3-2003

Multimission Aircraft Design Study: Electromagnetic Compatibility

Jenna M. Davis

Recommended Citation

Davis, Jenna M., "Multimission Aircraft Design Study: Electromagnetic Compatibility" (2003). *Theses and Dissertations*. 4157.
https://scholar.afit.edu/etd/4157

MULTIMISSION AIRCRAFT DESIGN STUDY:
ELECTROMAGNETIC COMPATIBILTIY

THESIS

Jenna M. Davis, Captain, USAF

AFIT/GAI/ENY/03-01

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GAI/ENY/03-01

MULTIMISSION AIRCRAFT DESIGN STUDY: ELECTROMAGNETIC COMPATIBILITY

THESIS

Presented to the Faculty

Department of Aeronautics and Astronautics

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Engineering

Jenna M. Davis, BS

Captain, USAF

March 2003

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

AFIT/GAI/ENY/03-01

MULTIMISSION AIRCRAFT DESIGN STUDY: ELECTROMAGNETIC COMPATIBILITY

Jenna M. Davis, BS
Captain, USAF

Approved:

____________________////Signed////__________	10 March 2003
Curtis H. Spenny, PhD (Advisor)	date
____________________////Signed////__________	10 March 2003
David R. Jacques, Lt Col, USAF (Reader)	date
____________________////Signed////__________	10 March 2003
Mikel M. Miller, Lt Col, USAF (Reader)	date

Acknowledgements

I would like to express my sincere appreciation to:

My Fiancé: Thanks for your perspective, vision, support, and love.

My girls: For unconditional love and affection and only demand in return is a scratch on the belly.

The twelve SENG 520 students: Capt. M. Bayer, USAF; Capt. J. Cho, ROKA; Capt. B. Miller, USAF; Capt. A. Walan, USAF; Capt. A. White, USAF; Lt. G. Ari, TAF; Lt. N. Coskuner, TAF; Lt. O. Gozaydin, TAF; Lt. A. Kahraman, TAF; Lt. T. Welker, USAF; L. Diaz-Rodriquez. Without your valuable input and part of the initial development, this would not have been a systems document.

Table of Contents

List of Figures

Page

List of Tables

AFIT/GAI/ENS/03-01

Abstract

The multi-mission aircraft (MMA) technical feasibility study looked at the replacement of the aging fleet of C-135 and C-130 theater based command & control (C2) and intelligence, surveillance and reconnaissance (ISR) fleet. It is proposed that the MMA be out-fitted to combine some or all the functions of existing AWACS, JSTARS, RIVET JOINT, COMPASS CALL, and ABCCC platforms. It would also have links to other manned or unmanned ISR aircraft, as well as satellites.

The objective of the proposed design study is to examine the technical risks involved in combining multiple functions onto one aircraft that currently reside on separate aircraft. This thesis specifically focused on the risks that are due to electromagnetic interference between transmitters and interference between active and passive sensors.

Two architectures were examined: one tail number (OTN) and different tail number (DTN). The OTN architecture was found to be incompatible due to interference between the air moving target indicator transmit and high band receive functions, whereas, the DTN was found to be compatible for all variant architectures.

MULTIMISSION AIRCRAFT DESIGN STUDY: ELECTROMAGNETIC COMPATIBILTY

I. Introduction

Background

Tasking

Major General Glen D. Shaffer, Director for Intelligence, Surveillance and Reconnaissance (ISR), DCS, Air and Space Operations, United States Air Force (USAF) has requested a technical feasibility study for a multi-mission aircraft (MMA). According to Major General Shaffer, the MMA concept has been proposed as a replacement for the aging fleet of C-135 and C-130 theater-based command and control (C2) and intelligence, surveillance and reconnaissance (ISR) fleet. It is proposed that the MMA be out-fitted to combine some or all the functions of the existing AWACS, JSTARS, RIVET JOINT, COMPASS CALL, and ABCCC platforms. It would also have links to other manned or unmanned ISR aircraft, as well as satellites.

Objective

In performing a MMA feasibility study, the primary goals are to replace the current aging fleet with a single platform. Reduced life cycle costs, increased system value through measure of mission utility and mission integration and compatibility, and minimal risk are the primary objectives considered. The overall need is to ensure that every mission currently being served by this fleet will not only continue but also enhance a theater's ability to perform time critical targeting (TCT).

To consolidate the platforms, we must first understand current mission requirements. The AWACS is in charge of air moving target indication (AMTI), weapons C2, air battle management (ABM) and identification of friend or foe (IFF). The

JSTARS provides long-range ground moving target indicator (GMTI) surveillance, synthetic aperture radar (SAR) surveillance and wide area search (WAS), ground C2, and ground battle management (GBM). RIVET JOINT provides ISR information and electronic warfare support to theater commanders (electronic battlefield management). COMPASS CALL provides primarily air C2 and communications countermeasures (C3CM) but can provide jamming support to ground forces. The ABCCC is the overall tactical command and control.

Preliminary Analysis

Preliminary Group Design

The investigation of the multimission aircraft began with a preliminary group of twelve students comprised of logistics and maintenance operations, air and space operators, and acquisition, science and engineering backgrounds. The preliminary group brainstormed and researched the current platforms to develop two baseline hierarchies and value system designs (VSD) using Hall's Seven Steps.[1] In addition, a concept map (Appendix 1.2) was constructed to show relationships between key players, systems and operational considerations.

Based on an interactions matrix similar to the matrix in Appendix 1.3, an interface and flow model (Appendix 1.4) were created using techniques defined by Hatley, Hruschka and Pirbhai (HHP)[2]. The HHP techniques help to stimulate system specifications to iteratively generate a set of system requirements and architecture models. The interface model depicts key requirements and interactions within the MMA

---

[1] Hall's Seven Steps will be discussed in detail in Chapter 3. Methodology.

[2] Hatley, Hruschka and Pirbhai (HHP) methodology will be discussed in Chapter 3: Methodology.

design. The flow model was then used to build and track the architectures and some of their variants. The process interface was the centerpiece or driving force behind the iterations. As each architecture was developed, the system requirements were enhanced and fed back into the interface. As the process continued, several architecture variations developed and are noted as sub-bullets in the systems architecture model.

MMA Thesis Team

The MMA thesis team consisted of a group of three students including Lieutenant (LT) Nevin Coskuner, Turkish Air Force (TUAF), LT Ahmet Kahraman, TUAF, and myself. The MMA thesis team reinvestigated, compiled and developed a new and complete baseline including a systems definition consisting of key players, stakeholders, needs, alterables and constraints. An interaction matrix was developed based on these system definitions to visually show cross-interactions.

The interaction matrix found in Appendix 1.3 was a key element to building the system synthesis architecture as it identified where special or in-depth research was needed to accomplish an understanding of the system design to the fullest extent. To logically assign levels of interaction, the designated strengths; high, medium, and low, were assigned numerical values. Each element value was totaled based on its interaction among the other elements. For each group (objective, alterable, constraint and need), the elements were arranged in order, based on this total, and natural group interaction levels were established. The cross-interactions have been summarized and categorized by level in Table 1. The analysis of the interaction-matrix determined the system variables that drove the design to the most or at the “highest level.” Other interaction levels were addressed as needed.

Table 1: Objectives, Needs, Alterables and Constraints Summary by Level of Cross-Interaction.

	HIGH INTERACTION	MEDIUM INTERACTION	LOW INTERACTION
OBJECTIVES	Max Mission Effectiveness Mission Integration & Compatibility	Minimize Risk	Minimize LCC
NEEDS	Air C2 Ground C2 ISR Collect. & Recog. Mission Dissemination & Transmission	ISR Processing & Exploration Air BM Ground BM C3 CM Joint Service Interoperability	Longterm Compatibility All-Weather Capability (24/7)
ALTERABLES	System Architecture	Mission Requirements	Future Politics/Players/… CONOPs
CONSTRAINTS	**Operations Environment** Tecnnology Availibilty Development Time **System Compatibility**	**Air Frame Limits** Funding Classification of System Logistics Supportability	Safety Gov't regulations & Policies

Areas of Investigation

The MMA thesis team determined three key areas[3] for further investigation from the cross-interactions of the system definition constraints. These areas consisted of: 1) payload limitations based on airframe limits, 2) the operations environment, and 3) system compatibility. The One Tail Number (OTN) and Different Tail Number (DTN) architectures will be examined under these emphasis areas. The DTN architecture will consist of four alternative architectures.

Aircraft Design as it Pertains to Payload Limitations

In order to give specific answers for a MMA design and its compatibility, we should be aware of what is going to be integrated into the MMA architecture. Basically, we can say that those should be the sensors for the joint missions, the crew, and all of the software and the hardware for the missions. By investigating aircraft payload integration, we will be able to make decisions based on key factors such as weight, volume, range, and some other related limits of the aircraft. To accomplish this, we need an

---

[3] Chapter 4. Process Tailoring and Results will include a more detailed discussion of how the levels of interactions were determined.

understanding of the sensors and antennas mass and volume characteristics. We will then be able to make decisions about the compatibility of the two architectures and their variants. LT Kahraman, TUAF, is accomplishing this research. (Kahraman)

Operations Environment Design Parameters

By assigning all of the C3CMISR missions capabilities under one aircraft, the requirements may prove to be too diverse and cover too large of a defined mission area for a single MMA aircraft. Thereby reducing the purported advantage of consolidating the capabilities. As the Area of Interest (AOI) and/or the number of multiple taskings grow, the mission effectiveness may decrease along with overall performance. It is for these reasons that the operations environment is believed to be a key decision area, as it will affect the concept of operations, logistics and C2 and ISR areas of coverage. This portion of the research will develop a hypothetical conflict area with a defined set of constraints by which the OTN and DTN architectures will be evaluated. Lt Coskuner, TUAF, is accomplishing this research. (Coskuner)

Payload Integration as it Pertains to Electromagnetics

By the Department of Defense, Joint Pub 1-02, the electromagnetic environment effects (E3) is defined as

> The impact of the electromagnetic environment upon the operational capability of military forces, equipment, systems, and platforms. It encompasses all electromagnetic disciplines, including electromagnetic compatibility/electromagnetic interference (EMC/I); electromagnetic vulnerability; electromagnetic pulse; electronic protection, electromagnetic radiation hazards to personnel, ordnance, and volatile materials; and natural phenomena effects of lightning p [precipitation]-static

As the specific mission aircraft are integrated, the discipline of EMC/I will be a key concern. This key element must be understood completely before development begins or else there will be a higher potential for unintentional interference throughout the system. The emissions, attenuation, power influences, shielding influences, antenna placement, radiation and characteristics of the C3 and ISR equipment were a few specific areas that were investigated.

Scope

The intent of this thesis is to develop and apply a first order model focused on the primary decision variables and parameters that allow an evaluation of the impacts of electromagnetics on MMA configuration. A preliminary EMC analysis developed by Don White Consultant will be used to determine potential antenna-to-antenna interference among the major systems.

EMC/I impacts on the MMA value system design will be discussed and a summary of the system design including the results from Lt Kahraman's thesis. The results of this work are intended to give additional insight into the ongoing Multimission Command and Control Architecture (MC2A) and to hopefully provide ideas or thoughts not considered before.

Assumptions/Limitations

All of the aforementioned systems are US classified systems and will only be referred to as the job that each system performs. Each aircraft platform was given a generic system performance description based on open literature information and notional data. These system parameters can be found in Appendix 3.3. The performance data will then be generated based on typical values for each type of sensor. An example is the sensor frequency where the mean of the community standard range for each asset will be used to generate a recommended architecture. It will be left to the end user to evaluate the decision model at the properly assigned spectrum frequency.

Based on potential interference severity levels defined by J.L. Wilson and W.B. Jolly[4], only antenna-antenna radiated coupling will be evaluated for the consideration of EMC.

For a complete EMC analysis, each transmitter-receiver pair would need to be analyzed. In this study, only the air moving target indicator (AMTI), ground moving target indicator (GMTI), low frequency (LF) receiver, high frequency (HF) receiver, and super high frequency (SHF) receiver will be analyzed. The communications links are assumed to work with all architecture combinations. In reality this assumption is more than likely not feasible but the inclusion of the communications architecture would be overwhelming with the consideration that each combination would need to be analyzed. This detailed analysis will therefore be left to a person specializing in EMC/I. With this said, ABCCC is strictly considered a communications node and will not be analyzed along with the mock systems of AWACS, JSTARS and Rivet Joint.

Terminology

Throughout the paper multimission aircraft (MMA) and multimission command and control architecture (MC2A) will refer to the architecture under investigation and will be used interchangeably. Command, control, communication, countermeasures, and intelligence, surveillance and reconnaissance (C3CMISR) will be referred to as the mission requirements to be performed by the MC2A.

---

[4] Levels of EMI severity involved with modifying various command, control, communications and intelligence systems (C3I) as described by Wilson and Jolly are shown in Table 4.

Preview

Chapter Two of this thesis describes the current systems engineering approaches, EMC background, and discusses ongoing multimission aircraft development activities in the United States Air Force (USAF). Chapter Three presents the methodology employed in the study. Chapter Four describes and analyzes the resulting model. Chapter Five provides conclusions and recommendations based on the model

II. Literature Review

Systems Engineering Process

The what, how, and methods of facilitation of systems engineering have evolved through time with the creation of processes, modeling techniques, and tool development, respectively. The process defines what is to be done by establishing a logical sequence of tasks. In the 1970's, the waterfall process was the primary construction element of systems processes. Designs like A. D. Hall's three-dimensional morphological box, Space Mission Analysis and Design (SMAD), and System Engineering Process by INCOSE are based on this pseudo-iterative, one directional flow approach. Each of these processes places emphasis on different areas of the development process. The Hall's morphological box process focuses on project planning, value system design and alternative design and analysis. While the SMAD process deals with concept exploration for detailed physical development requiring a considerable amount of upfront planning. Lastly, the INCOSE process primarily deals with the development, production test, deployment, training, support and disposition. The INCOSE process is slightly different from the previous two processes in that it looks at concurrently developing the design layers of the system and looks at the external and enterprise environmental factors.

In the 1980's, the community began to refine the process via multiple iterations referred to as the spiral development. The 1990's made way for two-way interactions. No longer was the thought of a project a direct flow from the beginning to the end product. Instead one could start the process from the bottom, middle or top and enhance the detail as appropriate. This was the beginning of the processes and methods based on structured analysis such as Hatley/Pirbhai methods.

The start of the 2000's brought even more enhancements to these processes with design of the architecture being developed alongside the requirements. The Process for System Architecture and Requirements Engineering (PSARE) also known as the Hatley, Hruschka and Pirbhai (HHP) methods and the integrated definition for function modeling (IDEFO) as described by Dennis Buede are two examples of this era. (Buede, Hately)

Several other processes have been developed during each of the time periods discussed above. The Hall's morphological box, SMAD, and PSARE will be discussed in detail, as they will be used in the methodology of this study.

Although these processes have evolved over time, each process is still viable and implemented and used today. No one process could adequately describe all possible situations or studies. The choice must be based on the end product or the type of study to be performed. The final process could even be a combination of a number of different methods based on the final goal of the study. The strengths of a few processes could be combined to create a tailored process.

There are basically two types of studies: feasibility studies and studies with a product implemented. A feasibility study focuses on needs, alterables and constraints to develop alternative architectures and recommendations for implementation based projects. A detailed value system design is established. However, an overall lack of emphasis on system requirements exists.

Contrary to the feasibility study, the studies with a product to be implemented focus on requirements development, cost analysis, performance and risk. A value system design is not needed for architecture evaluation because only one defined architecture exists. In this case, the value system becomes the constraint for the architecture.

In the end each study must use a systems engineering process which is logical, repeatable and defendable for designing and or selecting a system to answer the study in question (SENG 520 Notes).

Hall's Morphological Box

Hall's morphological box's vertices are comprised of the logic in which the process is to be carried out, the phases of time that occur throughout the development, and the knowledge base of which information is derived from specialized disciplines.

Both the phase and logic component are comprised of seven elements. The one directional flow begins with the first step of the phase structure and works right through the logic structure. Once all of the logic steps have been accomplished for the current phase, the phase advances and the logic steps are reaccomplished. Iterations should be continuously performed within each phase and the process should be advanced to the next phase once all logic steps have been thoroughly evaluated (Sage: 3-4; Hill: 610-611). Halls's activity matrix in Table 2 outlines the relationships between the logical steps and phases elements of the system's engineering process.

Table 2. Hall’s activity matrix. (Sage: 5; Hill: 611)

Steps of the Fine Structure LOGIC → Phases of the coarse structure TIME ↓	Problem Definition	Value System Design	System Synthesis	Systems Analysis	Rank (optimize) Alternatives	Decision Making	Planning for Action
Program Planning							
Project Planning							
System Development							
Production							
Distribution							
Operations							
Retirement							

The third dimension of the morphological box, knowledge, is a very important aspect of the process. This knowledge dimension is especially important for the problem definition that should be accomplished as a group activity. This group should be comprised of the stakeholders, the functional engineers, and policy, government, and management specialists. At the beginning of the study, the overall system manager should ensure that all disciplines required for the project are represented. This helps to prevent individual biases based on personal perception to not be incorporated into the system. The assortment of specialties included in the group will also allow for a more complete or total picture of the situation (Lendaris: 604).

SMAD

James Wertz and Wiley Larson address requirements development based on values and objective structuring in their text entitled *Space Mission Analysis and Design.* SMAD is a process very similar in order and content to the Hall’s morphological box.

The main exception being that SMAD focuses on the steps of a feasibility study by focusing on the performance objectives (needs), constraints, and concept exploration. These items are generally investigated during the first phase of Hall's process. In addition, the SMAD process primarily focuses on one architecture and performs feasibility analysis at decision nodes of the design development. In doing this, the SMAD process doesn't have a need to concentrate on a value system design. (SENG 520 notes)

SMAD's equivalent to the Hall's knowledge axes specifically includes the inputs of the operator, user and developer to ensure a more realistic and affordable end product. Table 3 shows the space-focused process that has been continuously iterated on over the past 40 years.

Table 3. The Space Mission Design and Analysis Process. (Wertz : 2).

Define Objectives	Step 1. Step 2.	Define broad objectives and constraints. Estimate quantitative mission needs and constraints.
Characterize the Mission	Step 3. Step 4. Step 5. Step 6.	Define alternative mission concepts. Define alternative mission architectures. Identify system drivers for each. Characterize mission concepts and architectures.
Evaluate the Mission	Step 7. Step 8. Step 9.	Identify critical requirements. Evaluate mission utility. Define mission concept (baseline).
Define Requirements	Step 10. Step 11.	Define system requirements. Allocate system requirements to elements.

The SMAD process is an iterative approach. In general one would work down from step 1 to 6. At steps 7-11, one could choose to continue on or flow back to any of the first 6 steps.

PSARE

The PSARE process consists of three major blocks forming a closed loop: 1) external stakeholders, 2) system in service, and 3) system development project blocks.

These blocks are composed of a network of elements each having equal status and therefore, are of no particular sequence. This is generally referred to as a concurrent development process. The most significant difference between the PSARE process and the previously mentioned processes is that the PSARE addressed both the requirements development along with the architecture development. In analyzing the requirement and architecture elements together, the essential problem (the what) and constraints imposed on the system (the how to solve) are concurrently developed. This allows for extremely complex system construction to be manageable, and upgrades and/or the reuse of current technologies to be easily integrated.

The PSARE process is outlined in Figure 1. Within the deliverable system development, the system layer addresses the overall structure of the system model. The top system element level further decomposes the individual elements of the system layer. The exact system technology to be used on a specific function configuration is established in the system technologies configuration layer. The system technologies configuration maps the structure of the architecture to the real physical component. The last layer, implementation, mostly consists of detailed design. Each of these layers produce specifications which are fed into a sub-layer and/or into the integration and test development. The integration and test development phase helps to identify constraints on the system. The issues are fed back into the deliverable system development or the completed product is pushed to the system in service to field test/operate.

