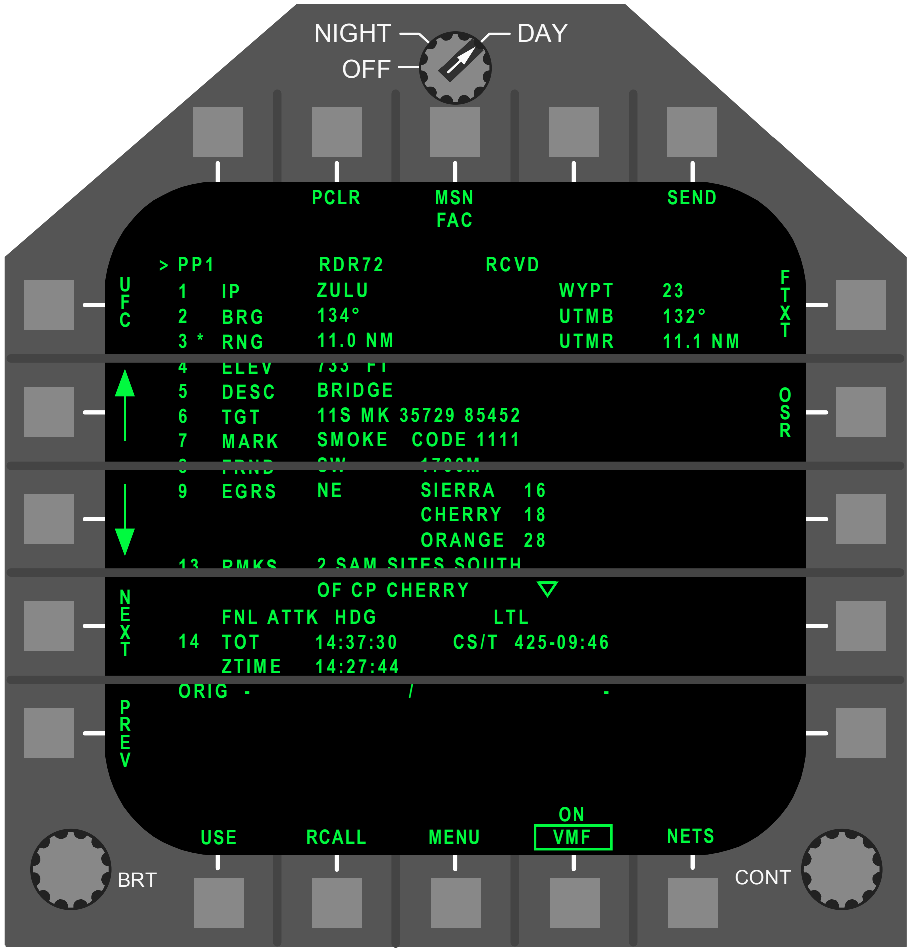
Remarks (as appropriate): ____________
(Threats, hazards, weather, restrictions, ordnance delivery, attack heading, danger close, or SEAD)

Time on target: TOT____________

— or —

Time to target: standby________ plus ________ ... Hack

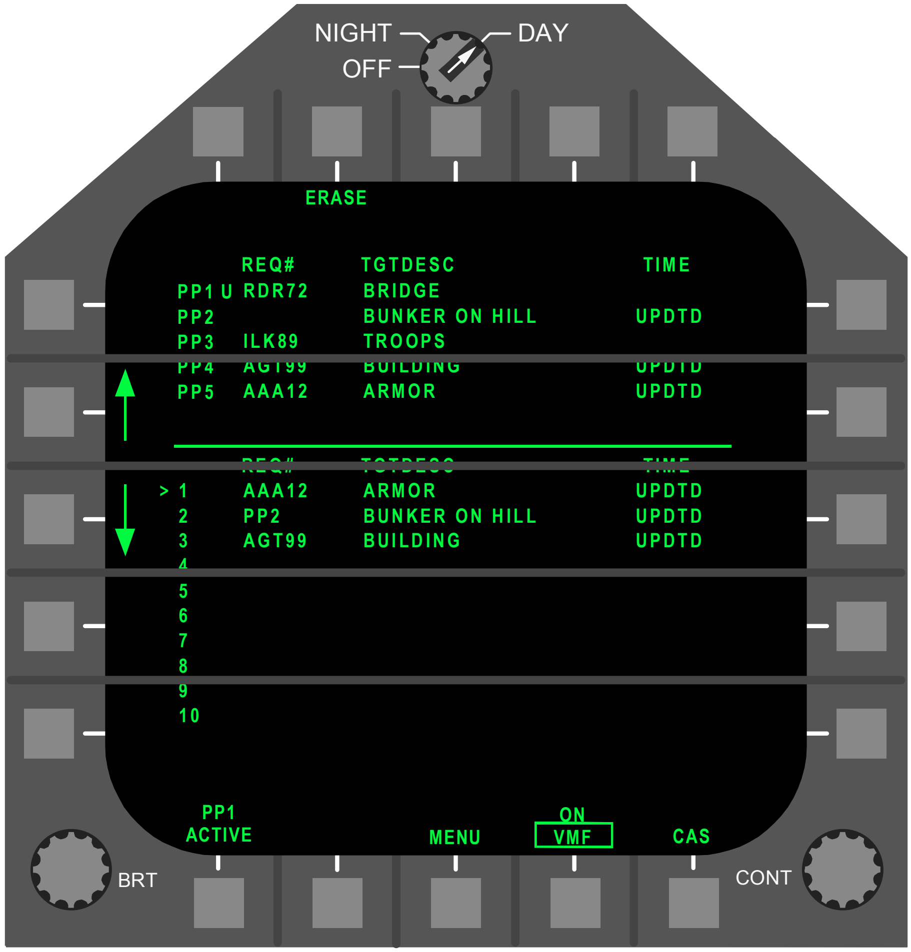
Figure B-2
Close Air Support Briefing Form (9-Line)
(MCWP3-23.1)



MDTSS XX DCS-102

Figure B-3
VMF Close Air Support Briefing Form (9-Line)
(Boeing Presentation Slide)

The DCS VMF system also provides the capability of preprogramming 9-Line missions as well as saving 9-Line missions that were sent, as illustrated below in figure B-4.



MDTSS XX DCS-119

Figure B-4
VMF Preplanned/Saved CAS 9-Line Missions
(Boeing Presentation Slide)

Control Point (CP) "the position at which a mission leader makes radio contact with an air control agency." (Joint Pub 1-02) Although not shown on either figure, the CP is where the flight will proceed to contact the FAC/FAC(A). Normally, a CP is outside the range of enemy effective weapons envelope and is typically 15-30 nautical miles (nmi) from the Initial Point (IP). During ingress, the aircrew contacts the terminal controller at the CP. A CP allows coordination of final plans before entering heavily defended airspace. Control points should be easily identified from the air and should support the battlefield commander's scheme of maneuver.