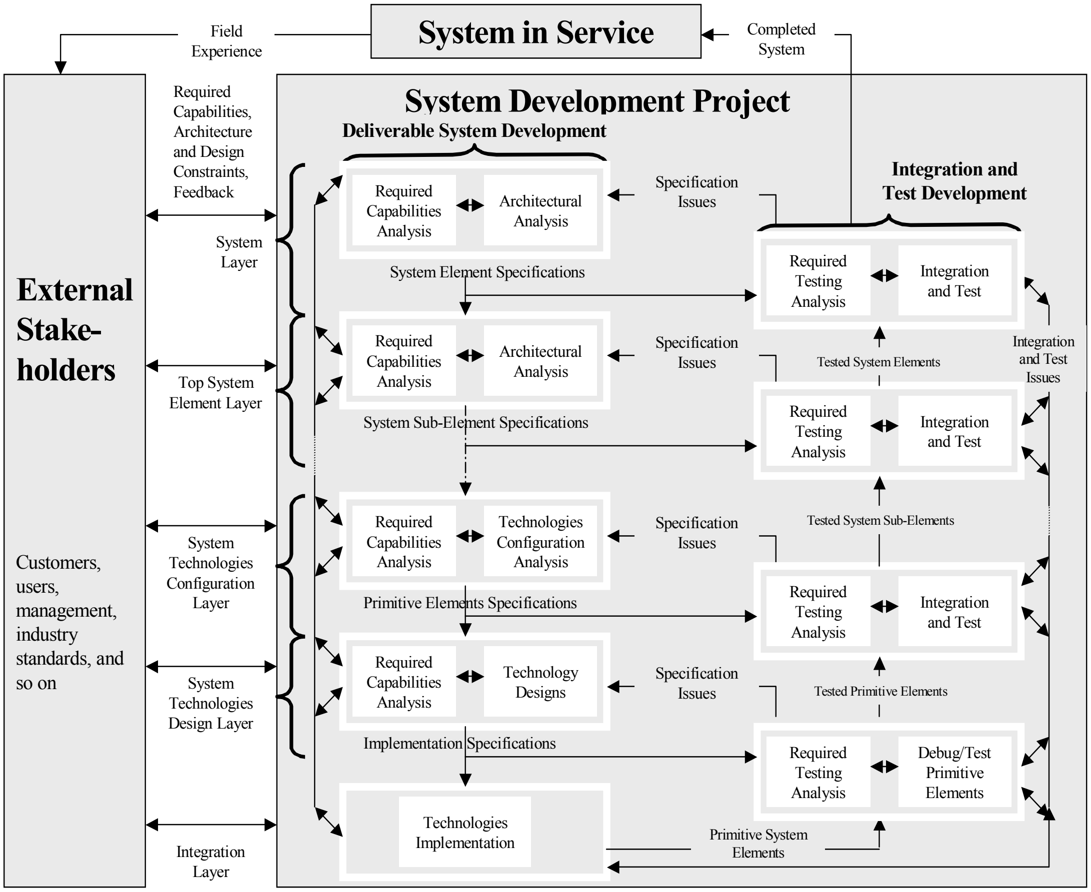

Figure 1. The Total System Life Cycle (Hatley: 182)

Electromagnetic Compatibility and Interference

Electromagnetic Compatibility (EMC) is the ability for a collection of independent electrical systems to perform without degradation or malfunction to one another in the system's given electromagnetic environment. Electromagnetic Interference (EMI) is the amount of intentional or unintentional degradation inflicted upon one electrical system by another. In general, there are two types of EMI considered: intrasystem and intersystem. In intrasystem EMI degradation is caused within a system by the system itself. Intersystem EMI is when the conflict is introduced from the surrounding environment in which the system resides. The focus of this research will be on intrasystem compatibility. However, this is not as straightforward as one would think. When discussing the antenna-to-antenna interference characteristics of intrasystem compatibility, the analysis becomes similar to intersystem compatibility. The antennas are actually a part of the internal system, however, their impacts on one-another is via the outside environment.

Conducted interference and radiated interference are two subdivisions within the system EMI that describe the wave-coupling paths. When power is directly transferred via physical connection, the coupling is referred to as conducted. Usually this coupling path is via cabling or wires within a box or system that guide the waves. When a wave is unguided and transferred without physical contact, the path is radiated. The general interference paths are defined by how electromagnetic energy travels from the source to receptor. The radiated paths are:

- Wire-Wire (Cable-Cable): wires (cable) or wire (cable) bundles in close proximity to one another
- Antenna-Antenna: power transmitted from one antenna is received at the port of another antenna exceeds the receptor's susceptibility
- Box-Box: individual black box systems leak power into the vicinity of another system
- All combinations of above: Wire-Antenna, Antenna-Wire, Antenna-Box, Box-Antenna, Wire-Box, and Box-Wire

In a technical report produced by J.L. Wilson and M.B. Jolly, the potential severity of interference inflicted by each of the preceding radiated path combination is (Wilson: 8):

Table 4. Levels of EMI Severity Involved with Modifying Various C3I Subsystems (Wilson: 8)

Interference Potential		Equipment as Source of Receptor of EMI on Baseline C3I System			
		Antenna	Cable	Box	Power System
Candidate Equipment Modification on C3I System	Antenna	Slight to Severe	Slight to Severe	Minimal	Minimal
	Cable	Slight to Moderate	Slight to Moderate	Minimal	Minimal
	Box	Minimal	Minimal	Minimal	Slight to Moderate
	Power System	Minimal	Minimal	Slight to Moderate	Slight to Moderate

As can be seen from the table, the radiated path combinations are not expected to impact EMI equally. The dominating path combination is dependent on the system under investigation. “Consequently, in many cases the nine possible radiated coupling paths…reduce to antenna-to-antenna, antenna-to-cable, cable-to-antenna, and cable-to-cable” (Violette: 150). This investigation will cover antenna-to-antenna radiated coupling interference analysis.

Wilson and Jolly include power as an important factor to be paid attention to in addition to the radiated paths. The power supplied may not be able to meet the performance requirements of the multiple systems. Long duration demands may overstrain the power supply causing operational failure during or after the mission (Wilson: 9).

Antenna-Antenna Power Spectral Density

EMI potentially occurs when the power spectral density transmitted from one antenna and received at the port of another antenna exceeds the receptor’s susceptibility. Power spectral density is the description of how the average power signal is distributed in frequency due to a one-ohm resistor load (Weiner: 1).

An antenna's transmit and receive wave signature potentially creates several types of EMI. A transmit wave contains the fundamental or passband frequency and harmonic emissions. A receive wave generally consists of the fundamental and spurious radio frequencies. Overlap of any of these wave components potentially results in EMI. There are three standard types of transmit-receive EMI: 1) co-channel, 2) adjacent channel (intermodulation, transmitter noise, etc.), and 3) out-of-band (Duff: Vol. 7, 2.2; Wilson: 7, 9). The three transmit-receiver EMI types are graphically depicted on the left side of Figure 2.

In co-channel EMI, the fundamental frequencies directly line up within "plus or minus one-half the narrowest [intermediate frequency] IF bandwidth" (Duff: Vol. 7, 2.2). The adjacent channel is similar to the co-channel except that the fundamental frequencies do not directly line up. Instead, the passband or falloff of the main frequencies may overlap. Adjacent channels can occur over a broad range of frequencies. However, the receiver is generally not sensitive to these outlying frequencies and is only investigated for collocated systems (i.e. same aircraft). The potential co-channel and adjacent EMI types are generally measured as a fundamental interference margin (FIM).

Adjacent channel EMI typical results are intermodulation and broadband transmitter noise. Intermodulation can occur when two or three power spectrum peaks (fundamental, spurious, or harmonic) interact to create a third or fourth peak that lay in-band to the fundamental transmitter or receiver power spectrum. The linearity of the surface material can also cause passive intermodulation affects (Weston: 586-587; Wilson: 9). "Third harmonic and third order intermodulation products are the most likely to cause problems (i.e. 3f, 2f1 +/- f2, 2f2 +/-f1) (Weston: 586)."

Lastly, the out-of-band EMI occurs when the: transmitter fundamental overlaps with the receiver spurious, the transmitter harmonic overlaps with the receiver fundamental, and/or the transmitter harmonic overlaps with the receiver spurious. These potential levels of EMI are measured by the transmitter interference margin (TIM), receiver interference margin (RIM), and spurious interference margin (SIM), respectively. Figure 2 graphically shows the EMI measurements on the right side.

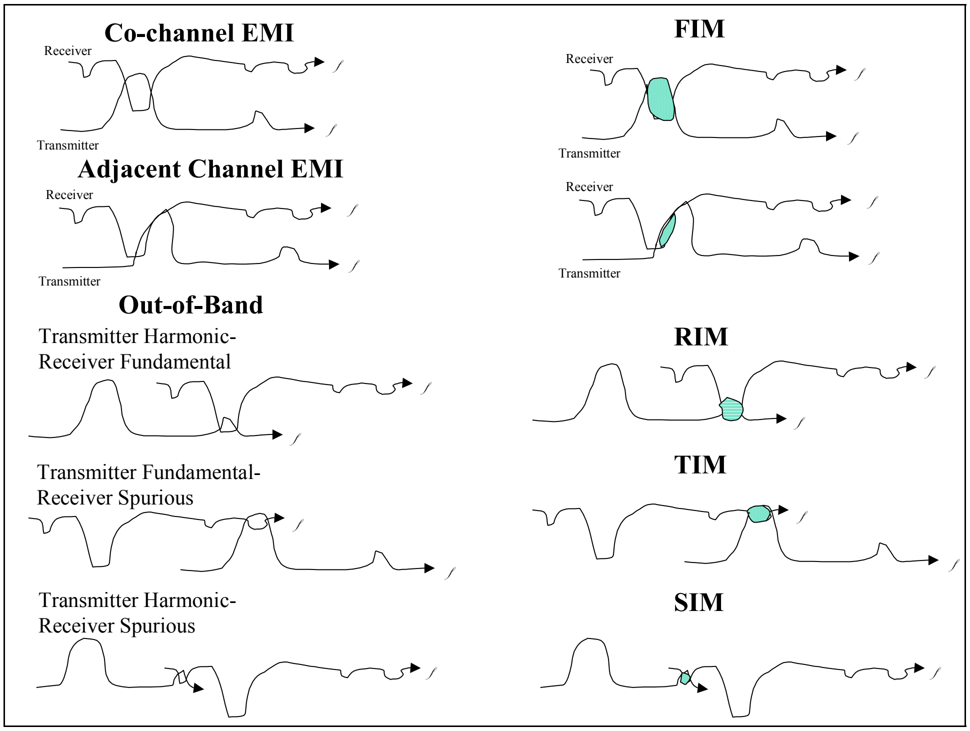

Figure 2. Types of Transmitter-Receiver EMI and the Respective Measurements (Duff: Vol.7, 2.3; Violette: 137)

For each depiction in Figure 2, the receiver power density (main frequency input and spurious responses) and the transmit power density (main frequency output and harmonic responses) are represented by the top and bottom signature, respectively. The FIM measurement directly corresponds to co-channel and adjacent channel EMI. Whereas, the RIM, TM and SIM measurements align with the out of band EMI.

Antenna-Antenna Interference Margin

The FIM, RIM, TIM, and SIM are each a special case of the interference margin (IM). The IM is the potential for the transmitted power available at the receiver to exceed the susceptibility threshold. If the IM is positive the likelihood of interference is positive. However, if the IM is negative there is little to no chance of interference. When the two are equal there is a marginal chance that interference may or may not exist.

The energy of the transmitted wave changes as it propagates from one point to another due to the loss of some of the energy into the atmosphere and the accuracy of the pointing direction. Therefore, the relationship must be corrected to show these effects in the following way: (Duff: Vol. 7, 2.8-.10)

$$IM\,(f,t,d,p) = I/N = P_T\,(f_E) + G_{TR}\,(f_E,t,d,p) - L\,(f_E,t,d,p) + G_{RT}\,(f_E,t,d,p) - P_R\,(f_E) + CF\,(B_T,\,B_R,\,\text{delta}\,f) \tag{2.1}$$

where,

I/N is the interference-to-noise ratio

$P_T\,(f_E)$ is the power transmitted in dBm at f_E

$G_{TR}\,(f_E,t,d,p)$ is the transmitter antenna gain in dB at f_E in the direction of the receiver

$L\,(f_E,t,d,p)$ is the propagation loss in dB at f_E between transmitter and receiver

$G_{RT}\,(f_E,t,d,p)$ is the receiver antenna gain in dB at f_E in the direction of the transmitter

$P_R\,(f_R)$ is the receiver susceptibility threshold in dBm at f_R

$CF\,(B_T,\,B_R,\,\text{delta}\,f)$ is the correction factor in dB to account for B_T, B_R, and delta f

f_E is the emission frequency

f_R is the response frequency

t is the time dependency

d is the distance between the transmitter and receiver

p is the polarization of the wave

B_T is the transmitter bandwidth

B_R is the receiver bandwidth

delta f is the absolute difference between the transmitter and receiver bandwidths

The way the wave propagates from the transmitter to the receiver determines the propagation loss. The waves can travel directly (for co-site antenna, directivity is modified by a reflection correction), by reflection (which is a function of the conductivity or permittivity of the reflectance surface and the angle of incidence), by surface coupling and by bouncing off the particles in the sky (Weston: 579-580). The pointing direction correction is based on the gain and bandwidths of the transmitting and receiving antennas.

Interference Margin Independent and Dependent Variables

Frequency, time separation, distance, and direction are the independent variables of EMI. The transmit and receive antenna equipment type, age, maintenance condition, and seasonal, environmental and/or atmospheric parameters influence the independent variables. Frequency is the best control for EMI but spurious emissions at other frequencies are hard to control and increase the overall complexity of the EMC problem. Each transmit-receiver pair must be considered in the selectivity and analysis. The antenna rotation, scanning and moving equipment, solar cycles, diurnal effects, seasonal effects and operations influence time separation. The most challenging and/or highest level of expected EMI problems are dealt with in the near-field region. This near-field region is where the determination of minimum distance separation occurs. Direction is the last independent element and is described as the three-dimensional direction and polarization of the electromagnetic wave (Duff: Vol. 7, 2.5-.6).

The variables directly contributing to interference are amplitude, power transmitted, transmission coupling function and the susceptibility threshold. The following relationships summarize Duff's description of the dependent variables (Duff: Vol. 7 2.6-.8):

- Amplitude can be used as a 'weeding-out' process.
- As P_T increases, the potential for interference increases.
- As transmission coupling increases, the potential interference increases.
- As L decreases, the potential interference increases.
- As PR decreases, the potential interference increases.

Antenna-Antenna Modeling Techniques

Modeling of antenna-antenna EMI begins with the electromagnetic characteristic definitions. The receiver characteristics needed to determine potential degradation include the operating frequency range, demodulation process, susceptibility, sensitivity, and IF band input density spectrum. The operating frequency range, type of modulation, modulation bandwidth, and the power density spectrum are required for the transmitter input. The next step is to include any attenuation changes to the transmitter such as any in-line filters. A comparison of the EMI system characteristics is accomplished using a math model. This math model is then used to determine the radio frequency (RF) margins for all transmit-receive combinations. Based on the final IM result, the designer can assess what, if any, corrective measure is needed.

In most of the EMI prediction, the structural coupling path, antenna gain, transmission system mismatch, transmission emission spectrum, and the receive susceptibility response are all sub-model components of the mathematical models. In addition, operational doctrine and data handling strategies are sometimes modeled. Wilson and Jolly thoroughly discuss the five modeling attributes along with a discussion of the computerized models utilizing these attributes and some of the inaccuracies and difficulties of the computerized models utilizing these attributes. The reader is referred to Wilson and Jolly's paper for further discussion.

This paper will utilize the "Short Form EMI Prediction" tool developed by Don White Consultants in 1972. *The Electromagnetic Compatibility Handbook* by Violette, White, and Violette and *The Handbook Series on Electromagnetic Interference and Compatibility* (Vol. 7) by Duff both discuss this short form model in detail (Violette, Duff).

The form consist of five parts: 1) the FIM, SIM, TM, RIM quick-look, 2) Amplitude, 3) Frequency, 4) Detailed parameter analysis, and 5) Performance Analysis. The form is first used as a preliminary analysis tool to quickly look at and remove low probability EMI cases. After the quick-look, the remaining four analysis levels are considered for further investigation. As each of the remaining level of analysis is performed, 90 percent of the non-interfering situations should be removed (Duff: Vol. 5, 2.17). If applicable, the FIM, TIM, RIM, and SIM cases are tested in each level. Advancement of the antenna-antenna pair into the next level is based on failure to meet the baseline IM requirement.

In the amplitude analysis, the transmission loss is assumed to be minimized and the "emission output and receptor response are aligned in frequency such that the vulnerability device provides minimum rejection to the potential interference signal

(Duff: Vol. 7, 2.17)." Amplitude analysis solves the IM equation with rough propagation loss estimates and doesn't consider the correction factor.

The frequency analysis uses the amplitude results and incorporates the transmitter bandwidth and modulation, bandwidth and selectivity of the receiver, and the frequency separation between the antenna-antenna pair. Each type of transmitter-receiver EMI is compared. In short, this step adds the correction factor into IM equation. "The results of frequency analysis yield surviving cases that have a significant potential for producing interference (Duff: Vol. 7, 2.28)."

Detailed Analysis incorporates the time, distance and direction independent variables and determines the interference probability distribution. Finally, the performance analysis measures the signal-to-noise ratio to identify and determine the extent of damage to the operational performance.

<u>"Short Form EMI Prediction" Assumptions and Limitations</u>

Ten assumptions are defined for the process and suggested values in the form. The assumptions are (Duff: Vol. 7, 2.38-.39):

> 1) Frequency limits for transmitter spurious emissions and receiver spurious responses are from 0.1 to 10 times the fundamental frequency. This assumes that there are no significant emissions or responses outside these limits.
>
> 2) Maximum TX-RX [transmit-receive] frequency separation for fundamental interference is 0.2 times the receiver fundamental. This assumes fundamental interference is not significant for larger frequency separations.
>
> 3) Free-space propagation loss is assumed.
>
> 4) Levels for transmitter spurious emissions are 60 dB below fundamental emission.
>
> 5) Levels for receiver spurious susceptibility are 80 dB above fundamental susceptibility.
>
> 6) An additional 20 dB rejection each is assumed for transmitter and receiver minor emissions and responses.

7) Values for antenna gains in unintentional radiation directions and at unintentional frequencies are 0 dB.

8) Differences in transmitter and receiver bandwidth are assumed to modify the power available in the manner specified in Table 2.1 of Duff [bandwidth corrections in dB].

9) Frequency separation delta f between transmitter emission and receiver response are assumed to reduce the effective power available by an amount given by 40*log (0.5 [$B_T + B_R$])/delta f.

10) A go, no-go interference margin level of –10dB is used. Thus, potentially interfering situations are eliminated only if the mean signal level is less than –10 dB relative to the receiver susceptibility threshold.

The “Short Form EMI Prediction” tool has many limitations. Some of the biggest issues with the short form are the geometry assumptions of a flat plane and not a cylindrical surface. Additionally, the short form is not an automated process. This is not a factor for a small number of antenna combinations, however, when the antenna number is large this is a fairly time consuming and inefficient process. Several automated tools that utilize a cylindrical geometry exist. However, these tools require a higher level of detailed input data. For this level of analysis with the fictitious data set, the “Short Form EMI Prediction” tool will be adequate. J. L. Wilson and M. B. Molly created detailed explanations of several automated tools along with the associated modeling attributes and suitability. Although the readers are encouraged to read the detailed discussion themselves, this table has been included in Appendix 3.2 for easy reference.

EM Mitigation Techniques

For the failing transmit-receive pairs, several techniques exist. The type and level of IM determine difficulty and ultimately the incurred costs to perform the correction. The frequency, time, angle, and location are the drivers for control. Frequency management can be used by adjusting transmitter modulation bandwidth, pulse rise and fall time, addition of harmonic filters, and frequency allocation and assignments.

Additionally, the receiver EMI impacts can be controlled by the addition of preselectors, filters and correlators. Time-sharing, radar pulse synchronization and time/range gate controls are examples of time management techniques. Direction management can be implemented by controlling the azimuth and elevation use and assignment, sector banking, space filters and polarization. These techniques are all identified by Duff under intersystem interference and control; however, these can be used for the intrasystem antenna-antenna co-location systems (Duff: Vol. 1, 1.23).

As for intrasystem EMI control, Duff breaks the management into five categories: 1) circuits and components, 2) filtering, 3) shielding, 4) wiring, and 5) grounding. The subcomponents of these categories include arc suppression, power main filters, housing material and thickness, packaging seals and gaskets, cable grouping and grounding, connector shields, and structure and bond grounding, etc (Duff: Vol. 1, 1.22).

The addition of a low pass or bandpass filter between the transmit-receive pair should easily resolve the out-of-band (TIM, RIM and SIM) problems.

For co-channel or adjacent interference, time-sharing, pulse shaping, or signal-by-signal cancellers can be used to potentially obtain EMC. FIM interference is generally more difficult and can even be as severe as requiring expensive redesign of the transmitter. Intermodulation induced interference generally cannot be fixed. The solution is to continue operations at a limited performance level or to resolve with frequency management. (Wilson: 7, 24)

Changes in location may change the area of influence and/or the radiation patterns. Changes include separation distance, position and attitude, natural terrain shielding and line-of-site masking. This change also changes the aerodynamics of the system and could cause additional problems. (Wilson: 7, 24)

The operations environment must be prioritized for EMI situations in which no current technology solution can resolve the problem. In the power case mentioned by Wilson and Jolly, additional regulation or filtering of the power may help to meet the performance requirements. (Wilson: 24, 26)

USAF Multimission Aircraft Research and Development

Several key drivers are being worked as the United States Air Force (USAF) plans for 2025. One of the overarching drivers is the quest for information dominance. Joint Pub 3-13 defines information dominance (superiority) as "the capability to collect, process, and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same" (Joint Pub 3-13: I-11). To obtain the goal of continuous and uninterrupted flow of information, air space and information operations must be integrated seamlessly and quickly. Information technology is the key to sifting through the potential overload of information to deliver "the right information to the right place at the right time" (Jumper: 57) by horizontally integrating manned, unmanned and space platform command and control, communications and computers and intelligence, surveillance, and reconnaissance (C4ISR) systems. (Jumper: 57, 59)

A prime opportunity has come about with the need to replace the 40-year-old tanker fleet. The Boeing KC-135Es are scheduled to be replaced by a common widebody aircraft. The common frame of choice has been declared the Beoing 767 and work is under way to modify the commercial-of-the-shelf aircraft to accommodate the tanker and transport missions. In addition to the tanker/transport missions, the replacement for the aging fleet of E-3, E-8, RC-135 and C-130 aircraft theater-based command and control (C2) and intelligence, surveillance and reconnaissance (ISR) fleet is underway.

In addition to the current platform retirement needs, the requirement of horizontal integration of C4ISR assets to accomplish information dominance over the battlefield can begin to become a reality with this widebody concept. The commander in charge of the battlefield must be provided all possible information in a timely manner in order to make the most accurate decision. This venture will almost resemble an air-based air operations center (AOC). The commander will have a complete air and ground battle management view to control the theater assets.

The common widebody aircraft integration referred to as MC2A or MMA will be an attempt to seamlessly incorporate current stove-piped theater C2ISR assets into a single cohesive unit. This is a fundamental change in the current acquisition process. It is proposed that the MMA be out-fitted to combine some or all the functions of the existing AWACS, JSTARS, RIVET JOINT, COMPASS CALL, and ABCCC platforms. It would also have links to other manned or unmanned ISR aircraft, as well as satellites. "The end result of this amalgamation of sensors, communications, and battle management elements will be the horizontal integration of surface, air and space-borne sensing and communications elements known collectively as the multi-sensor command and control constellation (MC2C) (Behler: 1)."

The USAF has established five integrated product teams (IPTs) to investigate the MMA development: 1) Concept of Operations (CONOPs) and Requirements IPT, 2) Threat and Scenario IPT, 3) Technology, System Concepts and Classified Systems IPT,

4) Modeling and Simulation IPT, and 5) the Acquisition Strategy IPT. These teams are comprised of members from Air Combat Command, Air Force Material Command, Air Force Space Command, and Air Mobility Command. The MC2A and MC2C concepts are highly praised and supported by the Air Force Chief of Staff General John Jumper and the Secretary of the Air Force Dr. James Roche (Paone, Roche).

In order to get the C2MA into the warfighters hands quickly, a spiral development approach has been chosen. The first spiral will consist of the Multi-Platform Radar Insertion Technology Program (MP-RITP) radar (JSTAR-like capabilities) incorporated with a battle management suite. The battle management suite will allow “cruise missile defense, control of unmanned aerial vehicles and time critical targeting” (Tuttle). The second spiral will be the incorporation of similar AWACS AMTI and C2 system capabilities. The passive remote sensors would be introduced in the final development phase (Tuttle, Fulghum: July 2002).

A report discussing the analysis of alternatives (AoA) for the MMA concept has been reported in an October 2002 study. Global Security summarized the “Alternatives for Joint Multi-Mission Aircraft” report as in Table 5 below:

Table 5. Analysis of Alternatives

Analysis Parameters / Alternative	Estimated Cost	Number of Aircraft Required	Comments
Single Aircraft	$189 Billion	176	Most costly and risky Estimated to take 3-5 years longer to field
Single A/C without signals-gathering capability	$132 Billion	144	Same problems as single aircraft
Joint SIGINT program	$23 Billion	32	AF must commit to larger 767 aircraft
Common Airframe	$111 Billion	191	Could force Navy to buy bigger plane than needed

Several issues have been identified as key drivers for the integrated aircraft. David Fulghum discusses some of these decision variables in Aviation Week and Space Technology as (Fulghum: July 2002):

- The antenna location, number, and combination electromagnetic effects are not fully understood and must be accomplished before work begins on the GMTI radar.
- Aircraft aerodynamics being influence by top and bottom fuselage drag.
- Electrical power requirements. Will the current generators provide enough power (640kw) to support two major radar systems?
- Data fusion limitations.

In addition to the IPTs work has been in progress for establishing a final mission need statement (MNS) and CONOPS for both a MC2A 707 testbed and final MC2A. The MC2A 707 testbed also called Paul Revere has already accomplished its first flight during the Joint Expeditionary Force Experiment (JEFX) 2002.

JEFX 2002 via the Paul Revere testbed is the means to solve some of the development concerns to include the previously mentioned drivers. The findings from the experiment confirm earlier integration concerns and potentially limiting results. Problems were identified with the operator workstations, unstable data links, classified network vulnerabilities, interference problems, burnt cards and wires, aircraft blockage and multiple formats between C2 and intelligence assets. The overall drive for the horizontal integration was proven successful. Dynamic retasking of ISR and complete view of the battlefield drove timelines down from hours to minutes (Fulghum: September 2002).

In the end, the challenge of incorporating the radar systems has been proven too difficult based on the current technology. Stephen Trimble quotes the Deputy Director of Information Dominance for Air Force Acquisition, Bobby Smart as saying “interference, power and weight are three concerns…with today’s technology, with today’s engine performance, it’s prudent to think about this in terms of two separate fleets” (Trimble: November 2002). The final result from JEFX 2002 is the development of two fleets of aircraft. One fleet consisting of the GMTI mission elements and the other fleet with the AMTI mission elements.

III. Methodology and Tools

The Hall's morphological box, SMAD, and PSARE process were briefly discussed in the previous chapter. In this chapter, the methodology and tools of these three processes will be discussed. The chapter will conclude with a description of the tailored process used for the MMA analysis.

Hall's Seven Steps

The problem definition can be grouped into two components: 1) the introduction, background and discussion of the problem and 2) the interrelated elements. The title, scenario, professional backgrounds of system developers, scope, actors, partitioning of elements into relevant components, and isolation of subjective elements make up the first group. The needs, alterable, constraints, societal sectors, and a description of the interactions amongst these elements are the interrelated products developed in the problem definition step.

The interrelationships are described using a self-interaction matrix and/or a cross-interaction matrix. In the self-interaction matrix each element within a product is evaluated. The relationships between two products can be described using a cross-interaction matrix. The level of interaction can also be annotated in the matrix using symbols. Figure 3 is an example of a need self-interaction matrix and a need-alterable cross-interaction matrix. A cross- and self-interaction matrix is usually generated for the needs, alterables, constraints and societal sectors as shown in Figure 4 to show linkages between the problem definition elements.

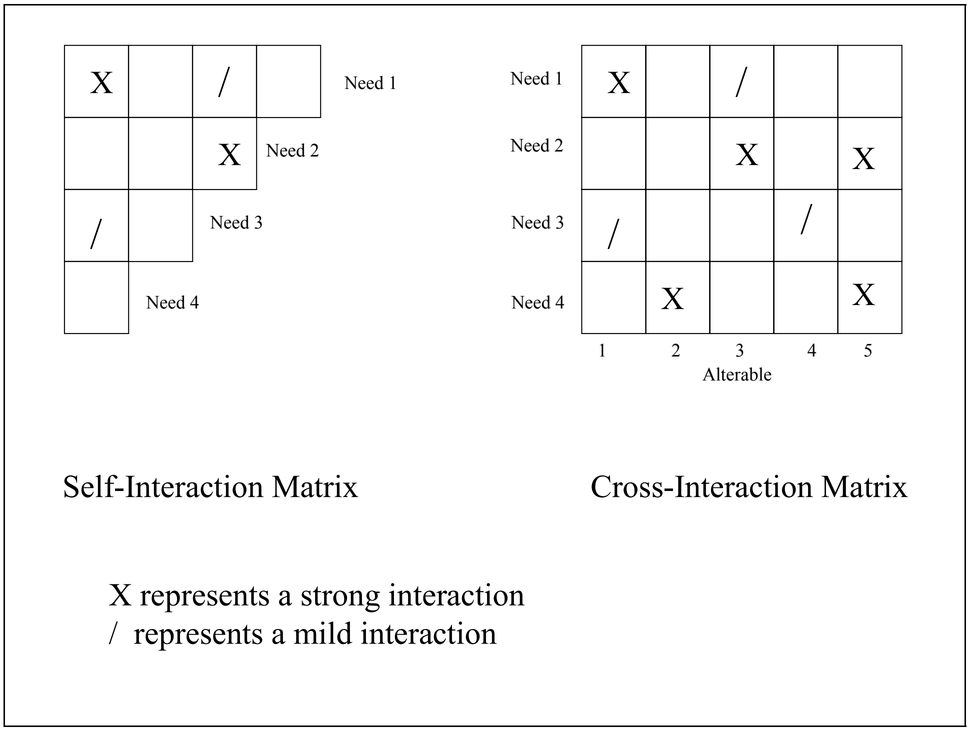

Figure 3. Examples of Self- and Cross-Interaction Matrices

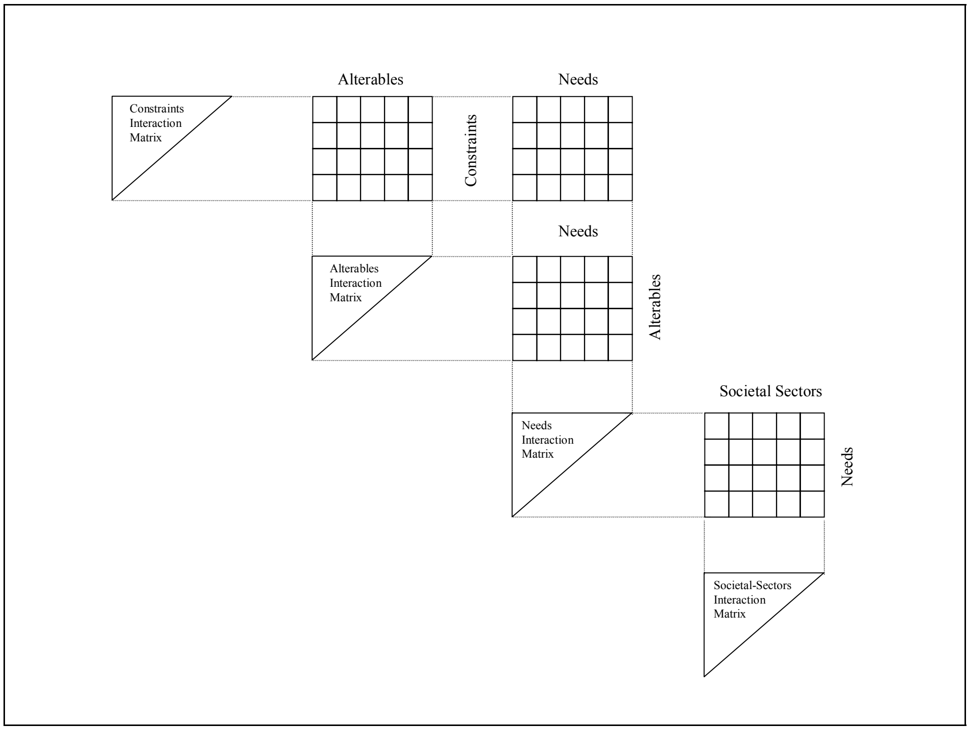

Figure 4. Problem Definition Linkages (Sage: 68)

The value system design step generates an objectives hierarchy/object tree with the final node incorporating measures of effectiveness (MOEs) to quantify how well the architecture being studied meets the criteria of effectiveness. The objective tree is used to create an objective self-interaction matrix. The last step is to generate a cross-interaction matrix between the objectives and the objective measures.

Brainstorming of concepts, alternative architectures and system designs are created during the system synthesis step. The problem definition, value system and system synthesis interaction matrices are joined together for a whole system view (Figure 5)

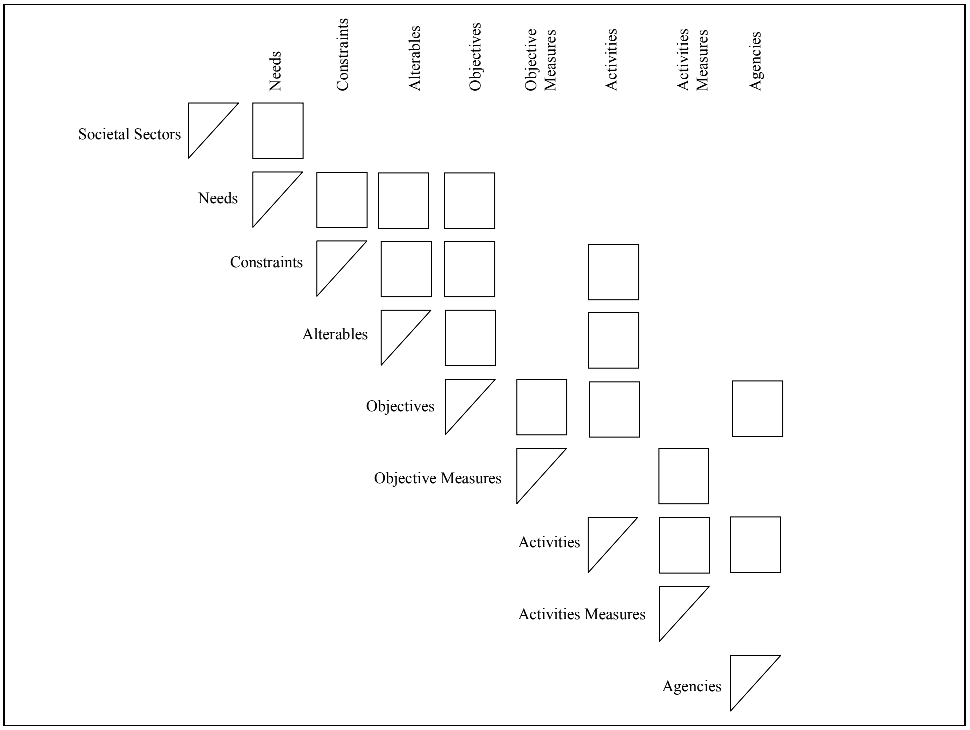

Figure 5. Program Planning Linkages (Sage: 74)

The fourth step, system analysis utilizes the previous three steps to model and assess the consequences of a given alternative architecture. The optimization step finds the best system given the value system design and constraints based steps 1-4. Once the alternative architectures have been evaluated based on the optimized value system design, an architecture is chosen to proceed with. This occurs during the decision-making step followed by the implementation of the next phase.

SMAD

The SMAD methodology is very similar to Hall's and therefore only the requirements definition will be discussed as it pertains to the MMA methodology. The requirements baseline development (steps 10 and 11) begins by identifying the customer and user of the product, prioritization of these customer's needs, and identification of internal and external constraints on the system. A tool called "Quality Function Deployment (QFD)" (Wertz: 78) is then used to evaluate the needs and the corresponding technical attributes. This QFD process evaluates the attribute and function development. Figure 6 is an outline of the 'House of Quality'.

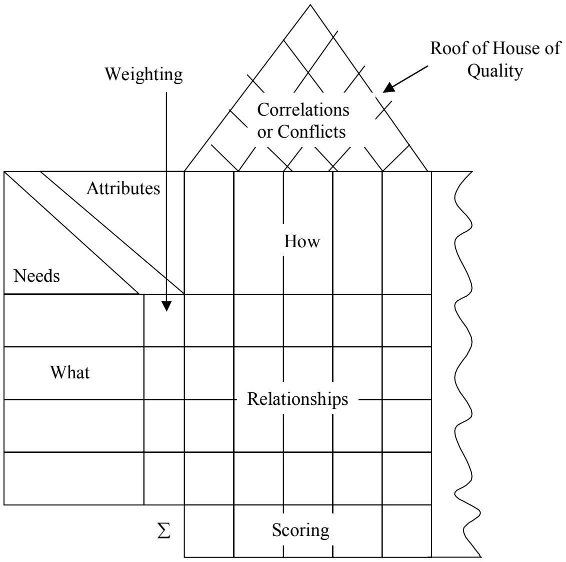

Figure 6. House of Quality Structure

The house of quality structure is similar to the interaction matrices described in the Hall's methods and tools. The correlations or conflicts triangle is a representation of the inter-relationships of the 'Hows' whereas the relationships matrix is a cross-interaction of the 'Whats' and 'Hows'. To establish priorities of the 'Whats' and to define the trade space, the 'Whats' are multiplied by a weighting factor and the 'How' columns are then summed up. This evaluation helps to determine where additional analysis should be accomplished.

The functional requirements are then established and decomposed along with the flow. The functional requirements are converted into technical characteristics. Quantifiable requirements are established based on the above steps. Next, block diagrams are used to express a single architecture's interfaces and relationships. These functional requirements are decomposed into lower levels based on the predefined architecture (Wertz: 93).

HHP

HHP is the methodology of the PSARE process and in essence the concurrent development of the architecture, essential requirements, and enhanced requirements system specification models. Figure 7 is a generic view of this concurrent methodology.

The total system life cycle (Figure 1) relates to the system specification models (Figure 7) in the following ways:

- Essential Requirements Model and Enhancing and Deriving Requirements Model correspond to Required Capabilities Analysis
- Architecture Model corresponds to the Architectural Analysis

The HHP method begins with the external stakeholder needs being assigned to an architectural model or passed through for requirement decomposition. Process, control, time and module specifications are developed along with a dictionary to trace architecture-to-external-requirements. From the decomposition of the architecture, a requirement-to-requirement trace is generated to record process or dictionary parent/child relationships. This requirement-to-requirement traceability matrix is updated as the decomposed requirements are detailed or further derived. Once the requirements have been derived to their lowest level, the requirements are enhanced and allocation of the architecture elements to the requirements elements is accomplished producing an architecture-requirements traceability matrix or architecture dictionary. The architecture components are assigned using superbubbles that are drawn around the respective requirements. These assigned superbubble architecture modules are then decomposed into finer detail creating an architecture-to-architecture traceability matrix.

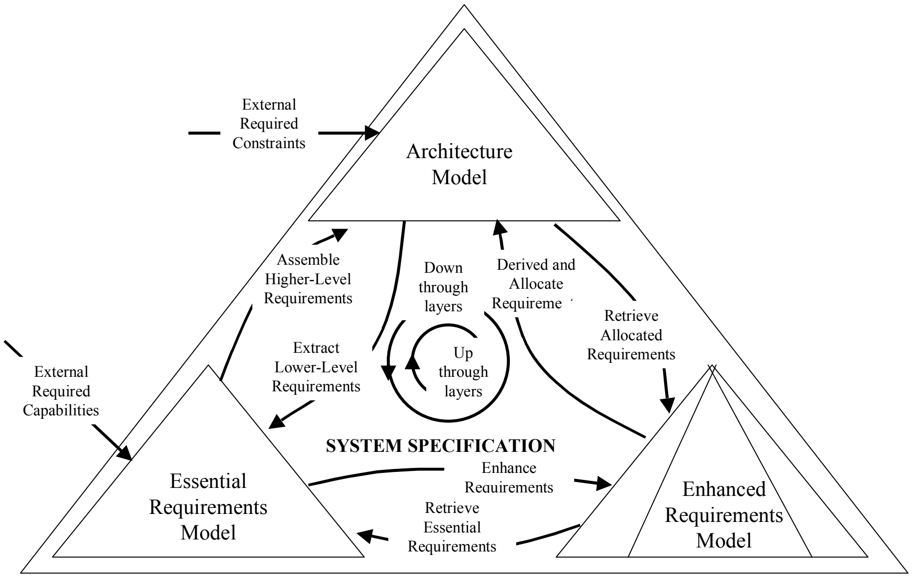

Figure 7. System Specification Models (Hatley: 191)

In creating the traceability matrices, the incoming requirements can be used to easily check for completeness and design criteria satisfaction. The traceability matrices also allow for history compilation and validation to justify its existence and allow for impact analyses for change impacts at a later time. It is important to note that this methodology has no beginning or end and can be started at any point. Additionally, only the modules, diagrams and specifications that make sense to be completed are accomplished.

The development models can be summarized in the following manner:

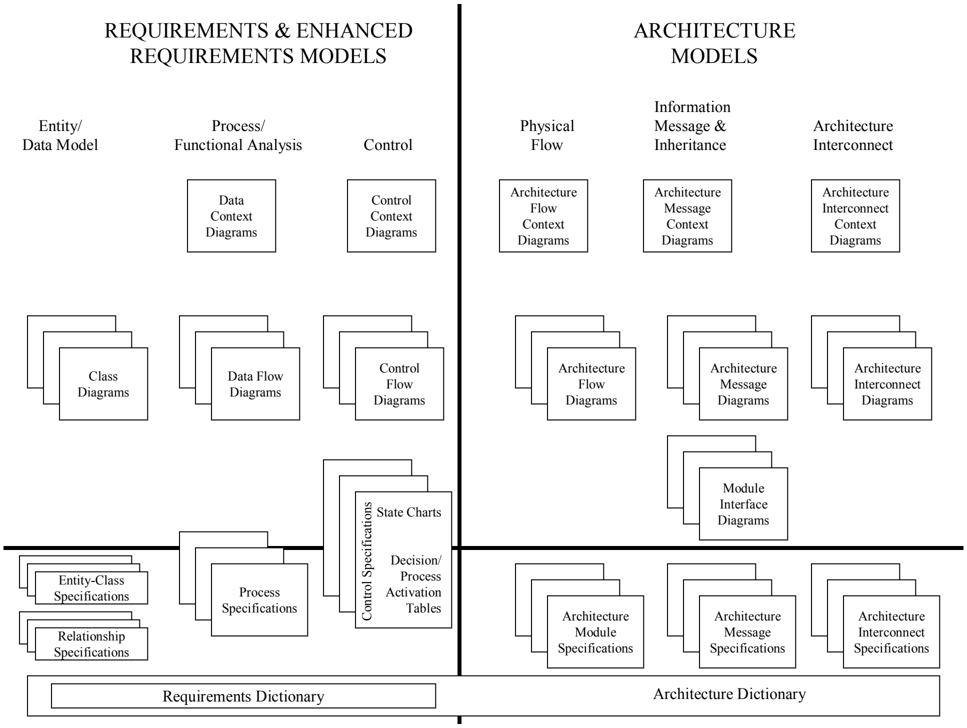

Figure 8. Development Models Summary (Hatley: 73)

The context diagrams are the baseline view of how the system interacts with its environment. The flow diagrams are the hierarchal representations of the components within the system. As discussed above, the specification and dictionary elements are derived during the flow diagram developments. The flow diagrams and specification models occur as many times as is necessary to decompose the system to its lowest detail required for development, whereas, the context and dictionary inputs have only one occurrence.

HHP successively defines lower-level functional and performance requirements using the process modules. The process module in the requirements model defines the functional requirements. The process module is a layered set of data flow diagrams (DFDs) with a data context diagram (DCD) at the highest level, and a process specification (PSPEC) at the lowest level of each vertical thread (also includes a time specification (TSPEC) and a requirements dictionary (RD)). The requirements are traced back to the physical performance constraints/capabilities (which drive requirements) in the architecture model (data flow diagram (DFDs) by using superbubbles.