Initial Point (IP) "used as the starting point for the bomb run to the target" (Joint Pub 1-02). IPs are well defined and easily identified (visually or electronically) and are typically located 5-15 NM from the target area. Terminal controllers and aircrews use IPs to help position aircraft delivering ordnance.

Heading The heading is given in degrees magnetic from the IP to the target. Terminal controllers give an offset (offset left/right) if a restriction exists. The offset is the side of the IP-to-target line on which aircrews can maneuver for the attack.

Distance The distance is given from the IP to the target. For fixed-wing aircraft, the distance is given in nautical mile (nmi) and should be accurate to a tenth of an nmi.

Target Elevation The target elevation is given in feet above MSL.

Target Description The target description should be specific enough for the aircrew to recognize the target. The target should be described accurately and concisely.

Target Location The terminal controller can give the target location in several ways (e.g., grid coordinates, latitude and longitude, navigational aid fix, or visual description from a conspicuous reference point). Because of the multiple coordinate systems available for use, the datum that will be used must always be specified in the JTAR. If using grid coordinates, terminal controllers must include the 100,000-m grid identification. For an area target, give the location of the target's center or location of the greatest concentration. For a linear target, give the location of the ends of the target.

Mark Type Mark type is the type of mark the terminal controller will use (smoke or laser) and the laser code (code) the terminal controller will use.

Friendlies The distance of friendlies from the target is given in meters and is a cardinal heading from the target (north, south, east, or west). If the friendly position is marked, identify the type of mark.

Egress These are the instructions the aircrews use to exit the target area. Egress instructions can be given as a cardinal direction or by using control points. The word "egress" is used before delivering the egress instructions.

Egress Control Point (ECP) An ECP is a well-defined geographical control point outside the enemy air defense area. The ECP identifies a CAS aircrew's egress from the target. Contact with terminal controllers normally ends at the ECP. The DASC is the overall coordinator for the ECP. A FAC or FAC(A) can control the ECP. An aircrew can use an ECP as a secondary CP to start a second attack.

Remarks The following information should be included if applicable: laser-to-target line (in degrees magnetic), type ordnance delivery, threat and location, final attack heading (final attack cone headings), hazards to aviation, weather, and restrictions. Additional target information SEAD and location Laser, illumination, and night vision capability Danger close.

Attack Headings Terminal controllers provide aircrews with an attack heading. The attack heading must allow acquisition of the reflected laser energy and should be outside the laser designator safety zone. The safety zone is defined as a cone (generally 20 degrees wide) whose apex is at the target and extends equidistant on either side of the target-to- laser designator line. This cone has a vertical limit of 20 degrees. Aircraft may engage targets from above the cone, as long as they remain above the 20-degree limit.

The minimum safe altitude for aircraft will vary with the aircraft's distance from the target.

TOT/TTT The terminal controller gives aircrew a TOT or TTT. TOT is the synchronized clock time when ordnance is expected to hit the target. TOT is the timing standard for CAS missions. There is no time "Hack" statement when using TOT. TTT is the time in minutes and seconds, after the time "Hack" statement is delivered, when ordnance is expected to hit the target. The time "Hack" statement indicates the moment when all participants start the timing countdown. TTT was not implemented when the VMF 9-Line was developed.

Time Separation Time separation requires the most detailed coordination, and it may be required when aircraft must fly near indirect fire trajectories or ordnance effects. The timing of surface fires must be coordinated with aircraft routing. This ensures that even though aircraft and surface fires may occupy the same space, they do not do so at the same time. All timing for surface fires will be based on the specific aircraft event time, time-on-target (TOT). This technique is appropriate when aircraft and firing units engage the same or nearby targets. The weapon's fragmentation envelope and the likelihood of secondary explosions need to be considered when deconflicting aircraft and surface fires. Figure B-5, (MCWP 3-23.1, page 3-39) illustrates altitude separation while figure B-6 (page 3-42) illustrates time separation for typical CAS scenarios.

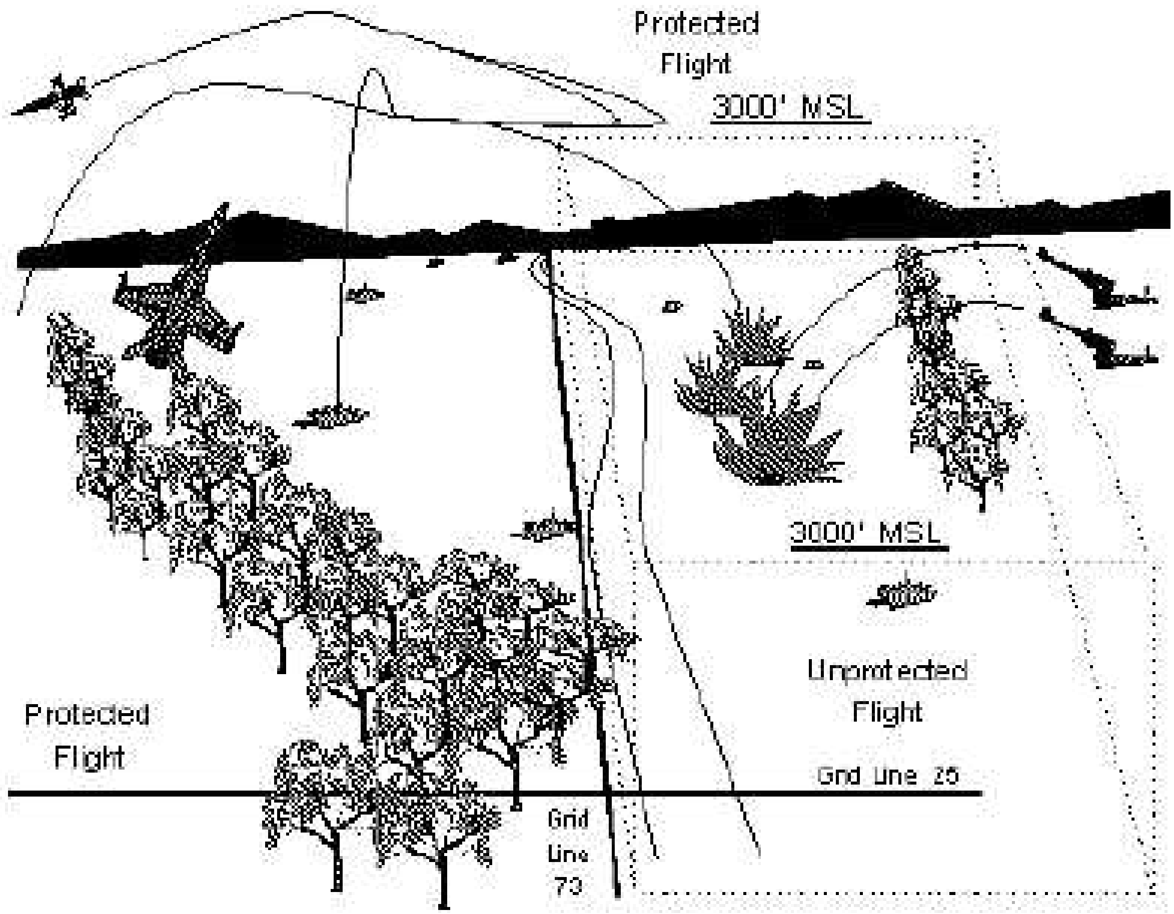


Figure B-5
Artillery-Close Air Support Aircraft Altitude Separation
(MCWP3-23.1)

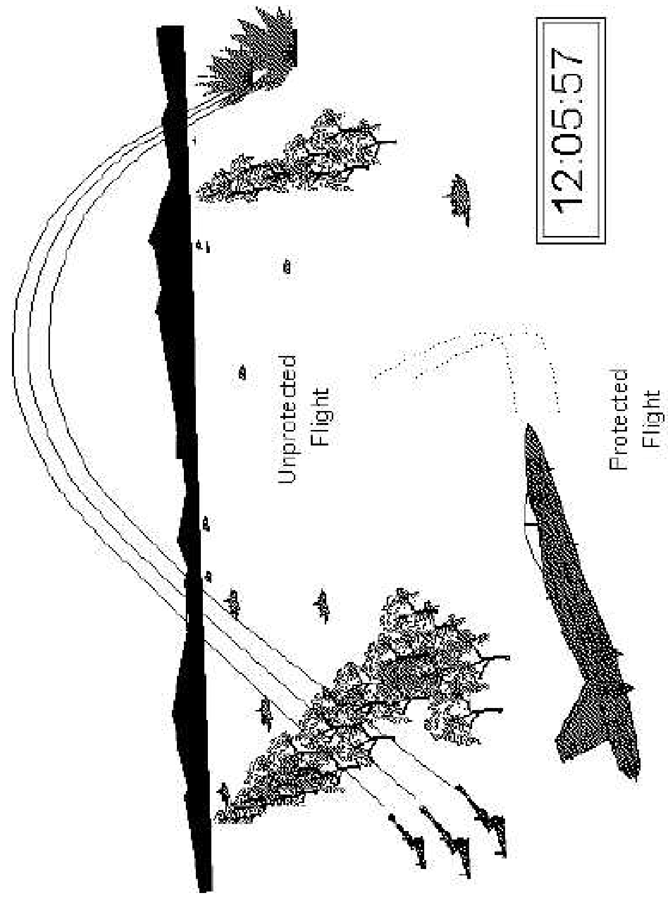


Figure B-6
Artillery-Close Air Support Aircraft Time Separation
(MCWP3-23.1)

Free Text Messages The FAC, with a ruggedized handheld computer (RHC), can use his keyboard to send a free-text message of up to 200 characters in length. These messages can be in any radio mode (i.e. UHF, VHF, HQ I…). The VMF format is illustrated below in figure B-7. This capability only exists between aircraft using Pre-Planned (PP1-10) messages. The aircraft can store up to ten of these messages. As shown on the status line in this example, HWK 22 was the originator and successfully completed sending the message to 4 out of 4 recipients.

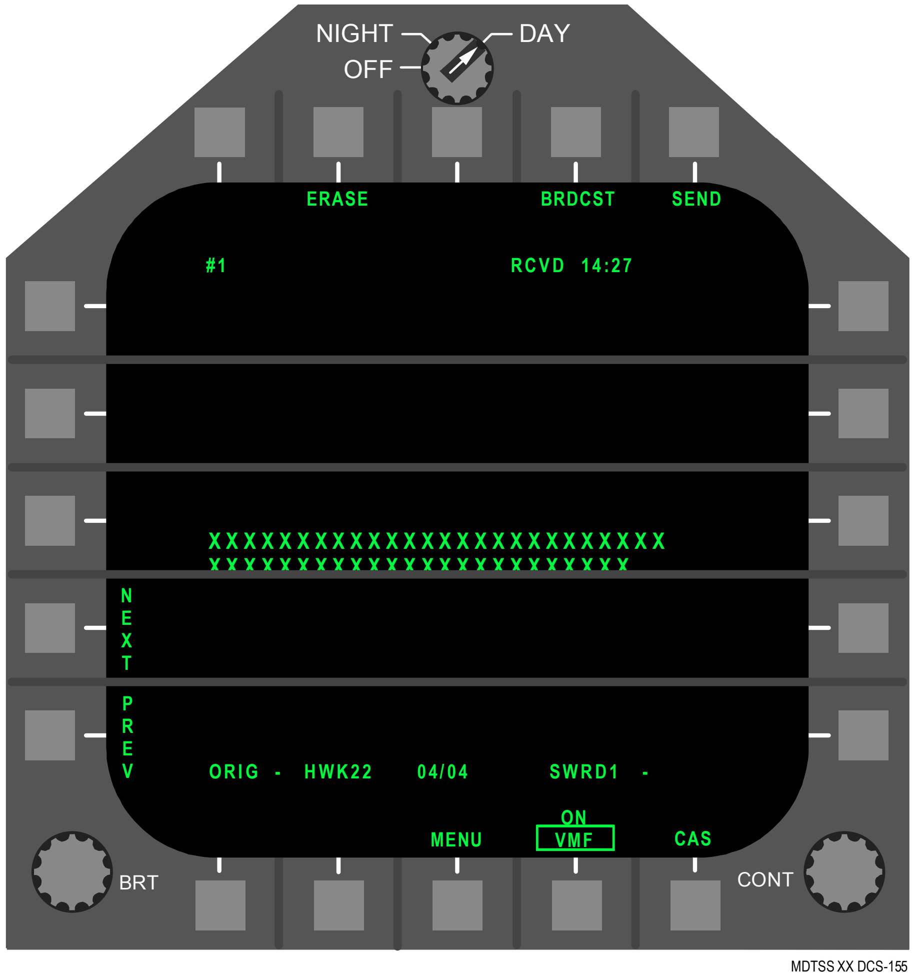


Figure B-7
VMF FREE TEXT MESSAGE FORMAT
(Boeing Presentation Slide)