The architecture (physical) models handle the functional interfaces and architecture. The physical architecture is described using the flow module (architecture flow context diagram (AFCD) and the subsequent architecture flow diagrams (AFDs)) while the functional interfaces of the architecture are handled using the interconnect modules (architecture interconnect context diagram (AICD) and its subsequent architecture interconnect diagrams (AIDs)). Note that in the HHP methods, an interconnect consist of two or more interfaces.

Functional and performance requirements track with higher-level requirements. The modules (both under the requirements (functional) and architecture (physical performance) models) use a naming convention using unique singular nouns and numbers. Each child diagram maintains the noun and numerical identifier from its parent diagram. The grandchild maintains the naming convention from both its parent and grandparent. Each new layer's (child diagram) numbers must comprise the diagram number (from the parent) appended by one additional number.

System requirements are allocated and defined in sufficient detail to provide design and verification criteria to support the integrated system design. The new layers of the data flow diagrams are created and the process specification completed to a point that the developed and defined system can be handed over to the developer. If the new system (generated from a top-down approach) is being integrated into an existing or legacy system (generated from a bottom-up approach), concurrent development and trade-off studies are needed. The HHP method suggests creating a sample analyzer module using the existing sampling module and comparing "the top-level model and the System Analyzer, the remainder of the system-level architecture, the allocation of requirements to the remaining architecture modules, and any further decompositions that are needed of those modules (Hatley: 347)." As can be seen by Chapter 11 of PSARE, the tracking of this integration can be followed using the enhanced requirements model. The enhanced requirements model elements are then allocated to the system using superbubbles.

System interface control requirements that are developed are fully documented. All requirements generated by the functional and physical architectures are document using specifications (process specifications (PSPECs), control specifications (CSPECs), timing specifications (TSPECs), architecture interconnect specifications (AIS), and others) and integrated dictionaries (requirements and architecture dictionaries).

The HHP method is a very detailed method for defining and decomposing the physical and functional components. However, the HHP method falls short when comparing multiple alternatives. The value system design was used to evaluate multiple alternatives in the Hall's and SMAD methodologies.

The choice of the overall system architecture and the major technologies it will include could be a major part of system development in a new or complicated system. Hatley, Hruschka and Pirbhai suggest that there are three tools used "to make architectural and technological decisions…feasibility analyses, trade-off studies, and prototypes (Hatley: 202)" with detail increasing in the order stated. HHP method states that criteria to measure the various alternatives needs to be established in advance and weighted according to their relative importance.

"A trade-off study is the consideration of several potential architectures or designs to compare their pros and cons, and either to select one of them as the best candidate, or to look for other candidates. Trade-off study results are recorded in the rationale sections of AMSs and AISs (Hatley: 417-18)." AMSs generally "contain numerous references to trade-off studies, company and industry standards, other systems in the same family and other specifications (Hatley: 382)."

An email from Hatley suggests that a complete model must be developed for each alternative system. And the individual models compared. Additionally, "a tool that automates the methods can make populating the repository and checking its consistency much easier. Nevertheless, all the actual thinking, the problem-solving, the trade-off studies, and the myriad of other development activities must be done by you, the system developer (Hatley: 200)."

In considering the feasibility of two or more choices for a given entity, the alternatives could be listed as different attributes to the alternative. Once a decision is made, the alternative attribute of choice could be annotated in the architecture module specification.

For the more detailed (full scale) comparison (trade-off study) of the alternative's cost, schedule, resource availability, and organizational politics, the design process would be completed on one (the most attractive, unique) alternative and then the next alternative with some change would be completed. These final results would be weighted based on criteria determined in advance. This process could become very overwhelming and rigorous with 2^n possible alternatives. It was suggested that the top two or three alternatives be chosen. These top alternatives would then be optimized based on the other alternatives.

A software tool called TURBOCASE has been designed based on the process and methodology of Hatley, Hruschka and Pirbhai. One of the greatest benefits to this graphical tool is its ability to perform consistency checks. These checks ensure that information going into and out of the modules are consistent and each module is traced back to a higher level reference. At the lowest level, the tool validates that all dictionary entries and specifications have been completed. The software is based on the unified modeling language (UML), structured analysis and structured design.

IV. Process Tailoring and EMI Results

Each of the methods discussed in Chapter 3 have their strengths and weaknesses. The Hall's methodology and SMAD methodology give great emphasis on the development of requirements and system definition. They both also include an analysis of alternatives. They do not, however, go into great detail on how to map requirements to architecture components. I do not feel the HHP methods fully address the build-up of the system definition and analysis of alternatives. The HHP methods seem to be more applicable once the up-front analysis has been performed. Once an architecture is defined, the HHP methods become the stronger method, as it is able to automatically check for consistency throughout the system model. Additionally, the HHP methods and tools allow for an automated process to track and map all of the system requirements to the architecture. For these reasons, the methods used in this study have used components and/or ideas from all three methods discussed.

Preliminary Analysis

The investigation of the multimission aircraft began with a preliminary group of twelve students comprised of logistics and maintenance operations, air and space operators, and acquisition, science and engineering backgrounds. The preliminary group brainstormed and researched the current platforms to develop two baseline hierarchies and value system designs using Hall's Seven Steps. In addition, a concept map (Appendix 1.2) was constructed to show relationships between key players, systems and operational considerations.

The objectives, needs, alterables, and constraints were analyzed in both a cross- and self-interaction matrices similar to Appendix 1.3. However, only the interactions themselves were annotated, not the level of interaction.

These matrices were then used to develop a modified interface and flow models (Appendix 1.4) using techniques defined by Hatley, Hruschka and Pirbhai. The user interface model established the baseline user interface, input processing, output processing, main functions and the support functions. The system requirements and architecture model development suggested by HHP was used primarily to summarize and graphically track the multiple architecture developments. The previously defined user interface model was used to stimulate system specifications to iteratively generate a set of system requirements and architecture models. The interface model depicts key requirements and interactions within the MMA design. The process interface was the centerpiece or driving force behind the iterations. As each architecture was developed, the system requirements were enhanced and fed back into the interface. As the process continued, several architecture variations developed and are noted as sub-bullets in the systems architecture model shown in figure A.1.4. The system architectures defined by the group were:

- *Baseline*: The current standings of each mission without future improvements. Today's System.
- *Legacy Improvements/ Standard Acquisition Process:* Follows the traditional method followed by DOD in replacing aircraft. Under the Legacy concept, each weapon system will be replaced by a similar upgraded system. The degree of enhancements will be determined case by case by using inputs from the

commands and the System Program Office. Legacy replacement results in system architecture almost identical to that of today. This is classical “stove-piping,” but given widely different schedules, budgets and technical risk, it remains a viable alternative.

- *One Tail Number (OTN)*: This would entail consolidation of multiple missions under a single airframe. This is the desired outcome from decision makers as it is expected to reduce life cycle cost and increase the ability to fuse data information, the original vision of the MMA.
- *Different Tail Number (DTN):* Each aircraft would consist of sets of compatible missions. For example tail number A1 may consist of Battle Management, C2 and IFF; tail number B2 may consist of C3CM, GMTI, IFF; tail number C3 may consist of C3CM and ISR; etc. Depending of the mission a tail number or set of tail numbers would be selected.
- *Receive-Transmit-Command (RTC):* The architecture consists of a suite of three types of aircraft missions. This concept centers on separating the three basic functions of systems described earlier into transmitting platforms, receiving and processing platforms, and separate command and control platforms. More than three aircraft could be used in the architecture but would be limited to one of the three primary missions.
- *Sensor Craft*: This is a long dwelling, real estate unlimited aircraft that could accomplish all potential missions under one aircraft.

- *Modular*: The aircraft would have a compartment or module that could be inserted based on the mission. Each module would be outfitted with different hardware and software specific to a missions needs.

MMA Thesis Team

The MMA thesis team consisted of a group of three students including Lt Nevin Coskuner, TUAF, Lt Ahmet Kahraman, TUAF, and myself. The MMA thesis team reinvestigated, compiled and developed a new and complete baseline including a systems definition consisting of key players, stakeholders, needs, alterables and constraints. The interaction matrix was reinvestigated based on these system definitions to visually show levels of cross-interactions.

The interaction matrix found in Appendix 1.3 was a key element in building the system synthesis architecture as it identified where special or in-depth research was needed to be accomplished. To logically assign levels of interaction, the designated strengths, high, medium, and low, were assigned numerical values of 9, 5 and 1, respectively. This is similar to the SMAD Quality Function Deployment in that each element value was totaled based on its interaction among the other elements. For each group (objective, alterable, constraint and need), the elements were arranged in order based on this total and natural group interaction levels were established. The cross-interactions have been summarized and categorized by level in Table 1. The analysis of the interaction-matrix determined the system variables that drove the design the most or at the “highest level.” Other interaction levels were addressed as needed.

The MMA thesis team determined three key areas for further investigation from the cross-interactions of the system definition constraints. These areas consisted of the operations environment, system compatibility, and payload limitations based on airframe limits. The technology availability and development time constraints were of higher interaction, however, it was felt among the group that the airframe limits and system compatibility would bring out some of these constraint details and in essence be addressed.

A value system design was also compiled based on the original group analysis using Hall's Seven Steps. Reduced life cycle costs and increased system value through measures of mission utility, mission integration and compatibility, and minimal risk are the primary objectives considered. The overall need was to ensure that every mission currently being served by this fleet will not only continue but also enhance a theater's ability to perform time critical targeting (TCT). Therefore, the MMA layered model was designed based on these goals and objectives and is as follows:

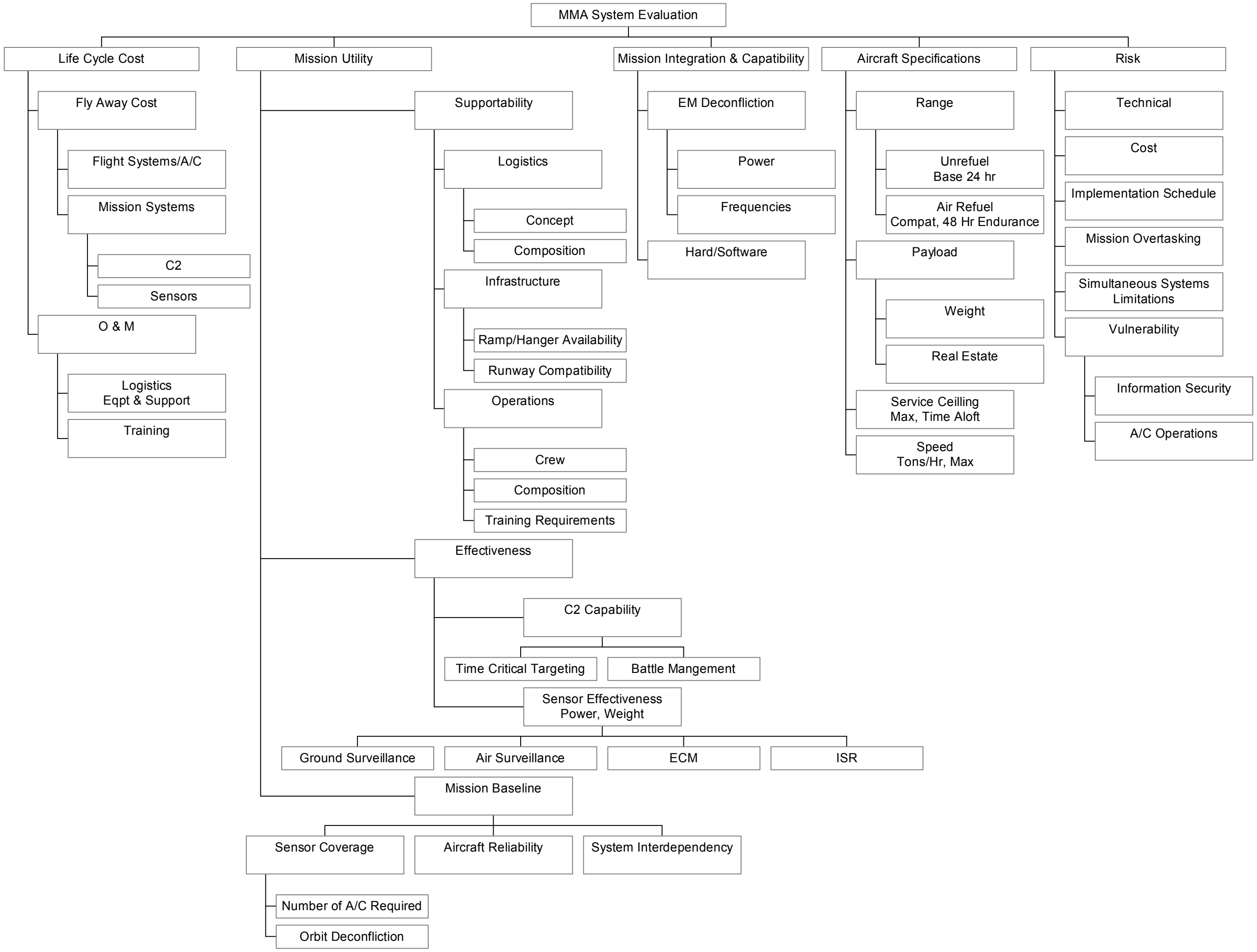

Figure 9. MMA Layered Model

In a review of the group alternative architectures, two main variations existed: 1) One Tail Number (all missions within a single aircraft) and 2) Different Tail Numbers (tail numbers representing the different sets of sensors within a particular aircraft). These two architectures were investigated in the individual study areas. Several DTN alternative architectures were generated based on the different combinations of the current aircraft functionalities. The OTN and DTN alternative architectures were evaluated using the operational scenarios discussed by Coskuner along with the sensor compatibility and payload design results. Table 6 is a summary of the architectures along with their alternative title.

Table 6. OTN and DTN Alternative Architectures

ARCHITECTURE TYPE	ARCHITECTURE ALTERNATIVE	ALTERNATIVE TITLE	ON BOARD A/C
One Tail	OTN	OTN	AWACS JSTARS Rivet JOINT C.CALL ABCCC
Different Tail Numbers	DTN1	DTN11	AWACS JSTARS
		DTN12	Rivet JOINT C.CALL ABCCC
	DTN2	DTN21	AWACS ABCCC
		DTN22	JSTARS Rivet JOINT C.CALL
	DTN3	DTN31	AWACS Rivet JOINT
		DTN32	JSTARS C.CALL ABCCC
	DTN4	DTN41	AWACS C.CALL
		DTN42	JSTARS Rivet JOINT ABCCC

Payload Integration as it Pertains to Electromagnetics

An EMC/I model was generated based on abstracted/detailed relationship modeling. In this type of relationship modeling, the downward usage adds detail or specializations, whereas the upward usage is used to generalize or abstract its subordinates. This type of model is generally used for requirements modeling to help reduce the complexity of the system at hand. Figure 10 shows this hierarchal decomposition.

As stated earlier, the antenna-antenna radiated intrasystem EMC will be investigated. Specifically, the transmit and receive spectrum power densities will be evaluated.

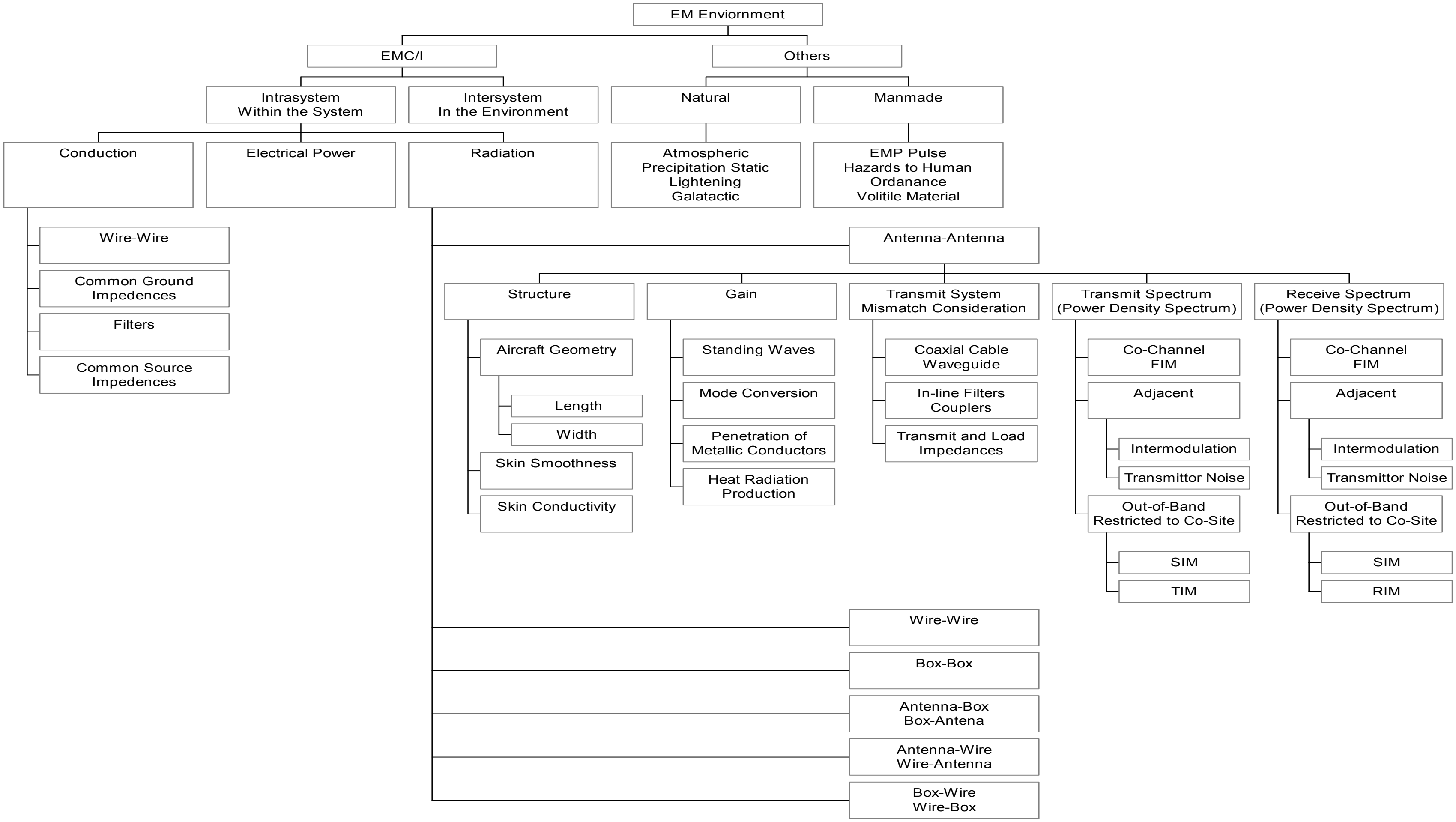

Figure 10. EMC/I Layered Model

“Short Form EMI Prediction”

Input Parameters

The preliminary EMC analysis tool discussed in Chapter 2[5] was used to evaluate the transmit-receive antenna combinations. The quick look, amplitude, and frequency analysis sections were performed to determine feasibility. As applicable, the FIM, TIM, RIM, and SIM cases were tested. Advancement of the antenna-antenna pair into the next level was based on failure to meet the baseline IM requirement. As each level of analysis was performed, 90 percent of the non-interfering situations should be removed.

The input parameters are listed in Appendix 3.3, Table A.3.2 for each transmit-receiver combination. The transmitter-receiver combination looked at for EMI analysis include: 1) GMTI-AMTI, 2) AMTI-GMTI, 3) IFF-GMTI, 4) GMTI-IFF, 5) AMTI-high band[6] (HB), 6) AMTI-low band[7] (LB), 7) AMTI-SHF, 8) GMTI-HB, 9) GMTI-LB, and 10) GMTI-SHF. The transmit input parameters required for the analysis include:

- Frequency: The mean of the working band i.e. X-Band is 10000 MHz for GMTI.
- Power Output: An example in *A Handbook Series on Electromagnetic Interference and Compatibility (Vol 1), Fundamentals of Electromagnetic Compatibility* assigned a power level of 200dBm to a similar radar system. This value of 200dBm is used for all cases.
- Antenna Gain: Based on the standard radiation characteristics for a given type of antenna. Aperture or array antennas are generally 25-60

---

[5] “Short Form EMI Prediction” tool developed by Don White Consultants in 1972. *The Electromagnetic Compatibility Handbook* by Violette, White, and Violette and *The Handbook Series on Electromagnetic Interference and Compatibility* (Vol. 7) by Duff both discuss this form in detail.

[6] High frequency (HF) and high band (HB) are used interchangeably in this paper.

[7] Low frequency (LF) and low band (LB) are used interchangeably in this paper.

dB/Isotrope (Duff: Vol. 1, 3.32). The IFF was chosen based on several IFF systems in *Janes's C4I Systems*. The gain could also be calculated as a function of the effective aperture and the frequency, but since the numbers are erroneous an estimate was given.

- Bandwidth: Except for IFF, the bandwidth was generically chosen. During the analysis, the bandwidth was adjusted to force compatibility[8].

The receiver input parameter information was based on:

- Frequency, antenna gain, and bandwidth: The same as the transmitter rational.
- Intermediate Frequency and Fundamental Sensitivity: Except for IFF, these values are based on examples used in *A Handbook Series on Electromagnetic Interference and Compatibility (Vol 1), Fundamentals of Electromagnetic Compatibility*.
- Local Oscillator: The Frequency plus the intermediate frequency.

The last portion of the parameter inputs covers the placement and distance between the sensors on the aircraft. The height was based on a ratio estimate using the Boeing 767 average radius of 5.4 meters. The distance was then calculated using right spherical triangles. The placement of the LB, HB and SHF equipment was tested at two locations: 1) just above either side of the GMTI sensor and 2) 180 degrees below the AMTI radar. The placement of the AMTI and GMTI were established based on their current locations and can pictorial be seen in Figure 11.