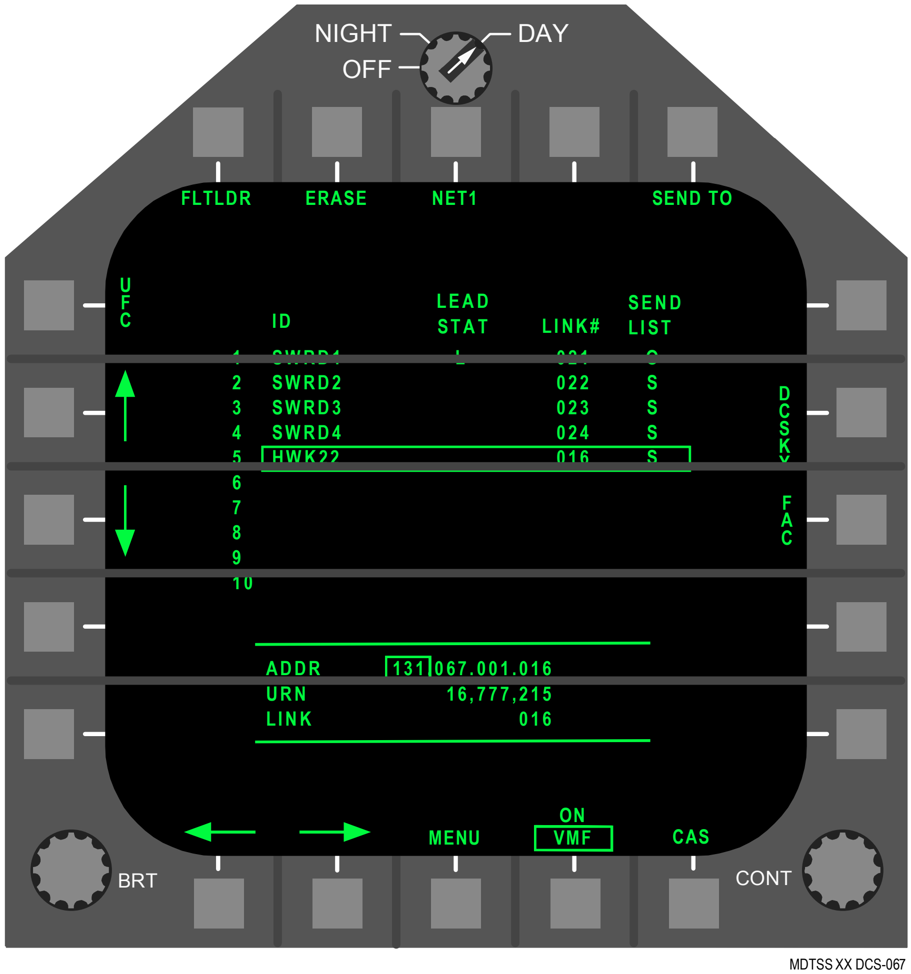


Figure B-8
DCS VMF NETS DISPLAY – SEND TO LIST (RECEIVER)
(Boeing Presentation Slide)

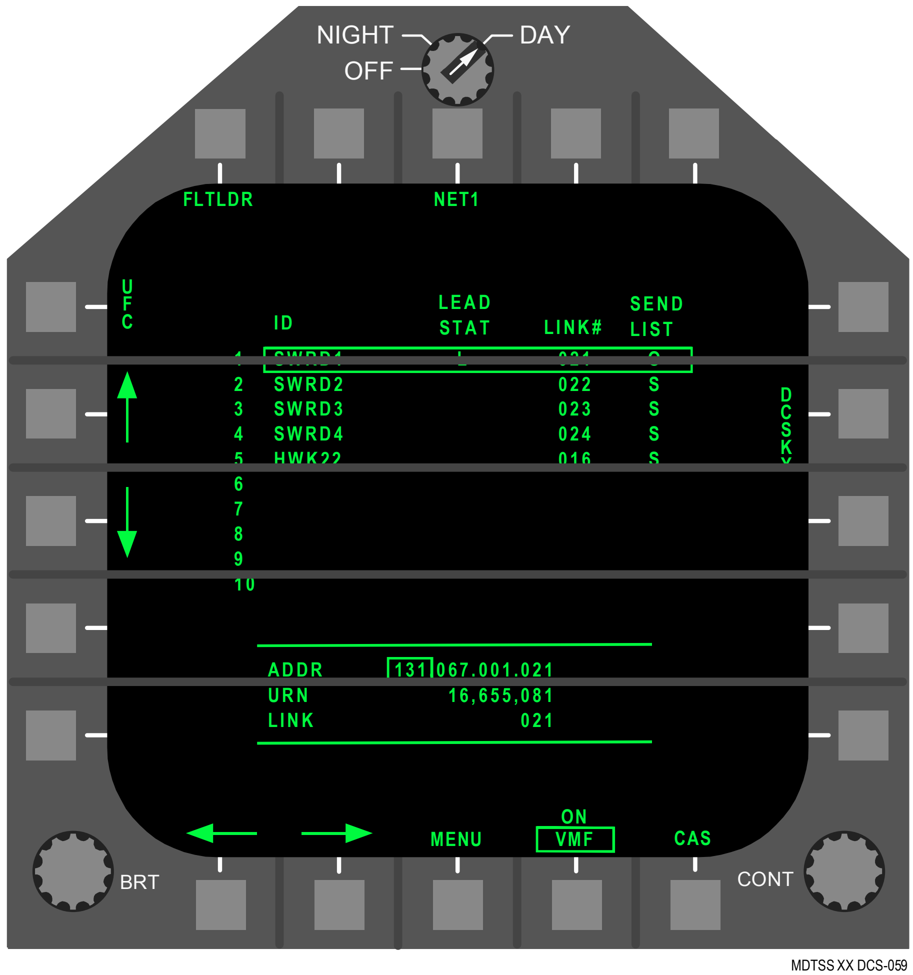


Figure B-9
DCS VMF SEND TO DISPLAY- OWNSHIP (FLIGHT LEAD)
(Boeing Presentation Slide)

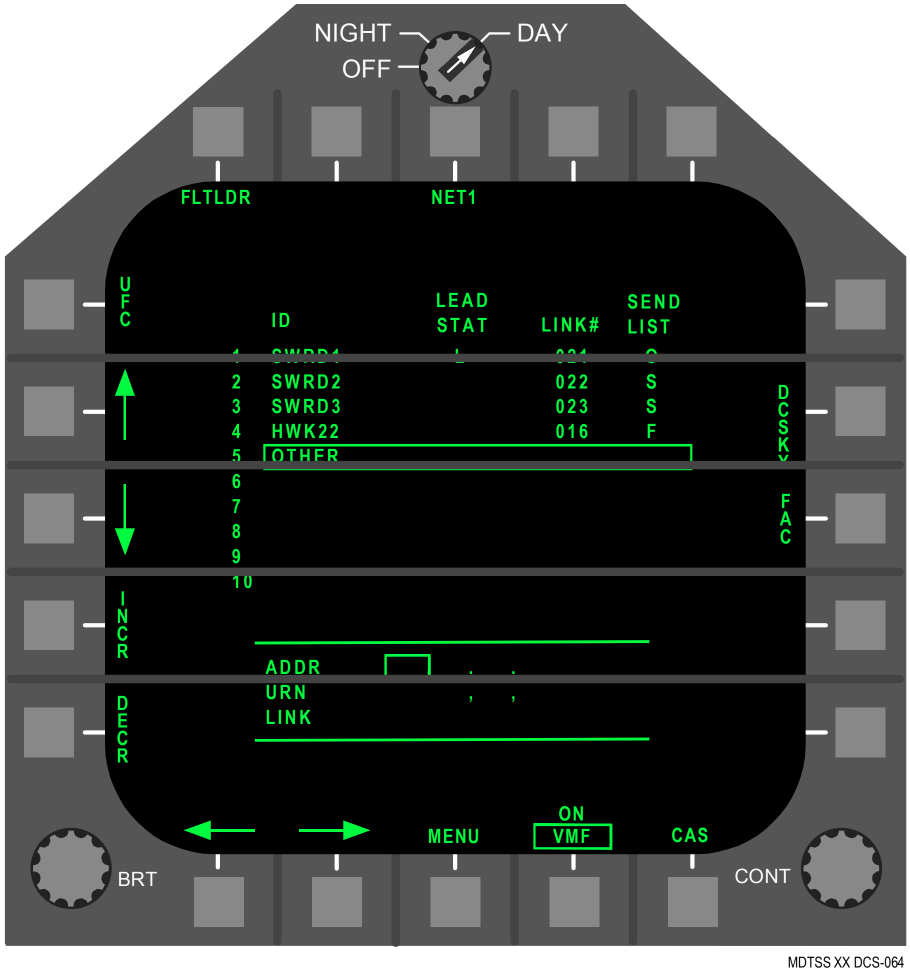


Figure B-10
DCS VMF NETS – UNKNOWN VCS CHECKS INTO LINK (OTHER)
(Boeing Presentation Slide)

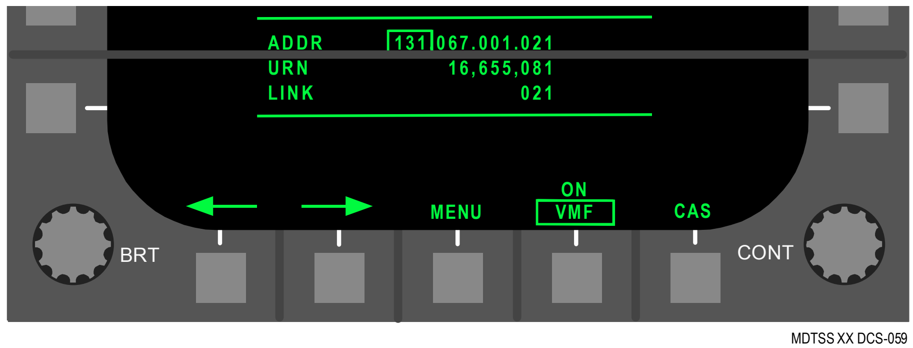


Figure B-11
DCS VMF NETS – MANUALLY TYPE IN ADDR INFO OR WILL BE AUTOMATICALLY FILLED IN AS IN THIS CASE
(Boeing Presentation Slide)

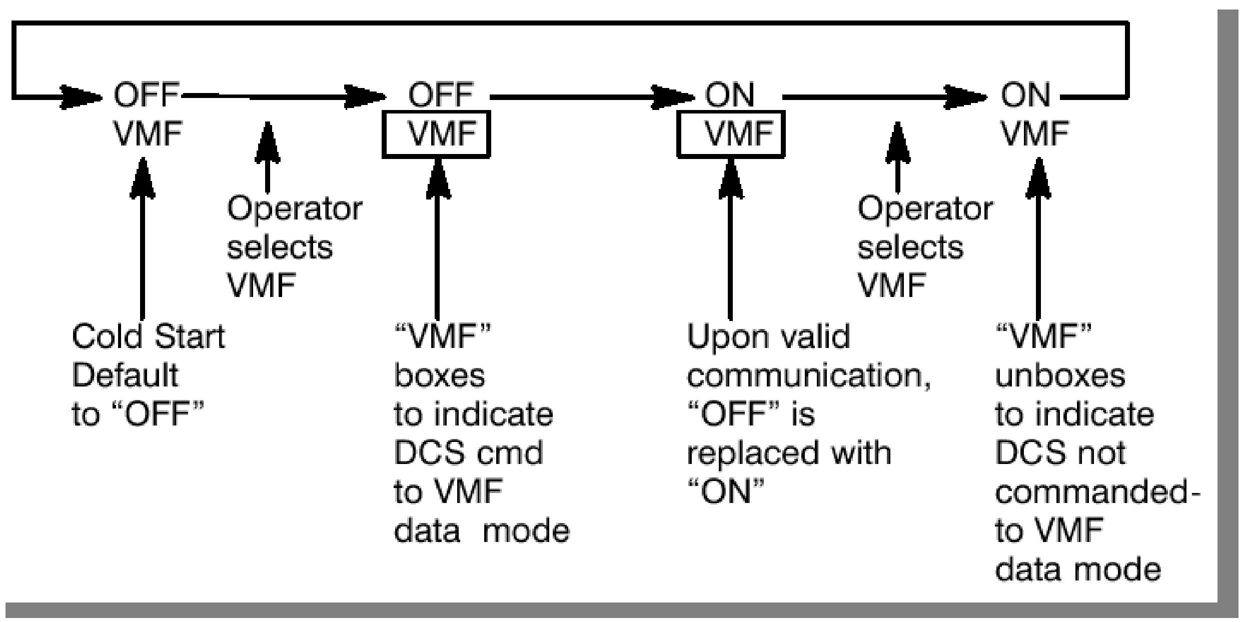


Figure B-12
BASIC VMF OPERATION – ON/OFF
(Boeing Presentation Slide)