---

[8] This is discussed in the "Short Form EMI Prediction" Results section.

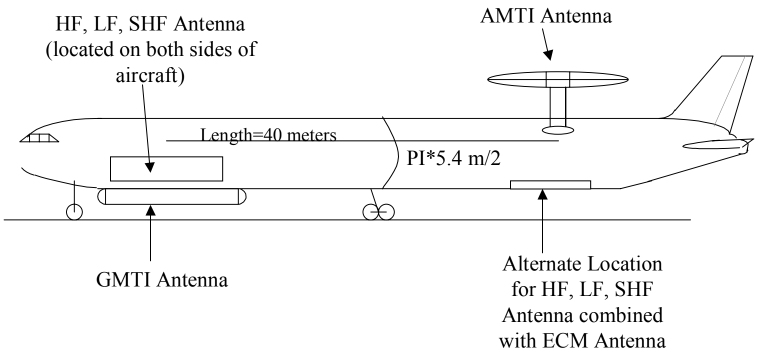

Figure 11. Schematic of Antenna Placement

<u>'Quick-Look' Analysis</u>

The short form model begins by setting the transmitter and receiver frequency limits bandwidths to 0.1 to 10 times the fundamental frequency. The maximum fundamental frequency separation is determined by 0.2 times the fundamental receive frequency. The calculated limits are then compared to determine SIM, RIM, TIM, and FIM. The minimum and maximum frequencies are tested for overlap. If overlap exists, the result will be positive for interference resulting in a yes response, whereas, no overlap corresponds to a negative (no) interference response. The limits and 'quick-look' analysis results can be found in Appendix 3.3, Tables A.3.3-3.6.

The sensor compatibility results of the preliminary short analysis showed that AMTI and GMTI combinations are expected to have interference due to the harmonic and spurious responses. This interference can be resolved by ensuring the bandwidth for the minimum transmit spurious frequency is greater than the maximum receive spurious frequency and the maximum transmit spurious frequency is less than the minimum receive spurious frequency. The GMTI and IFF combinations resulted in a compatibility issue as well. This is also the case with AMTI and IFF combinations. This is currently resolved on AWACS with time management. Therefore, GMTI and IFF antenna combination compatibility will be assumed to be manageable. Lastly, the AMTI and HB resulted in transmit harmonic and receive spurious interference. Unlike the AMTI and GMTI combinations, the AMTI and HB bandwidth cannot be adjusted to deconflict the wave patterns. The addition of RF filters for both the transmit and receive antenna and/or time management could be a potential solution. These results are summarized in Table 7. In this case, the no responses represent a probability that no interference exists, whereas, the yes represents a probability that interference will occur.

Table 7. EMI Prediction Case Results for Antenna Combinations

EMI Prediction Case	Antenna Combination					
	AMTI-RX GMTI-TX	AMTI-RX GMTI-TX*	GMTI-RX AMTI-TX	GMTI-RX AMTI-TX**	GMTI-RX IFF-TX	IFF-RX GMTI-TX
FIM	No	No	No	No	No	No
TIM	Yes	No	Yes	No	Yes	Yes
RIM	Yes	No	Yes	No	Yes	Yes
SIM	Yes	No	Yes	No	Yes	Yes

	AMTI-TX HB-RX	AMTI-TX LB-RX	AMTI-TX SHF-RX	GMTI-TX HB-RX	GMTI-TX LB-RX	GMTI-TX SHF-RX
FIM	No	No	No	No	No	No
TIM	No	No	No	No	No	No
RIM	No	No	No	No	No	No
SIM	Yes	No	No	No	No	No

* Minimum transmit spurious frequency is greater than the maximum receive spurious frequency.

** Maximum transmit spurious frequency is less than the minimum receive spurious frequency.

Although the systems are more than likely digital systems, an analog short form for out of band interference was performed (Appendix 3.3, Tables A.3.11.a.-A.3.12.b). These results predicted no harmonic or spurious interference for the AMTI and GMTI, and GMTI and IFF antenna combinations. All of the AMTI and HB/LB/SHF, and GMTI and HB/LB/SHF resulted in harmonic interference predictions. Only the AMTI and SHF, and GMTI and SHF combinations are expected to have spurious interference. A more detailed analysis of the transmitter noise, third order intermodulation, receiver intermodulation, and transmitter intermodulation should be performed.

Amplitude and Frequency Culling

The transmit-receive antenna combinations resulting in a positive probability of interference were advanced to the amplitude level of analysis. The antenna gain, direction, propagation loss, transmit power, power available at receiver, and receiver susceptibility (sensitivity) are used to calculate an IM for each surviving case. None of the cases passed the amplitude culling IM test and were advanced to the frequency culling. In the frequency culling analysis, the bandwidth is corrected. None of the cases passed the frequency culling IM test. At this point the analysis was stopped and the surviving cases were determined to be incompatible. The incompatible transmit-receive cases were determined to be AMTI-GMTI, GMTI-AMTI, GMTI-IFF, IFF-GMTI, and AMTI-HB. The analysis and results can be found in Appendix 3.3, Tables A3.7-A.3.10.b.

Impact to OTN and DTN Architectures

After the antenna combination compatibility analysis was completed, the OTN and DTN alternatives were analyzed and summarized in Table 8. For the combinations containing the Rivet Joint electronic counter measure for which no evaluation was performed, the overall compatibility was based on the assumption that time management and antenna direction could control the EMI. In addition, there is research currently being accomplished in which SIGINT (the HB, LB, SHF functions) and ECM are being combined into one physical component. This single module will focus the transmit or receive variable wavelength in a specific direction instead of omni-receive/transmit (Fulghum: 34).

Table 8. OTN and DTN Alternative EMC/I Summary

ARCHITECTURE TYPE	ARCHITECTURE ALTERNATIVE	ALTERNATIVE TITLE	A/C ON BOARD	*SENSOR COMPATIBILITY*	
One Tail Number	OTN	OTN	AWACS	AMTI-GMTI	Yes%
			JSTARS	GMTI-AMTI	Yes%
			Rivet JOINT	AMTI-RJ GMTI-RJ	No%% Yes
			C.CALL	C. Call No Evaluation	
			ABCCC	Comm Assume Yes	
	OTN Overall			No	
Different Tail Numbers	DTN1	DTN11	AWACS	AMTI-GMTI	Yes%
			JSTARS	GMTI-AMTI	Yes%
		DTN12	Rivet JOINT		Yes
			C.CALL	C. Call No Evaluation	
			ABCCC	Comm Assume Yes	
	DTN1 Overall			Assume Yes*	
	DTN2	DTN21	AWACS	AMTI-Comm	Assume Yes
			ABCCC	Comm-AMTI	Assume Yes
		DTN22	JSTARS	GMTI-HB/LB/SHF	Yes
			Rivet JOINT		
			C.CALL	C. Call No Evaluation	
	DTN2 Overall			Assume Yes*	
	DTN3	DTN31	AWACS	AMTI-HB	No
			Rivet JOINT	AMTI-LB/SHF	Yes
		DTN32	JSTARS	GMTI-Comm	Assume Yes
			C.CALL	C. Call No Evaluation	
			ABCCC	Comm-GMTI	Assume Yes
	DTN 3 Overall			Assume Yes*	
	DTN4	DTN41	AWACS	Assume Yes*	
			C.CALL	C. Call No Evaluation	
		DTN42	JSTARS	GMTI-HB/LB/SHF	Yes
			Rivet JOINT	GMTI-Comm	Assume Yes
			ABCCC	Comm-GMTI	Assume Yes
	DTN 4 Overall			Assume Yes*	

* Assume time management capability for ECM

% Assume time management capability for IFF and GMTI/AMTI. This is how compatibility is currently achieved for IFF and AMTI on AWACS.

%% Time management may be an option for compatibility. The AMTI-HB function is expected to have harmonic and spurious interference.

Analysis of Results

A summary of the MMA results including the compatibility and the payload limitations is provided in Table 9. The OTN architecture has been determined to be infeasible due to limits imposed by both EMC and power supply. As discussed earlier, time and directional control techniques may be possible solutions to overcome EMI. Power supply management may help to overcome the supply issue, however, this is probably not realistic due to the extreme overtasking of the supply. The aircraft system being used is a commercial off-the-shelf platform and therefore comes with a standard power supply unit. The addition of more power units (APUs) to supply the required energy draw is not a one-for-one trade and is not very efficient.

The power supply limitations limit all of the alternative DTN architectures. For additional information pertaining to the generation of the power limits and payload limitations in general, the reader is referred to Kahraman's thesis.

Table 8 breaks down the sensors into individual antenna-antenna evaluations. The overall system interference evaluation assumes that all the systems would be used at the same time. .Lt. Coskuner's scenario evaluations may actually show that the systems can reside on the same platform and still function based on whether the specific system set will be operational at the same time.

Table 9. MMA Feasibility Summary

ARCHITECTURE ALTERNATIVE	ALTERNATIVE TITLE	ON BOARD A/C	MAX WIEGHT	*CREW #*	*WEIGHT*	*POWER*	REFUELS REQUIRED (SEA LEVEL)**	REFUELS REQUIRED (FROM 8000 FT)**	Endurance (hr)	*SENSOR COMPATIBILITY*	
OTN	OTN	AWACS	?	Yes	?	No	2	3	9	AMTI-GMTI	Yes%
		JSTARS								GMTI-AMTI	Yes%
		RJ								AMTI-RJ GMTI-RJ	No%% Yes
		C.CALL								C. Call No Evaluation	
		ABCCC								Comm Assume Yes	
OTN Overall										No	
DTN1	DTN11	AWACS	Yes	Yes	Yes	No	2	2	12	AMTI-GMTI	Yes%
		JSTARS								GMTI-AMTI	Yes%
	DTN12	RJ	Yes	Yes	Yes	No	2	2	12		Yes
		C.CALL								C. Call No Evaluation	
		ABCCC								Comm Assume Yes	
DTN1 Overall			Yes	Yes	Yes	No				Assume Yes*	
DTN2	DTN21	AWACS	Yes	Yes	Yes	Yes	2	2	12	AMTI-Comm	Assume Yes
		ABCCC								Comm-AMTI	Assume Yes
	DTN22	JSTARS	Yes	Yes	Yes	No	2	3	11	GMTI-HB/LB/SHF	Yes
		RJ									
		C.CALL								C. Call No Evaluation	
DTN2 Overall			Yes	Yes	Yes	No				Assume Yes*	
DTN3	DTN31	AWACS	Yes	Yes	Yes	No	2	2	12	AMTI-HB	No
		RJ								AMTI-LB/SHF	Yes
	DTN32	JSTARS	Yes	Yes	Yes	No	2	3	11	GMTI-Comm	Assume Yes
		C.CALL								C. Call No Evaluation	
		ABCCC								Comm-GMTI	Assume Yes
DTN 3 Overall			Yes	Yes	Yes	No				Assume Yes*	
DTN4	DTN41	AWACS	Yes	Yes	Yes	No	2	2	12	Assume Yes*	
		C.CALL								C. Call No Evaluation	
	DTN42	JSTARS	Yes	Yes	Yes	No	2	2	12	GMTI-HB/LB/SHF	Yes
		Rivet JOINT								GMTI-Comm	Assume Yes
		ABCCC								Comm-GMTI	Assume Yes
DTN 4 Overall			Yes	Yes	Yes	No				Assume Yes*	

Functional (Requirements) Design & Architecture (Physical) Design

An HHP system architecture model (physical model) and requirements model (functional model) were generated using TURBOCASE. The models can be found in Appendix 2.1 and Appendix 2.2. The dictionary is listed in Appendix 2.3. The output from the preliminary EMC/I analysis was incorporated into the HHP model via a data table.

These models are the start to a physical development activity. Therefore, they are not comprised of specifications and detailed requirements, as this was not the focus of the study.

VI. Conclusion & Recommendations

The start to a MMA system design has been accomplished using Hall's, SMAD, and HHP methodologies. Every attempt has been made to make the system as complete as possible. However, with every new set of eyes comes new views and in essence new inputs. A system architecture is never complete for this reason.

As stated earlier, there are basically two types of studies: feasibility studies and studies with a product implemented. A feasibility study highly focuses on needs, alterables and constraints to develop alternative architectures and recommendations for implementation. A detailed value system design is established. However, there is an overall lack of emphasis on system requirements.

With that stated this study did not concentrate heavily on the product to be implemented, and therefore, a focus on detailed requirements development and specifications was not included. The HHP methodology begins to address the product development but more analysis must be accomplished once an architecture has been decided. In addition, the HHP model focuses on the OTN. The OTN is broken down into great detail, whereas, the DTN is only broken down into the mission objective combinations.

The study has shown the OTN architecture, the most desired by the customer, to be infeasible due to compatibility issues and power limitations. This is in agreement with results from the Paul Revere-MC2A testbed performance in JEFX-2002. The final result from JEFX 2002 recommended the development of two fleets of aircraft based on "interference, power [and] weight" (Trimble). One fleet consisting of the GMTI mission elements and the other fleet with the AMTI mission elements.

The EMC analysis performed was extremely limited. The true values were not used and the analysis technique was not as complete as some of the automated tools. Additionally, it was assumed that the communication systems would work in the new environment since the same communications systems work in the current environment. This is probably a poor assumption to make since the coupling of the multiple system waves could actually cause interference due to the intermodulation, harmonic or spurious frequencies. It is therefore, recommended that a spectrum analyzer be used to determine the true spurious and harmonic frequencies of the systems and an automated tool be used.

The last point of contention is that this study was accomplished without the continued input of the customer. This input is a vital part of a complete and accurate system design.

It is recommended that:

- The true values should be inputted into an automated analysis tool to obtain actual EMI results.
- The power estimates be iterated based on some known technology advancements. An example of this is the computer monitor. The 1988 equations used to compute power and weight for the computer monitors would be a significant difference when compared to a more compact and energy efficient flat-screen monitor. For an estimated 60 console work area, this could prove to be a significant difference.
- The operations evaluations should consider if all systems are required to function at the same time. Perhaps all of the systems can be installed onto

one aircraft with an accepted limitation that only certain systems could operate at the same time.

VII. Appendix

Appendix 1.1 System Definitions.

Key Players and Stake Holders

The MMA players include the decision makers (ACC, AMC, AFSOC, CINCs), owners/operators (Air Staff, Nav Air, Army) and stakeholders (theater commanders, fighters, bombers, combat search and rescue, support aircraft, etc.). The technical actors include the Boeing Company, Raytheon Corporation, and Northrop Grumman and other companies. Some of the necessary disciplines of the feasibility study members include physics (electromagnetic), logistics, operations, acquisition, and engineering (sensor, transistor, receivers, aeronautics, systems.)

Need: What the customer wants.

Continuous Operations: All weather, 24 hour/7 days a week.

Dissemination and Transmission: Any emission leaving the aircraft such as outbound communication of others and active remote sensing.

Command, Control and Communication Counter Measures (C3CM): The reduction or elimination of an adversary's use of their C3 components.

ISR Processing and Exploitation: The manipulation and data extraction of the collection data.

Receiving and ISR Collection: Inward communication from others and passive or active gathering of remote transmissions for intelligence data.

Air and Ground Battle Management (BM): The management and tracking of air and ground assets and adversaries.

Air and Ground Command and Control (C2)

Longterm Compatibility: It is desired to not only have this system meet the needs of today but also be designed to easily integrate future technologies.

Joint Service Interoperability: In today's environment, it is becoming more and more important to be able to leverage off of and communicate with sister services.

Alterable: What is proposed to be varied.

System Architecture: Although a single aircraft is ideal and highly desired, a modular platform may need to be used if the functions of some of the current missions are incompatible. Therefore, the system architecture will select the airframe based on all of the mission components being consolidated into one permanent platform or into a set of modular platforms.

CONOPs: How a system is employed affects the multi-mission/system compatibility because having multiple missions also means having multiple interest, desires and goals. For example, the theater commander may see it necessary to collect ISR information in one location but be out of range for the C3CM mission. A fully outlined training, techniques and procedures (TTP) manual will need to be developed.

Mission Requirements: The missions must all perform together. Tasking, processing, exploitation and dissemination (TPED) will have to be investigated amongst the missions for system hardware and software overlap, independence, and interference. The space, weight and power requirements for the missions will also need to be evaluated.

Future Politics/Players/Conflicts/Demands: Each of these future aspects could drive the design and development of the MMA in a completely new vector giving way to a new set of requirements.

Constraints: What is held fixed.

Classification of the System: Each mission aircraft currently consist of, works at and reports at different levels of security. Bringing these different levels together and meeting security requirements may increase the difficulty in obtaining the overall integration.

Government Requirements and Policies: International and National level policies and regulations may restrict and even drive some of the decision variables.

Safety: Crew, data information and technology, and the aircraft safety will play a role in limiting the operations area and the optimal architecture. The higher the number of people onboard increases the safety concerns and could limit how close to a conflict the aircraft could safely fly.

Development Time: If the technology is not in already in place, it could extend the time required to develop an operational aircraft. If the development takes to long, a new proposed enemy/conflict could impact the requirements and the current design become infeasible.

Operations Environment: Trained personnel, aircraft/human survivability, friendly and hostile electromagnetic environment, and the overall mission performance will limit the ability of the MMA program.

Logistics Supportability: Transportation, manpower, supply, environmental impacts, and rapid return to service will all constrain the logistics and maintenance of an operational aircraft.

Technology Availability: In order to consolidate missions that currently require their own airframe, technology must be in place to minimize the real estate needs and architecture systems of the missions. Newly designed transmitters and receivers will need to be designed that can handle the multi-missions.

Airframe Limits: Each airframe has its space, weight, range/endurance limits. The airframe must be able to manage the real estate and loiter requirements of the consolidated missions.

System compatibility: Will all of the different missions be able to work together? Will the C3CM mission prevent the C2 and communications and ISR collection missions form occurring? Therefore, the electromagnetic interference between transmitters and the interference between active and passive sensors will need to be investigated. Standardization, interoperability, and system supportability will all need to be considered.

Funding: The decision makers have not yet established the MMA funding level. Therefore, the life cycle cost approach will be to minimize the overall cost for the mission consolidation. This cost will be based on individual mission system requirements, modification cost of currently existing commercial airframe or development of a new airframe, open architecture cost and the consolidation of the missions into this architecture, a consolidated communications architecture, consolidated radar systems, console computer cost, size of aircrew required to perform the multi-missions, processing (on-board or ground), etc. Additionally, if the MMA proves to be too costly and the cost outweighs the benefit then the aging fleet could age even longer.

Appendix 1.2 Relations Concept Map

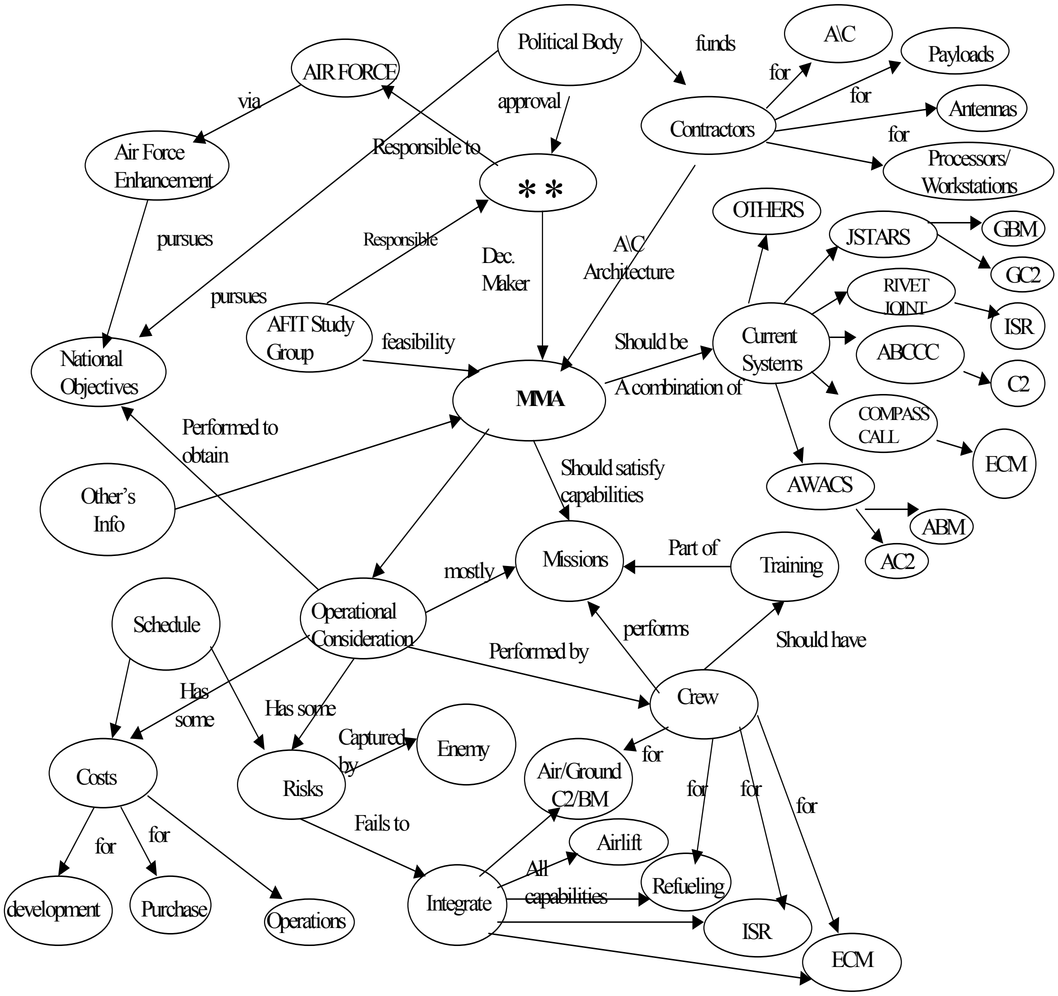

Figure A.1.1. Relations Concept Map

The above context map identifies the interactions and relationships between the key players and the system elements. This map helps to define the interactions matrix in Appendix 1.3.