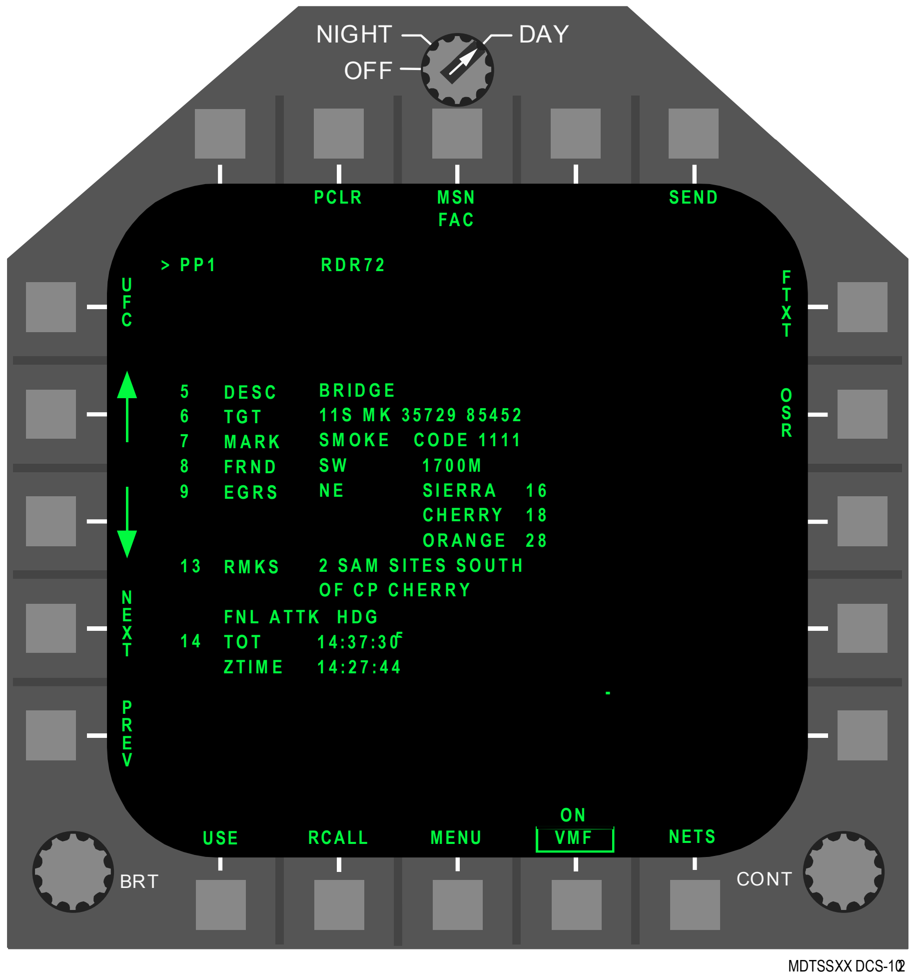


Figure B-13
SIMPLIFIED CAS 9-LINE DISPLAY
(Basic display by Boeing and modified by author)

DIGITAL CAS MISSION TIMELINE/ACTIONS

FOR PLANNED OR IMMEDIATE MISSION - ASSUMES FAC'S VMF ADDRESS IS KNOWN BY AIRCREW

1. FAC generates JTAR (Joint Tactical Air Request)
   - Occurs during "planning" phase
   - FAC sends to DASC (via HF radio voice net)
   - DASC sends to "command"
     - For USMC, TACC (Tactical Air Command Center)
   - Used by "command" as an input to the "Air Tasking Order" (ATO) generation process
   - JTAR gets a unique "Request Number" assigned by DASC or TACC
2. Air Tasking Order (ATO) Generation
   - Based on
     - Available aircraft
     - Mission needs (known partially due to JTAR)
   - Contents
     - Mission #, Request #, General Target Area, Control (holding or reporting) point, Time On Station, Time On Target, Comm assignments, recommended ordinance load, type of aircraft, voice call signs, notes (tanking, etc)
   - Details on ATO items
     - Request #

        - Assigned at lowest possible level (DASC for immediate missions, TACC for pre-planned via ATO)
    - Comm assignments (note change in doctrine)
        - Radio frequency to contact DASC
        - Comm mode (plain, cipher, Have Quick etc.)
        - Comm 2 = Cycle through agencies
        - Comm 1 = inter-section/division
- Proposed additions for digital CAS via VMF
    - IP, URN and Data Link addresses specified
        - IP & URN selected from block assigned to a squadron
        - Data Link address assignment
            - Ones digit must be set to flight position ID ("dash")
            - Tens digit could be assigned by "Command" if they can insure all Flt Groups working with a given FAC will have different tens digits
    - Aircraft specific MU loads for VMF addresses = flight test approach
        - If common load, then each aircrew must manually enter their ownship VMF address
- CAS pre-planned mission (5) are available from TAMPS pre-planning; includes the following info
    - Request #, Mission #, Control Agency Info (Call Sign, Freq), Contact (control) Pt. Info (name, location), IP, BRG (IP-Tgt), RNG(IP-Tgt), ELEV, Tgt DESC, Tgt Location & MARK, Friendly Info (direction, distance,

location (lat/long)), EGRS Info (direction, three control pts), Remarks (200 character, 8 lines max), TOT, Final Attack Heading

- F/A-18 CAS message TOT limitation (hours, minutes entry only)
    - Only whole minutes can be transmitted (VMF standard limitation)
    - On CAS format, position cursor to line 14, press INCR/DECR button to add/subtract 30 seconds to/from pre-planned TOT
    - On CAS format, position cursor to line 14, press UFC option, then enter any desired TOT (down to seconds)
    - MC automatically keeps track of TOT & updates the command speed/time accordingly
    - If seconds entered in CAS message & sent (i.e. SEND pressed), then:
        - Seconds portion of TOT is set to: **,
        - TOT flashes for 10 seconds (aircrew can re-enter seconds for his own timing considerations if desired)
        - After 10 seconds, :** replaced with :00

- Mission Number **must** be entered in TAMPS "DCS NETWORK PARTICIPANT NODES menu
    - Transmitted in OSR message to FAC
    - FAC ground terminal (TLDHS) uses to correlate flight group with JTAR and CAS brief
- F/A-18 CAS message IP Offset workaround
    - Offset value not transmitted in CAS message (VMF standard limitation)
    - Can only be transmitted in VMF CAS message remarks or by voice

    - Display can be updated for display purposes on the CAS format, position cursor to line 2, press INCR/DECR button to cycle through "R", "L", and "blank"
  - All this information will be loaded via the AMU (F/A-18 E/F) or MU (F/A-18 C/D)
    - Exception = Time On Station (must be manually entered by aircrew)
3. Flight Group (Flt Group) loads TAMPS load
  - MU/AMU loading
    - Read automatically on aircraft power-up if installed
    - Manual load
      - From SUPT menu, select "MUMI" (PB #10)
      - Select "MORE" (PB #10)
      - Select "DCS CAS" (PB #14) & "DCS NETS" (PB #15)
4. Flight Group (Flt Group) leaves base
  - Typically a section (Flt Leader + one wing)
  - Maximum would be a division (Flt Leader + 3 wingmen)
    - Flt Leader = position 1 = link address x1
    - Wing #1 = position 2 = link address x2
    - Wing #2 = position 3 = link address x3
    - Wing #3 = position 4 = link address x4 (x's all the same within a flight group)
  - Suggest lead send free text to wings to verify addresses setup correctly
5. Flt Group reaches DASC control (holding) point
  - Each aircraft enters Time On Station (TOS) from UFC

        - TAC Menu – CAS (PB #16) – OSR (PB #12) – UFC (PB #5)
        - TOS valid range is 1-126 minutes
        - Once entered (or received), mission computer decrements TOS
    - Each aircraft configures its VMF network
        - Turns VMF ON for Comm 2 (TAC Menu – CAS (PB #16) – ON VMF (PB #17))

6. Flt Group Check in With DASC
    - Flt Leader contacts DASC on Comm 2 voice
7. VMF Exchange With DASC
        - None at this time (since no DASC VMF capability currently exists)
8. DASC VMF Processing
        - None at this time (since no DASC VMF capability currently exists)
9. DASC Provides Handoff Information on Comm 2 voice
    - FAC's control point
        - Flt group enters as waypoint
    - UHF frequency to contact FAC
    - FAC's VMF address (new step for digital CAS mission)
        - Aircrew verifies (Planned mission) or enters (immediate mission)
            - On NETS format, unused row, enter provided (IP) ADDR, URN, & (Data) LINK #s, then XFER (PB #9), then press FAC (PB #13)
    - Situation brief (optional)
10. Flt Group **must** configure the FAC's VMF node before departing DASC holding/control point