Appendix 1.3. MMA System Interaction Matrix.

Objectives
Interaction Matrices

X	/	/	Min.LCC
X	/	Max.Mission Eff	
X	Min. Risk		
Mission Integration & Compatibility			

Constraints

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	/		/		X	/			X
/				X	X	X	/	/	
		/	X			X		X	/
/			X		/	X	X	X	/

Objectives

Alterables

A1	A2	A3	A4
X			X
X	X	X	X
	/		X
	/	/	X

Objectives

Needs

N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11
/		/	/	/	/	/			/	/
/	X	/	X	X	X	X	X	X	X	X
			/	X	/	X	/	/	X	X
X		/	X	X	X	X	X	X	X	X

Objectives

Constraints
Interaction Matrices

			X		X	X			Funding **(C10)**
/				/	/	X	X	System Compability **(C9)**	
		/		X	/	X	Air Frame Limits **(C8)**		
			X			Technology Availibility **(C7)**			
	X	/		X	Logistics Supportibility **(C6)**				
/	X	X		Operations Environment **(C5)**					
		/	Devolopment Time **(C4)**						
	X	Safety **(C3)**							
X	Gov't Regulations & Policies **(C2)**								
Classification of System **(C1)**									

Alterables

A1	A2	A3	A4
X			X
/	/	/	/
X	X	/	X
	X	/	X
/		/	X
X		X	X
	?		X
		/	/
X	/		/
/		/	/

Constraints

Needs

N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11
/		/	/	/	/	/			/	/
X		/	X	X	X	X	/	/	/	/
			X	/	/	X	/	/	/	/
X			X		/	X	/	/	X	X
/		/							X	X
	X	X	X	X	X	X	X	X	X	X
/		/	X	/	X	X	/	/	X	X
	/								X	X
		/								
			X	/	X	X	/	/	/	/

Constraints

Alterables
Interaction Matrices

X	X	X	System Architec. **(A4)**
X	/	CONOPS **(A3)**	
X	Mission Requirements **(A2)**		
Future Politics/Players/conflicts /Demands **(A1)**			

Needs

N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11
	/		X	/		X			X	X
	X	/	X	X	X	X	/	/	X	X
/	X	/	X	X	X	X	X	X	X	X
X		X	X		X	X			X	X

Alterables

X : HIGH INTERACTION
/ : MEDIUM INTERACTION
☐ : LOW INTERACTION

Needs
Interaction Matrices

/	X	/	X	X		X	/	X	x	Air C2 **(N11)**
/	X	/	X	/			X	/	Ground C2 **(N10)**	
/		X		X	X	/	/	Air BM **(N9)**		
/		X			X	/	Ground BM **(N8)**			
/	X		/	X	X	ISR Coll.& Rec. Mis. **(N7)**				
/			X		ISR Process.& Expl. **(N6)**					
/	/		X	C3 CM **(N5)**						
/	X	/	Dissem. & Transm. **(N4)**							
/		Joint Service Interoperability **(N3)**								
	All-Weather Capability (24/7) **(N2)**									
Longterm Compatibility **(N1)**										

Figure A.1.2. MMA System Interaction Matrix

Appendix 1.4. Generation of Alternative Architecture Concepts

User Interface Model

USER INTERFACE

- Processing, Exploitation & Dissemination (PED)
- Ground Station Interaction
- Communications between Aircraft
- Aircrew Consoles

INPUT PROCESSING

- Decision Maker Input
- Tasking
- Information from others
- IFF
- Signals
- Other Services
- Validation from other sources

MAIN FUNCTION

- Overall Command & Control
- Air/Ground Battle Management
- Sensors Collection – ISR
- C3CM