- NETS format actions
    - Select (box) the FAC's node (using the up/down arrows)
    - Designate the node as the FAC by pressing the FAC pushbutton (PB #13)
    - SEND LIST changes from blank to "F"
        - SAR 24831 (TAMPS/MC change to allow FAC designation to be pre-planned in TAMPS)

11. Flt Group Check in With FAC on Comm 2 Voice
    - Initial contact
        - Flt Leader listens for "open" channel, then contacts FAC
        - Gives aircraft call sign, location (lat/long & altitude) and/or control point name by voice
            - This information is not optional, must be done (See SAR 29171)
        - Flt Leader gets "standby" or OK to start digital CAS process on Comm 2 frequency

12. OSR Exchange With FAC
    - Flt Leader sends OSR to FAC with Op Ack requested
        - From CAS format, Flt Leader selects OSR format (PB #12), then presses SEND (PB #10)
            - SEND option only present if someone on NETS list designated "F"
        - SEND option "boxed", & remains boxed while these events occur (in order):
            - Network access slot is reached
            - VMF message is physically transmitted

        - Link layer acknowledgement(s) are received **or** message retries are exhausted
    - A "SEND" operation can be aborted by pressing the "SEND" option while it is boxed
        - If VMF message is being physically transmitted, it will be completed
        - If radio is waiting for network slot or link Acks, the process will be aborted
- FAC actions
    - Receives and designates this VMF address as the Flt Leader
    - Correlates previous JTAR/CAS to mission number in Flt Group's OSR
    - Automatically transmits Op Ack to Flt Leader
    - The FAC's VMF terminal can automatically receive VMF messages & reply without prior knowledge of the flight group's VMF addresses
- Flt Leader
    - Receives Op Ack automatically, no aircrew action required
    - Automatically sends his OSR to his wingmen (to all nodes with a "S" in the "SEND LIST" column)
    - RECV OSR flashes on HUD for 10 seconds following reception of wing's OSR
    - OSR display
        - Access from CAS format via OSR (PB # 12)
        - Ownship node displayed in position #1 (upper left)
        - Format changes following wing's reception

        - First received OSR place in position two (upper right)
        - Received OSR format
            - 1^{st} line = Node ID as displayed in the NETS format ID column
                - Voice Call Sign (if URN in VMF message matches URN-VCS correlation made in TAMPS DCS Network Voice Call Sign menu)
                - Mission Number (if no VCS-URN match, but match for URN-Mission Number as made in TAMPS DCS Network Participant Nodes menu)
                - “OTHER” or “WING” (if previous two items not true & URN matches existing entry on NETS format)
                - Blank (if no URN match to existing entry on NETS format
            - 2^{nd} line = Aircraft type
            - 3^{rd} line = Time-On-Station
            - 4^{th} – 8^{th} line = OSR Armament Report
            - 9^{th} line = DPIP display (time DPIP message received); see below
            - Mission # is not displayed (SAR 29172)
    - If FAC misses initial OSR message (plus retries) from the Flt Leader & the Flt Leader retries, MC only sends OSR to wingmen (see SAR 27353)
- Wingmen
    - Automatically receive Flt Leader’s OSR
        - RECV OSR flashes on HUD for 10 seconds
    - Automatically send their OSR report to:

    - Flt Leader
    - FAC (since they all have the FAC designated as “F”)
    - Other wingmen (to all nodes with a “S” in the “SEND LIST” column)
  - RECV OSR flashes on HUD for 10 seconds
- All aircraft & FAC now have all aircraft’s OSR reports
- Time to complete OSR process (from when FAC Op Acks) with link Acks on
  - Section: min = 6 secs (plain, fixed freq), max = 19 secs (cipher Have Quick)
  - Division: min = 18 secs (plain, fixed freq), max = 50 secs (cipher Have Quick)

13. FAC Processing

- When wingmen OSR messages are received, designate & store accordingly
  - Mission Number used to distinguish flight groups by FAC
- FAC now has the following information
  - Mission Number (if entered via TAMPS DCS Network Participant Node Menu)
  - Aircraft type (part of OSR message)
  - Time On Station (part of OSR message)
  - Inventory of weapons available on aircraft
    - Excludes wingtip stations
    - Air-ground missiles
    - Hung weapons
  - Number of aircraft
  - Abort code workarounds

- Option #1 = FAC could send abort codes in a Free Text message to the flight group with an operator reply requested
  - Flt Leader issues WILCO/CNTCO to confirm/reject abort codes
- Option #2 = Flt Group pre-plans its abort codes (and optionally, aircraft call sign) in a Free Text Message via TAMPS
  - Flt Leader sends Free Text message to FAC
  - FAC refers to authenticator table and notes reply

14. FAC Provides CAS message (9-line brief) to Flt Group
    - Receive indications for Flt Group
      - "CAS" appears under RECV (PB #6) on CAS FTXT or OSR formats
      - On HUD, "CAS" flashes
    - Message received by Flt Group 2-4 seconds (comm. mode dependant) after FAC sends
    - If RECV "CAS-F" is displayed:
      - Indicates that 10 received/modified pre-planned CAS messages are already stored
      - New message will overwrite the tenth stored CAS message (as viewed on the RCALL CAS format)
    - If RECV "CAS-O" is displayed:
      - CAS brief is from an "outsider" (i.e. a VMF platform (node) currently not on the NETS list and the node list is full (i.e. 10 nodes)
      - New node will overwrite current node 10
    - If RECV "CAS-FO" is displayed

- Two situations above occur simultaneously
- Aircrew presses RECV CAS button
  - CAS format automatically displayed, with 9-line brief
  - No other events occur (unless an Op Ack is requested, but F/A-18 17C no longer requests)
- Time to complete CAS process (from when FAC sends to when receive status line update complete) using F/A-18 17C (link Ack) processes
  - Section: min = 4 secs (plain fixed freq), max = 9 secs (cipher Have Quick)
  - Division: min = 6 secs (plain fixed freq), max = 13 secs (cipher Have Quick)

15. Flt Group Acks CAS message
- Method dependent on ack mode requested by FAC (if any)
  - Link Layer Ack with retries
    - Best speed & reliability (F/A-18 17C operation)
    - Current FAC VMF terminal doesn't inform FAC of pass/fail results
  - No Acks
    - Absolute speed & minimum channel usage, but no recovery for missed messages

16. Flt Leader Replies to CAS Message
- Only the Flt Leader has option to reply to a CAS message (VMF Op Reply Request)
- Options appear on CAS format
  - WLCO = if pressed, VMF message transmitted back to FAC which indicated the Flt Leader accepts the CAS message/mission

- CNTCO = if presses, VMF message transmitted back to FAC which indicates the Flt Leader rejects the CAS message/mission (equivalent to "UNABLE" voice brevity call)
  - If rejected, Flt Leader can modify the displayed CAS message
    - Causes SAVE option (PB #9) to appear on CAS format
    - USE option removed until SAVE pressed for a modified message
  - Flt Leader presses SEND button on CAS format to send CAS message back to FAC (plus all designated as "S" or "F" in the SEND LIST on the NETS format)
- Edits to CAS message not allowed until WLCO or CNTCO is pressed
  - Cursor on CAS format title line, no up/down arrow options displayed
- WLCO/CNTCO addressed to all on the SEND LIST ("S" or "F")
  - Link ack always requested
  - WLCO/CNTCO remains boxed until link acks received or retries exhausted
  - Lead's CAS format receive/transmit status line shows link ack results (x/x) for lead's reply, & the reply given (WLCO/CNTCO)
  - Wing's CAS format receive status line shows lead's reply
- This "negotiation" continues until Flt Leader WILCOs the CAS mission

17. Flt Leader/Group "Uses" CAS mission
    - Press USE button on CAS format
      - USE remains boxed until presses again

- If another CAS message received (& thereby displayed) while a previous message is in USE
    - Number above CAS format USE option indicates which CAS message is in USE
    - New CAS message cannot be used until the current mission in use is displayed & USE pressed (i.e. unbox USE)
- Causes CAS navigation data to be used by the Mission Computer (MC)
- HSI Impacts
  - SEQ L appears at pushbutton #15 on HSI & is boxed
  - WYPT boxed (waypoint steering)
  - CAS Initial Point (IP) = Route Flt Group is to take when it leaves the FAC's control area and flies toward target
    - CP is loaded into waypoint 45
    - IP is loaded into waypoint 46
    - Waypoint symbol is a square (instead of standard circle)
    - Straight line flight from IP to target
    - CP & corresponding waypoint number enhancement - display on CAS format (see SAR 29170) – provides better SA, flexibility for FAC (direct flight group to new CP), and allows flight leader to WLCO/CNTCO if CP in CAS message different from current CP
  - CAS Target Point
    - Loaded into waypoint 47
    - Waypoint symbol is a triangle initially

- Waypoint symbol changes to a diamond when the target is designated using the NAVDSG (NAV disengage) HSI option
- Friendly Arc displayed on HSI
  - Location determined by the location of friendlies with respect to the target given in the 9-line brief
    - Cardinal direction and distance (in meters) from target location
- HUD impacts
  - Command heading cue displayed (tick mark below aircraft heading line)
    - Indicates heading required to waypoint
  - Command speed cue (caret by airspeed)
    - If Time-On-Target data in 9-line & not elapsed, speed cue displayed (up or down depending on calculated requirement)
  - Friendly Rake Cue (line with five "tines")
    - Requires valid target, direction & distance to friendlies in 9-line, else not displayed
- CAS Remarks Section
  - Display holds 8 lines, 200 characters max; some information that may be included:
    - IP Offset (L or R, if needed)
    - Threat locations
    - Weather
    - Type & amount of ordinance to expend
    - Final attack heading <u>range,</u> i.e. +/- 10° (range is not part of VMF message)

        - Additional target information
        - Amplifying remarks from friendlies

18. Depart IP
    - Aircraft notifies FAC by pressing DPIP option on CAS format
        - DPIP must be sent manually (via DPIP button (PB #13) on CAS format)
        - DPIP sent to FAC (designated "F") & all designated as "S" in the SEND LIST column on the NETS format
        - DPIP remains boxed until link acks received or retries exhausted
        - No feedback of DPIP success
    - OSR format impact
        - "DPIP hh:mm:ss" displayed under the OSR Armament Report for ownship & other aircraft in flight group
            - Ownship DPIP time is not cleared when subsequent OSR sequence is started; remains until new DPIP is received (see SAR 27352)

19. "Continue" Call
    - FAC can send VMF free text message or use voice

20. Attack target
    - Aircraft files down on final attack heading provided on line 13 of CAS format
    - FAC gives final voice call on Comm 2
        - "Cleared Hot" or "Abort" + optional abort code

21. Aircraft returns to FAC control point via egress points
    - CAS Egress Points = Route to leave target
        - Loaded into waypoints 48-50 (one, two, three or none can be loaded)

- Note provisions for three egress points
    - Allows flexibility to be new/alternate FAC CPs, if a new run is to be performed
- Use standard waypoint symbol (circle)

22. Flt Group loiters at FAC control point for another mission or returns to DASC holding point or base
23. Next Voice Considerations In VMF

Comm 2 voice push-to-talk (PTT) and receive limitations in VMF mode (DCS software version F05)

- Voice PTT interrupts VMF activity (transmit or receive)
    - Delay time till voice PTT active comparable to non-VMF operation
    - VMF send options (SEND, DPIP, WLCO/CNTCO) removed during a voice PTT
- Voice reception is jammed by a VMF reception if the VMF reception RF signal level is slightly below, the same or above voice RF signal level
    - Jam time = duration of VMF digital message + 160 msec
    - VMF digital message times message type & comm mode dependent
        - Plain fixed frequency (best case): shortest message is about 300 msec (OSR); longest message (CAS) is about 600 msec
        - Cipher Have Quick (worst case): shortest message is about 600 msec (OSR); longest message (CAS) is about 1300 msec
- To prevent interruptions & subsequent delays to VMF processes, a voice PTT should be avoided during the following:

- When the SEND, WLCO/CNTCO, or DPIP option is boxed
- When SEND or DPIP options are blanked
- This does not mean that you cannot exercise a voice PTT at these times; however, optional voice PTTs should be avoided for optimal network operation

VITA

Gregory D. Bigalk was born in Iowa City, Iowa on May 10, 1965. He grew up in Loveland, Colorado and graduated from Thompson Valley High School in May of 1983. Upon graduating from the University of Wyoming with a Bachelor of Science degree in Electrical Engineering, he was hired by The Boeing Company, in April 1988. He worked as an Electrical Engineer in the Flight Line and Flight Test Liaison Engineering Offices for three and a half years. He was selected for Officer Candidate Course and reported to Marine Corps Base Quantico, Virginia in October 1991. Upon graduation from Officer Candidate School, he was commissioned a Second Lieutenant in the United States Marine Corps and completed The Basic School in July 1992. He reported to Pensacola, Florida to begin flight training as a Student Naval Aviator. After receiving his Naval Aviator wings in December 1994, he was selected to be a pilot in the F/A-18 Hornet. After completing initial F/A-18 training at Marine Corps Air Station El Toro, California, he served an operational tour in VMFA-212 "Lancers". During this tour, he completed a three-year tour in Iwakuni, Japan. In July of 1999, he reported to the U.S. Naval Test Pilot School at Patuxent River Naval Air Station, Maryland, and graduated with class 117 in June 2000. Upon graduation, he reported to Naval Strike Aircraft Test Squadron, NAS Patuxent River, Maryland. He served one tour as the F/A-18 Lead Test Pilot for all Communication, Navigation and Identification programs. He is now currently serving as a Fixed Wing and Systems Instructor at the U.S. Naval Test Pilot School, NAS Patuxent River, Maryland.