SUPPORT

- Tankers
- Communications Relay
- Logistics & Maintenance

OUTPUT PROCESSING

- MASINT, SIGINT, IMINT, GMTI
- Decision Maker Output - Warfighter Direction

Figure A.1.3. User Interface Model

System Requirements and Architecture Model Development

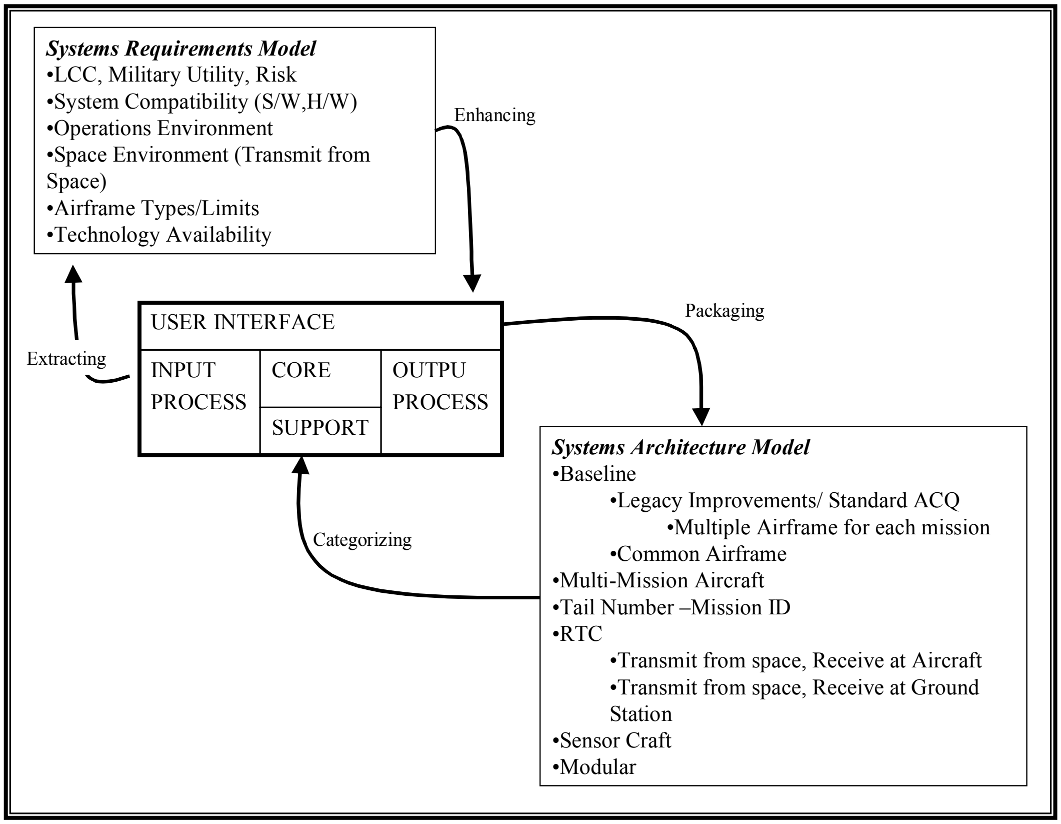

Figure A.1.4. Systems Requirements and Architecture Model Development

Appendix 2.1. Requirements (Functional) Model

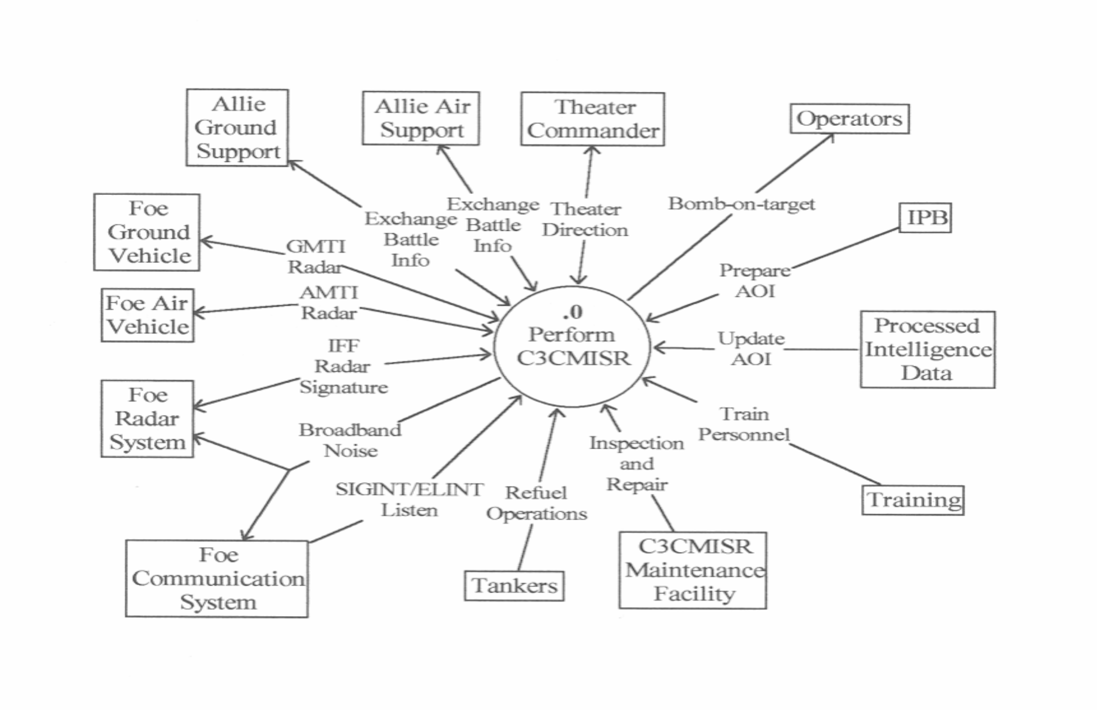

Figure A.2.1. C/DFD-1: Context Diagram

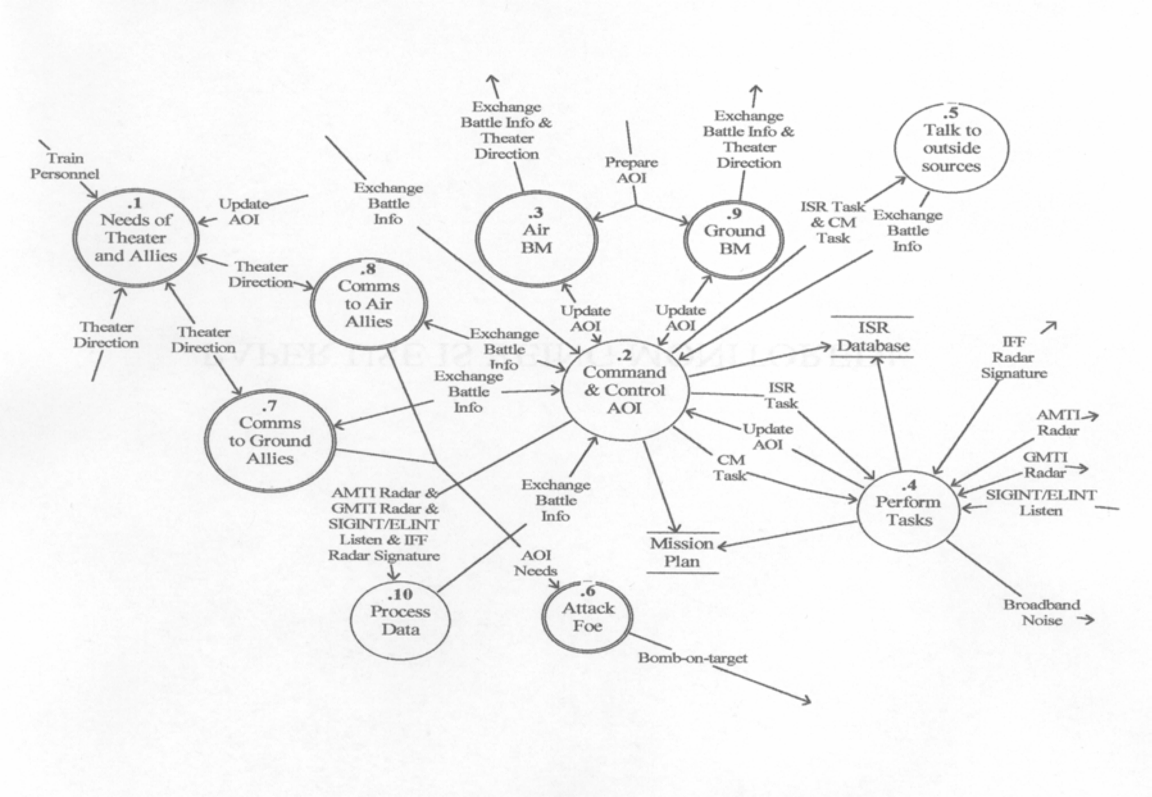

Figure A.2.2. C/DFD: Perform C3CMISR

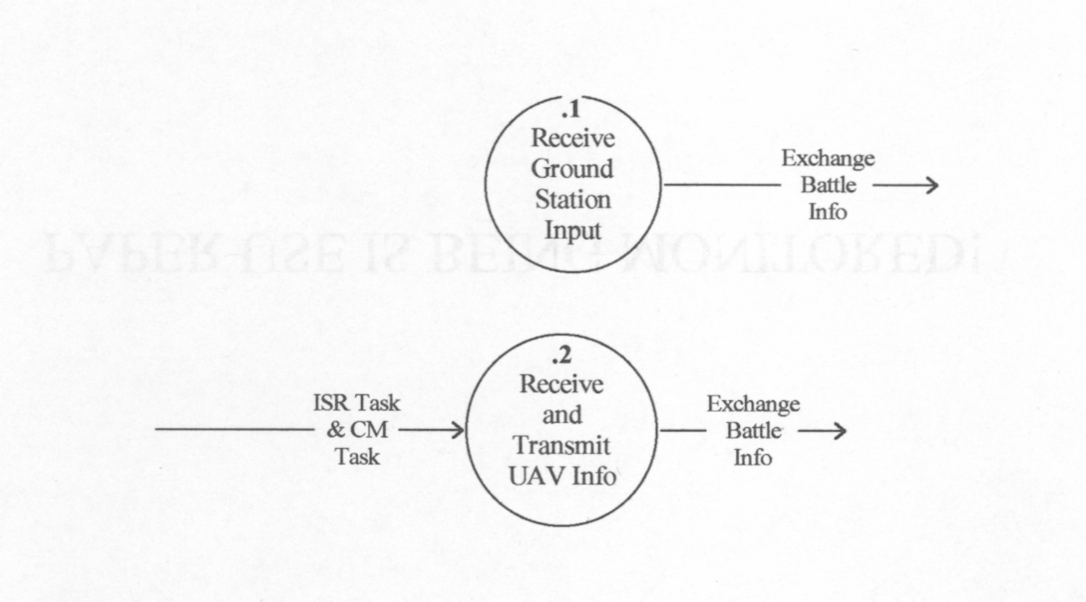

Figure A.2.3. C/DFD: Talk to Outside Sources

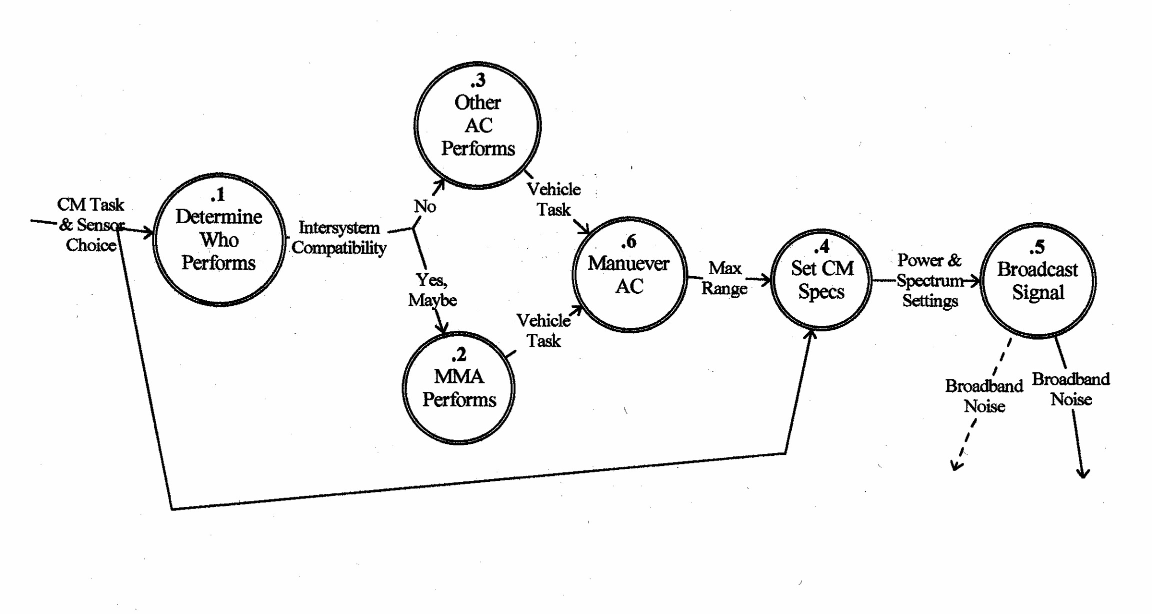

Figure A.2.4. C/DFD: Perform CM Task

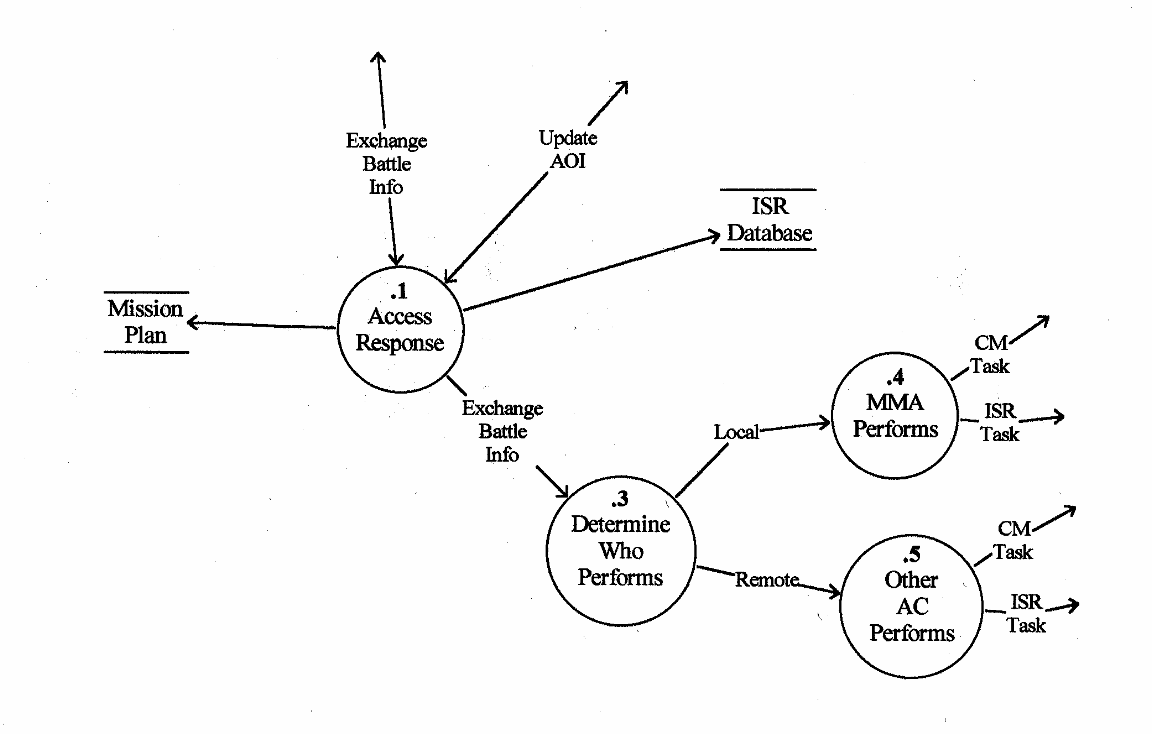

Figure A.2.5. C/DFD: Command and Control AOI

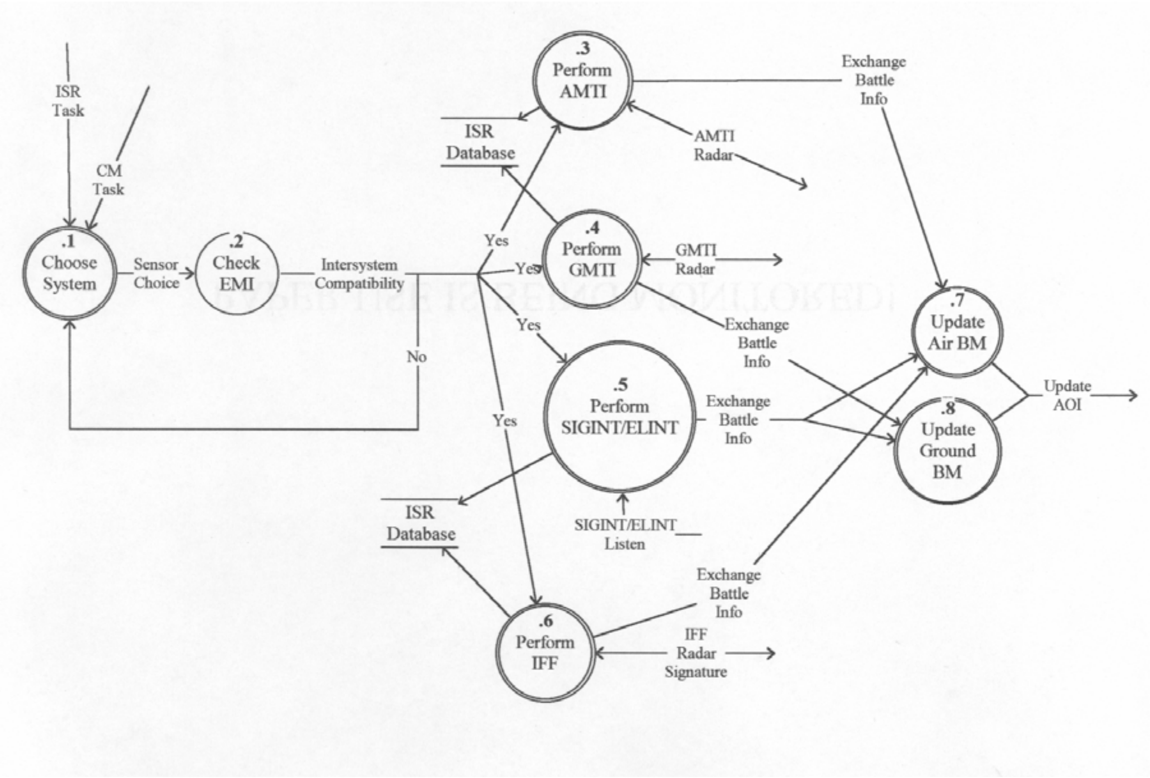

Figure A.2.6. C/DFD: Perform ISR Tasks

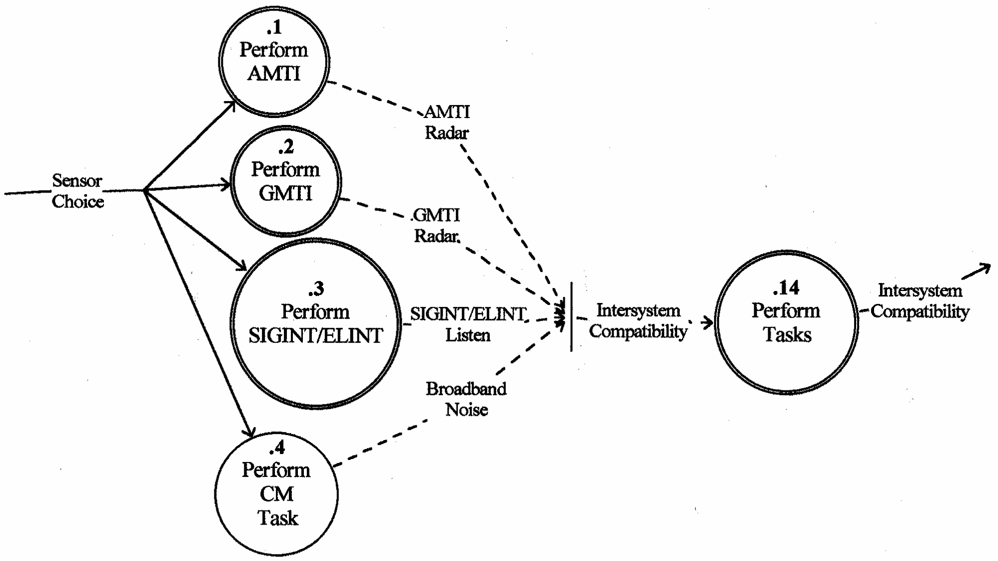

Figure A.2.7. C/DFD: Check EMI

<table>
<tr><th colspan="4">Input</th><th colspan="4">Process</th><th>Output</th></tr>
<tr><th>AMTI Radar</th><th>GMTI Radar</th><th>SIGINT/ELINT Listen</th><th>Broadband Noise</th><th>Perform AMTI</th><th>Perform GMTI</th><th>Perform SIGINT/ELINT</th><th>Perform CM Task</th><th>Intersystem Compatibility</th></tr>
<tr><td>On</td><td colspan="3">Off</td><td>1</td><td></td><td></td><td></td><td>Yes</td></tr>
<tr><td>Off</td><td>On</td><td colspan="2">Off</td><td></td><td>1</td><td></td><td></td><td>Yes</td></tr>
<tr><td colspan="2">Off</td><td>On</td><td>Off</td><td></td><td></td><td>1</td><td></td><td>Yes</td></tr>
<tr><td colspan="3">Off</td><td>On</td><td></td><td></td><td></td><td>1</td><td>Yes</td></tr>
<tr><td colspan="2">On</td><td colspan="2">Off</td><td>1</td><td>1</td><td></td><td></td><td>Yes</td></tr>
<tr><td>On</td><td>Off</td><td>On</td><td>Off</td><td>1</td><td></td><td>1</td><td></td><td>No</td></tr>
<tr><td>Off</td><td>On</td><td>On</td><td>Off</td><td></td><td>1</td><td>1</td><td></td><td>Yes</td></tr>
<tr><td colspan="3">On</td><td>Off</td><td>1</td><td>1</td><td>1</td><td></td><td>No</td></tr>
<tr><td>On</td><td colspan="2">Off</td><td>On</td><td>1</td><td></td><td></td><td>1</td><td>No</td></tr>
<tr><td>Off</td><td>On</td><td>Off</td><td>On</td><td></td><td>1</td><td></td><td>1</td><td>No</td></tr>
<tr><td colspan="2">Off</td><td colspan="2">On</td><td></td><td></td><td>1</td><td>1</td><td>Yes</td></tr>
<tr><td colspan="4">On</td><td>1</td><td>1</td><td>1</td><td>1</td><td>No</td></tr>
</table>

Figure A.2.8. Data Table: Check EMI

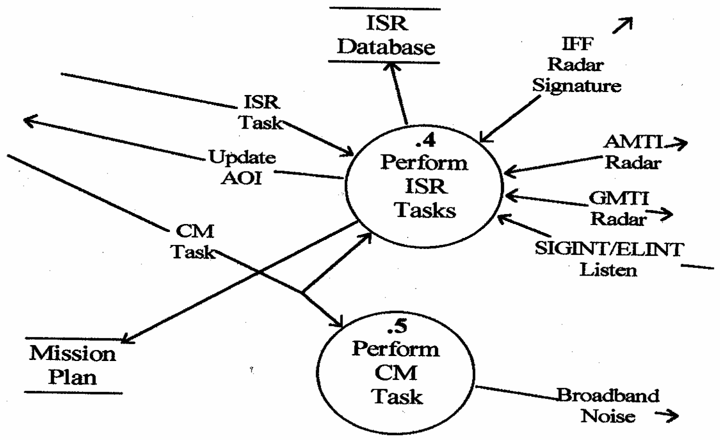

Figure A.2.9. C/DFD: Perform Tasks

Appendix 2.2. Physical Architecture Model

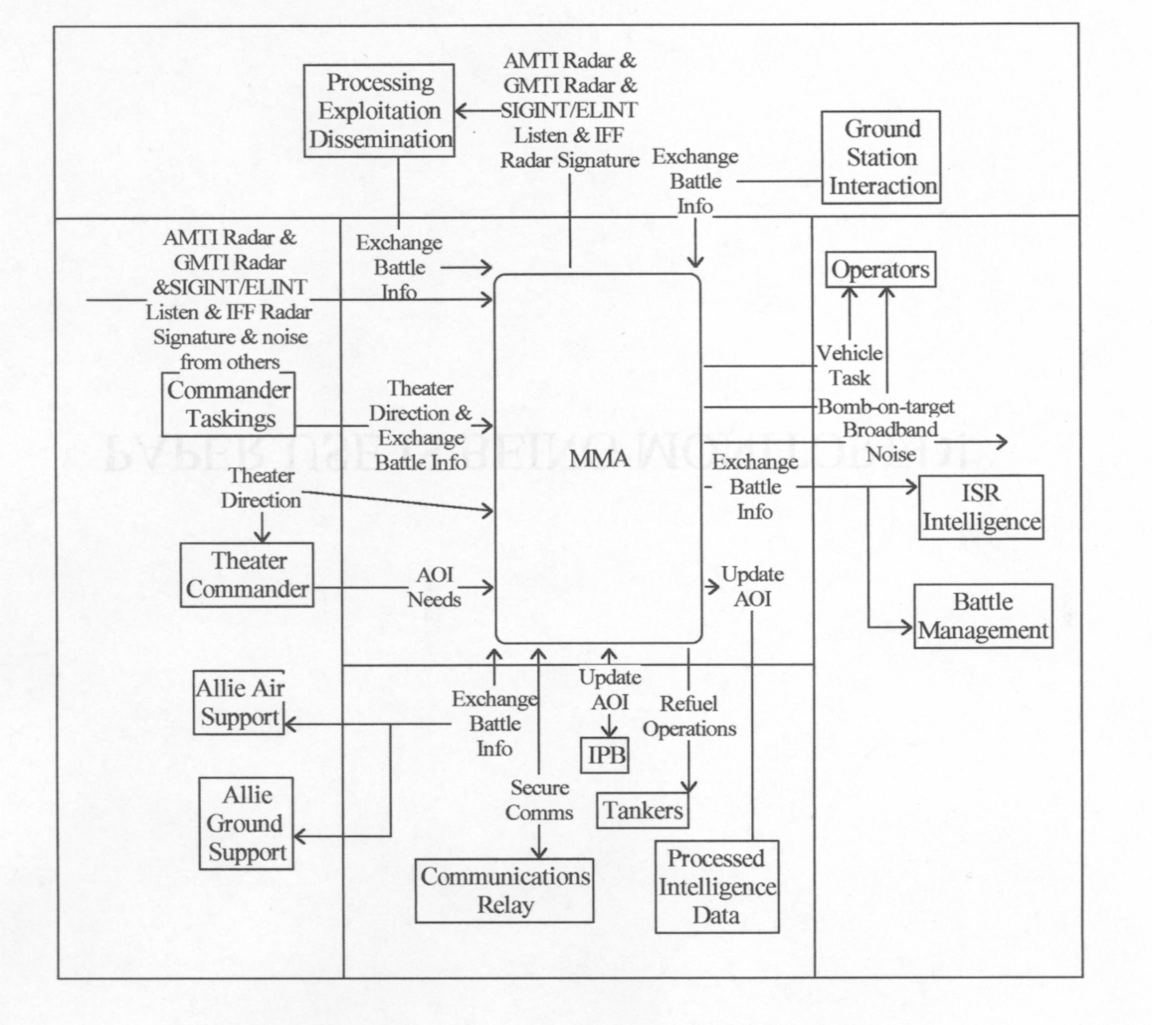

Figure A.2.10. AFD: Perform C3CMISR

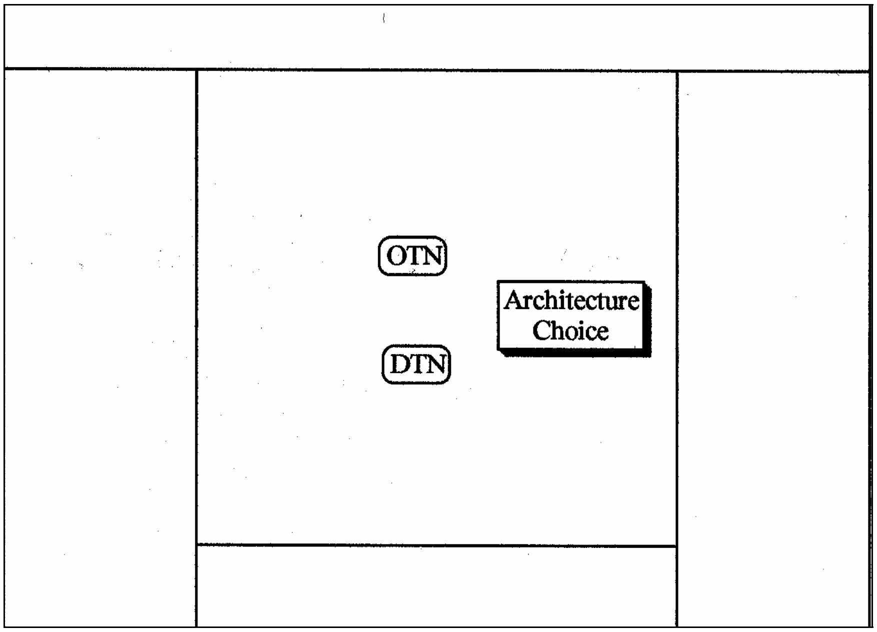

Figure A.2.11. AFD: MMA

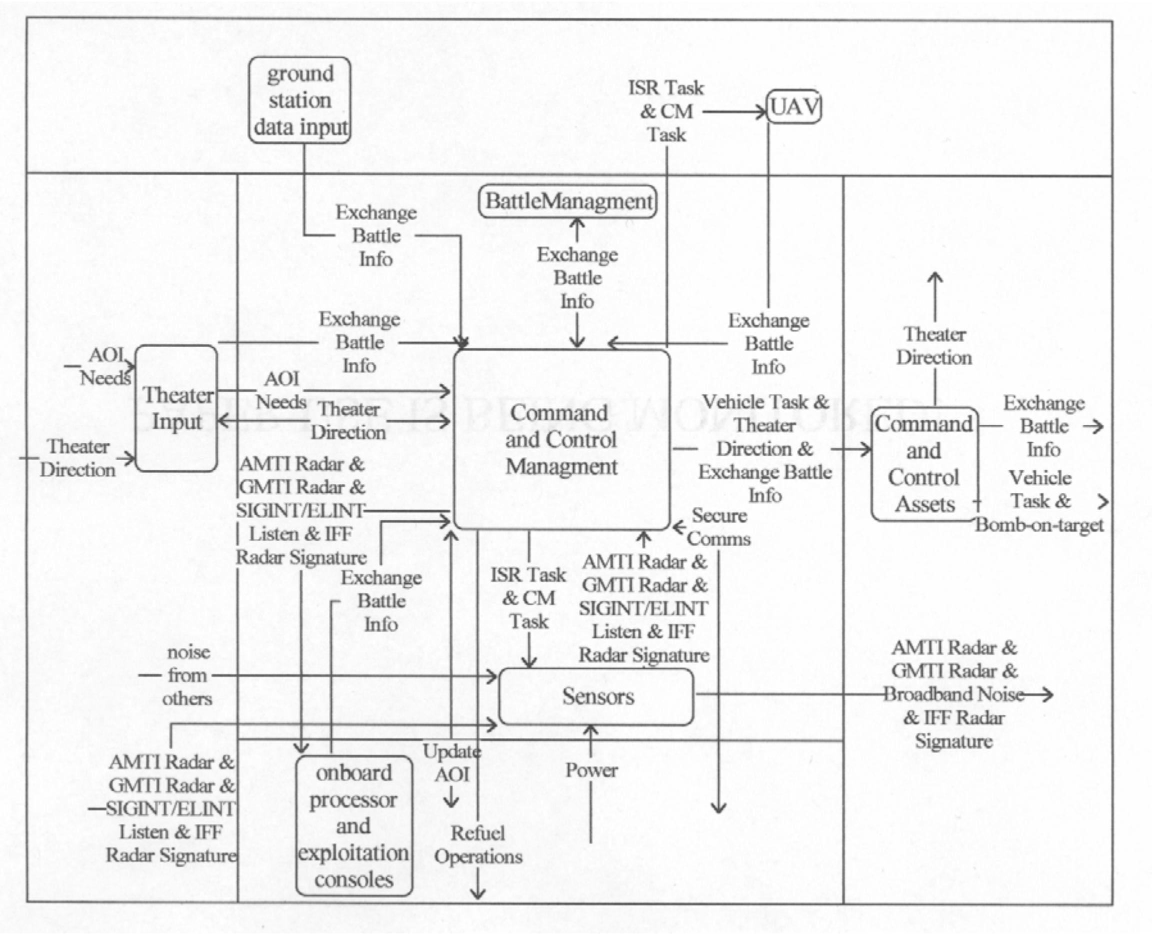

Figure A.2.12. AFD: OTN

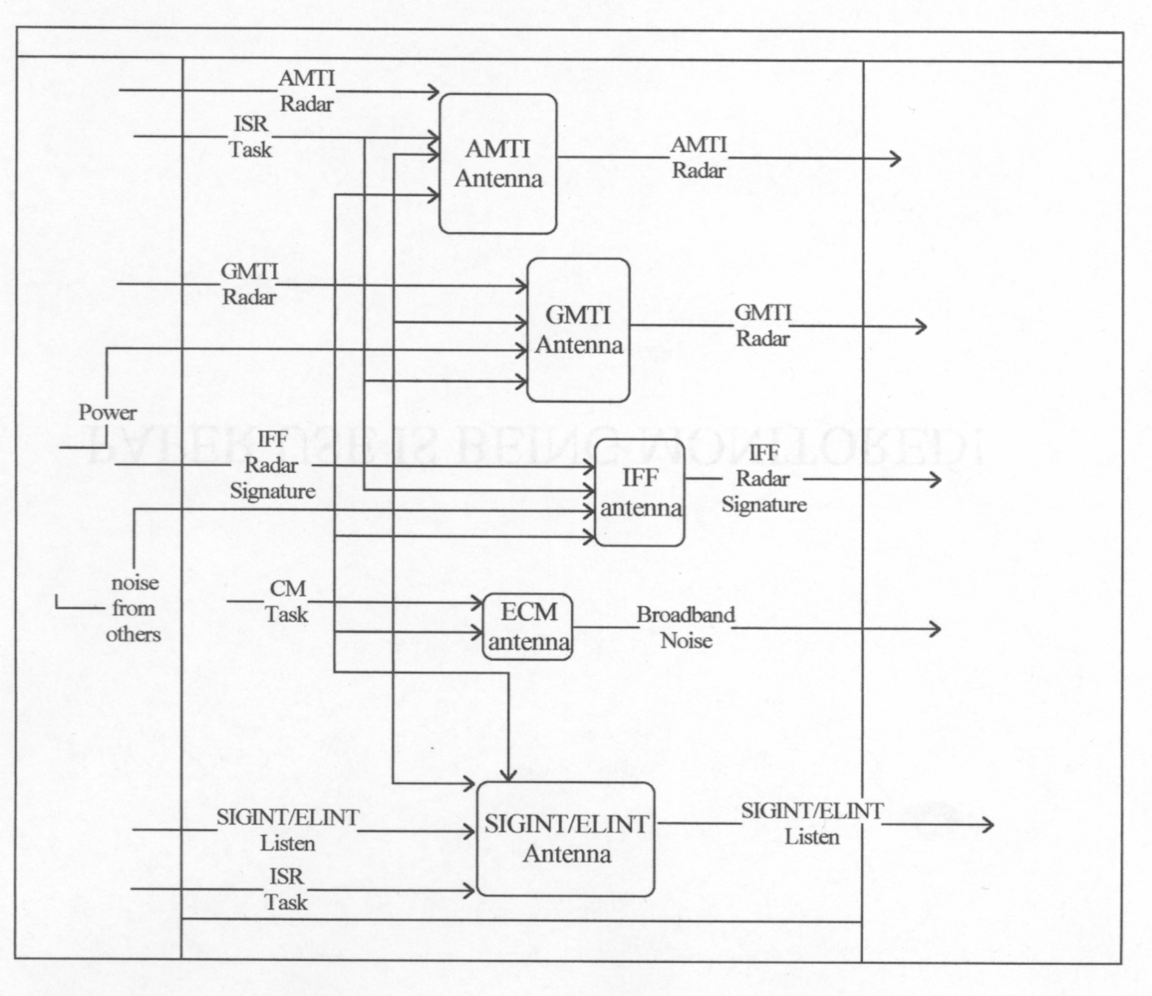

Figure A.2.13. AFD: Sensors

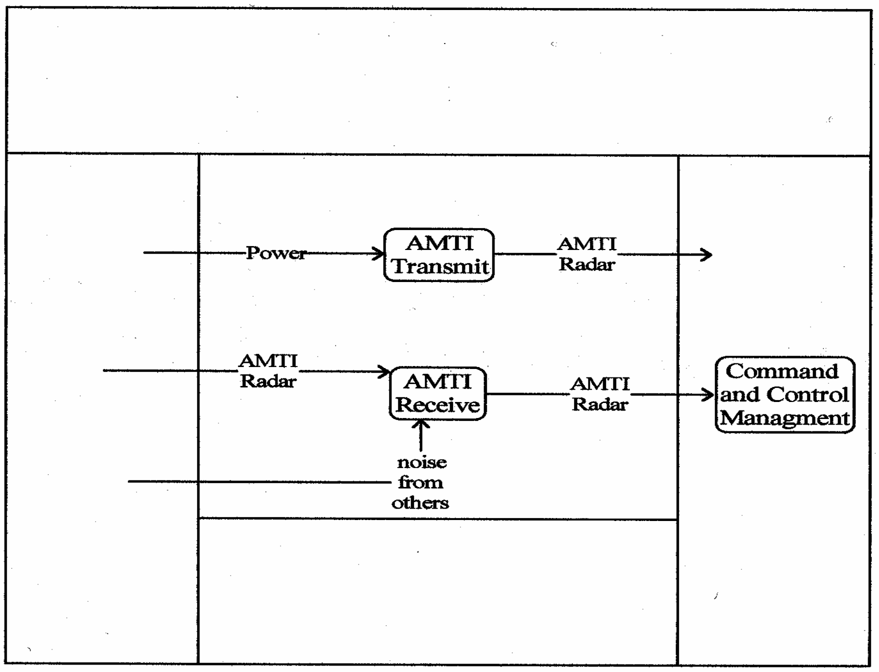

Figure A.2.14. AFD: AMTI Antenna

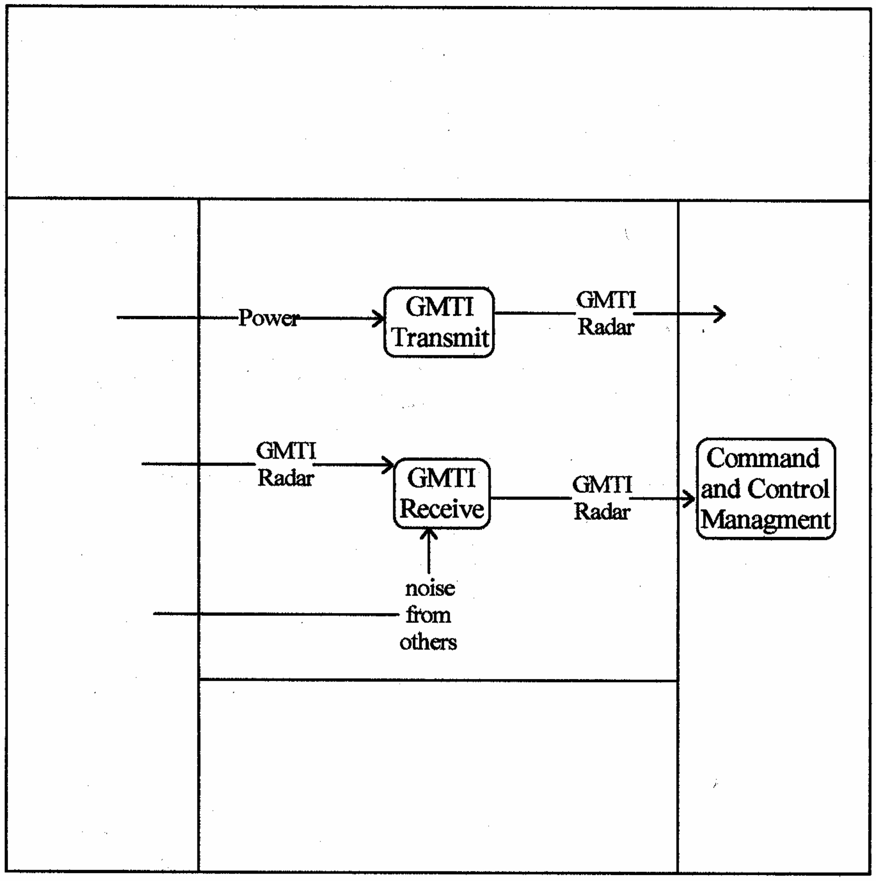

Figure A.2.15. AFD: GMTI Antenna

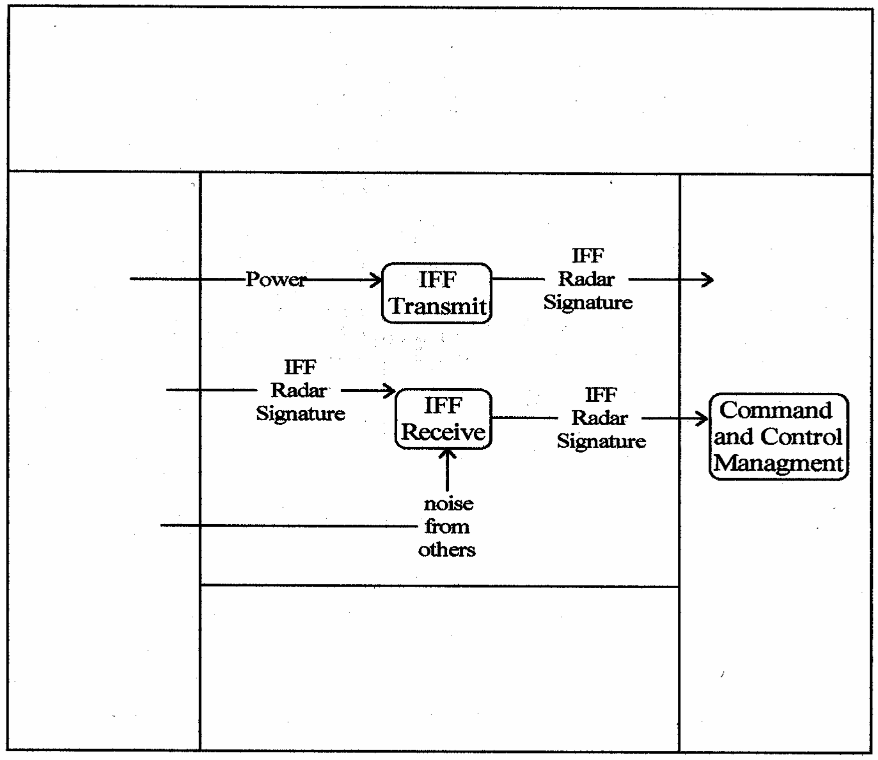

Figure A.2.16. AFD: IFF Antenna

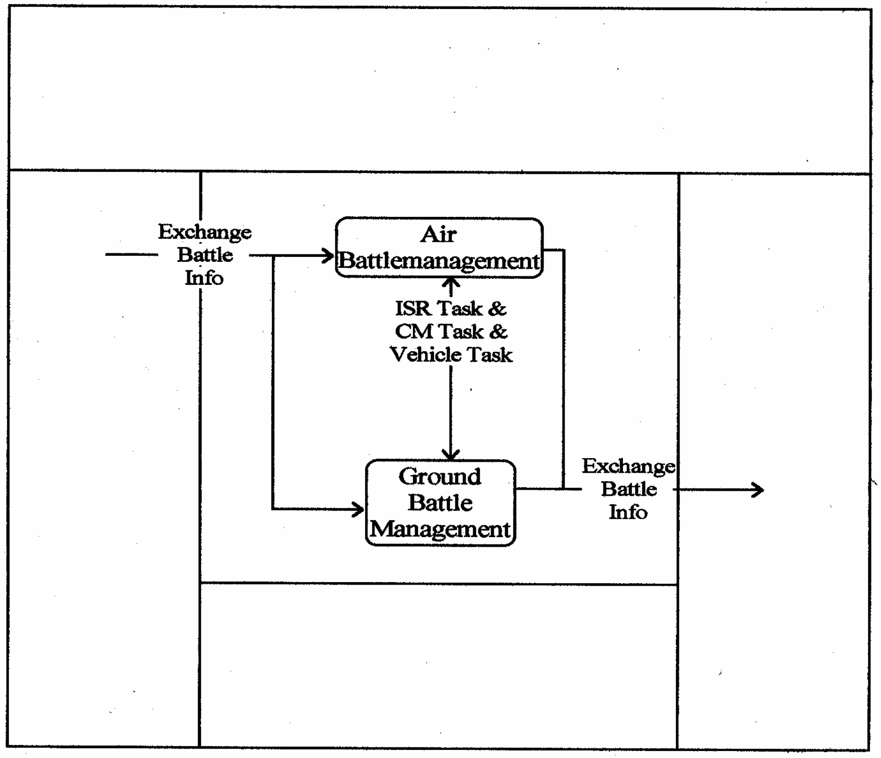

Figure A.2.17. AFD: Battle Management

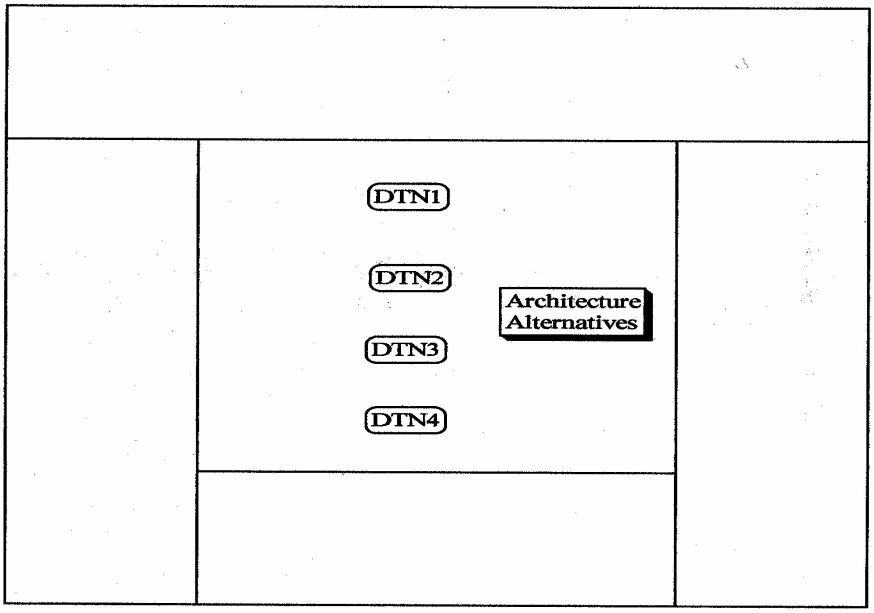

Figure A.2.18. AFD: DTN

Appendix 2.3 Enhanced Model

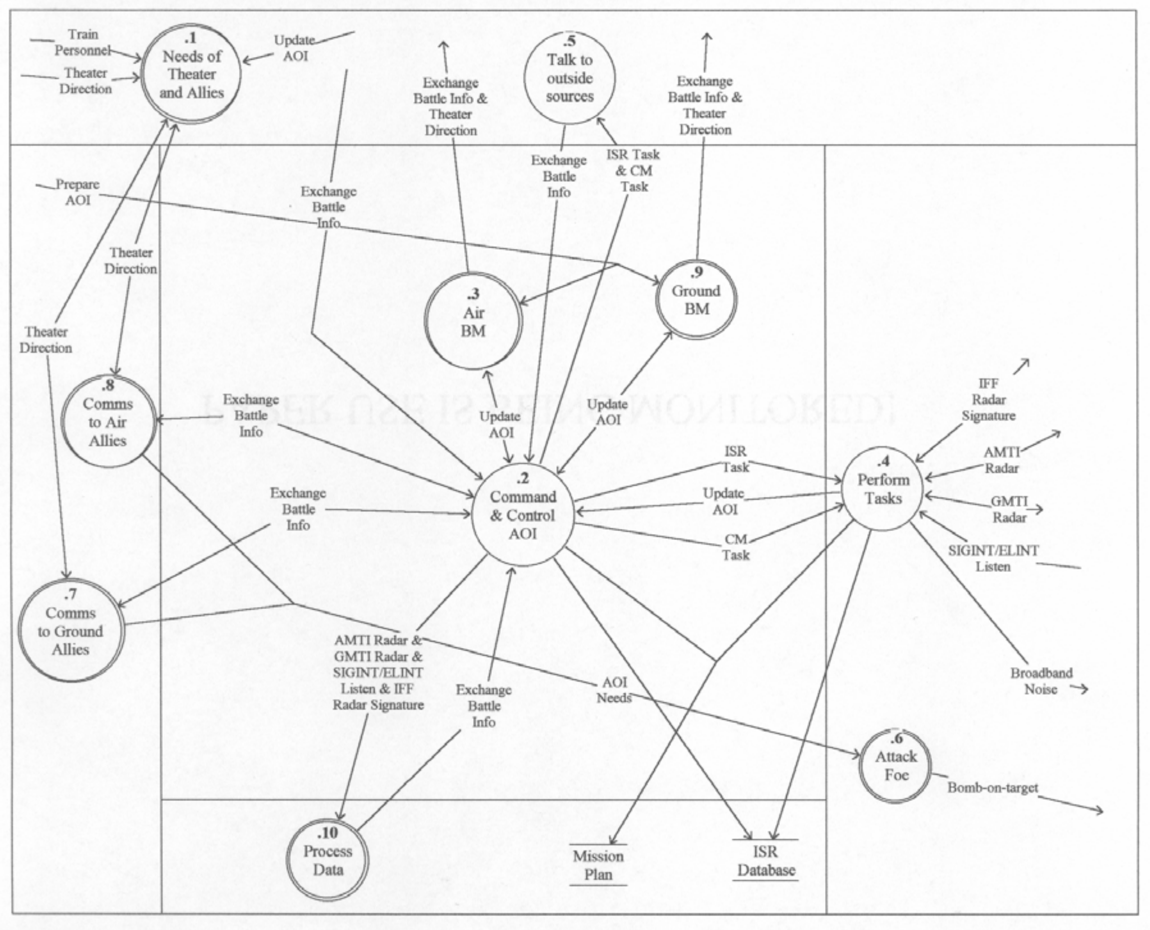

Figure A.2.19. EC/DFD Enhanced Perform C3CMISR

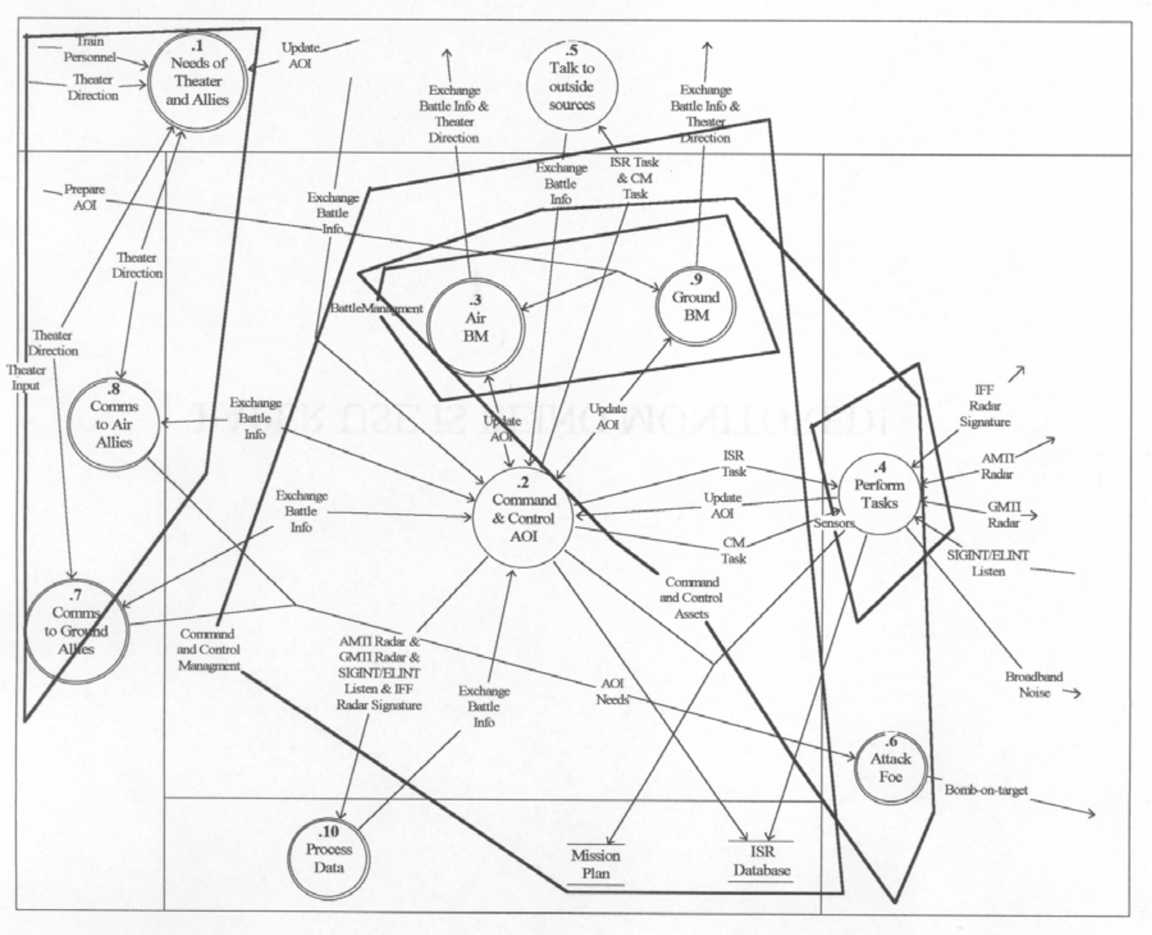

Figure A.2.20. EC/DFD Enhanced Perform C3CMISR with Supperbubbles

Appendix 2.4 Architecture and Requirements Dictionary

Name	**Definition**	**Type**	**Source**	**Destination**
AMTI Radar	*Air Moving Target Indicator Transmit & Receive Active IFF Included *DOMAIN: [On|Off]	Data/ Control	Sensors	C2 Management
			AMTI Receive	C2 Management
			MMA	Processing Exploitation Dissemination
			C2 Management	onboard processor and exploitation consoles
AOI Needs	*Needs requested by the area of interest to include theater commander and allied forces*	Data	Theater Input	C2 Assets
			Theater Input	C2 Management
			Theater Commander	MMA
Bomb-on-target	*Mission tasked to "Kill" aircraft or other source to inflict destructive or non-destructive means upon a foreign system*	Data	MMA	Operators
Broadband Noise	*Broadband Noise from ECM. Noise that is spread throughout a large spectra. *DOMAIN: [On|Off]	Data/ Control		

Name	Definition	Type	Source	Destination
CM Task	*Electronic counter measures tasks *Battlemanagement (BM)	Data	C2 Management C2 Management C2 Management Air BM Ground BM	Sensors C2 Assets UAV Ground BM Air BM

Name	Definition	Type	Source	Destination
Exchange Battle Info	*The exchange of information from or about the battlespace to include ground and air information and data collected from the system or from other sources*	Data	Theater Input	C2Management
			C2 Management	Theater Input
			BM	C2 Management
			C2 Management	BM
			UAV	C2 Management
			Onboard processor and exploitation consoles	C2 Management
			ground station data input	C2Management
			C2 Management	C2 Assets
			Processing Exploitation Dissemination	MMA
			Ground Station Interaction	MMA
			Allie Ground Support	Allie Air Support
			Allie Air Support	Allie Ground
			Allie Ground Support MMA	Support MMA MMA

Name	**Definition**	**Type**	**Source**	**Destination**
GMTI Radar	*Ground Moving Target Indicator Radar Transmit and Receive Active *DOMAIN: [On|Off]	Data/ Control	Sensors GMTI Receive MMA C2 Management	C2 Management C2 Management Processing Exploitation Dissemination onboard processor and exploitation consoles
IFF Radar Signature	*Identification of friend or foe radar signature*	Data	Sensors IFF Receive C2 Management MMA	C2 Management C2 Management onboard processor and exploitation consoles Processing Exploitation Dissemination
Inspection and Repair	*Maintenance. The aircraft is grounded*	Data		
Intersystem Compatibility	*Check for system compatibility. The ability for components to function as expected without hindrance *DOMAIN: [Yes|No|"MAYBE"]	Data/ Control		
ISR Database	*Database containing all spectrum information about the systems on board the aircraft to include range, power, power density spectrum*	Data	C2 Management Sensors C2 Assets	 C2 Management C2 Management

Name	**Definition**	**Type**	**Source**	**Destination**
ISR Task	*Intelligence, surveillance, and reconnaissance task performed by the aircraft sensors or other sensors outside the aircraft *DOMAIN: [True|False]	Data	C2 Management C2 Management C2 Management Air BM Ground BM	Sensors C2 Assets UAV Ground BM Air BM
Local	*The task is performed locally or within the system*	Data		
Max Range	*Maximum range of influence*	Data		
Mission Plan	*The plan of attack developed prior to conflict and updated as needed based on new information exchanged through	Data	C2 Management Sensors C2 Assets	 C2 Management C2 Management
No	TBD	Data		
noise from others	*Noise generated from the environment or outside sources. Intersystem compatibility issue*	Data		
Power	*Power required to sustain the system*	Data		
Prepare AOI	*Preparation for a future battlespace. Used to generate the mission plan*	Data		
Refuel Operations	*Tanker operations for in-air refueling. Increases the total operation time without landing*	Data	MMA	Tankers
Remote	*Operations occurring outside the system*	Data		

Name	**Definition**	**Type**	**Source**	**Destination**
Secure Comms	*Secure communications to inside or outside the system*	Data	Communications Relay	MMA
			MMA	Comms Relay
Sensor Choice	*Choice of system function to perform designated operation *DOMAIN: ["AMTI"|"GMTI"|"SIGINT/ELINT"|"EM"|"A-GMTI"|"AMTI-SIG"|"GMTI-SIG"|"GMTI-IFF"|"SIG-IFF"|"A-GMTI-SIG-IFF"]	Data		
SIGINT/ ELINT Listen	*SIGINT/ELINT Listen Active *DOMAIN: [On|Off]	Data/ Control	C2 Management	onboard processor and exploitation consoles
			Sensors	C2 Management
			MMA	Processing Exploitation Dissemination
Spectrum Settings	*Power density spectrum to be used by a function/operation/antenna*	Data		
Theater Direction	*Direction given to the theater based on battlemangement information*	Data	Theater Input	
			Theater Input	C2 Management
			C2 Management	Theater Input
			C2 Management	C2 Assets
			Theater Commander	MMA
			MMA	Theater Commander
			Commander Taskings	MMA

Name	**Definition**	**Type**	**Source**	**Destination**
Train Personnel	*Education and training of personnel onboard and offboard the aircraft includes operation of system, data processing & exploitation, report generation, maintenance, etc.*	Data		
Update AOI	*Updates to the area of interest based on battlespace information*	Data	C2 Management	
			C2 Management	C2 Assets
			C2 Management	BM
			C2 Assets	C2 Management
			BM	C2 Management
			Sensors	C2 Management
			MMA	Processed Intelligence Data
			IPB	MMA
			MMA	IPB
Vehicle Task	*tasks given to other aircraft or systems in the environment. UAVs are an example.*	Data	C2 Management	C2 Assets
			MMA	Operators
			Air BM	Ground BM
			Ground BM	Air BM

Appendix 3.1. Automated EMC/I Program Analysis (Wilson: 12)

Table A.3.1 Automated EMC/I Program Analysis (Wilson: 12)

Program Name (Developer)	**Modeling Attributes**					**General Comments on Program Suitability**
	Coupling Path Model	**Antenna Model**	**Mismatch Considerations**	**Emission Spectrum**	**Receiver Susceptibility**	
IEMCAP Intrasystem Electromagnetic Compatibility Analysis Program (Rome Air Development Center, USAF)	Uses an infinite cylinder truncated at one end by a cone. Includes wing and off wing fuselage models.	Both low and high gain antenna models, but no frequency dependence.	Conceptually, off line computations on empirical data can be included at attenuation of an in-line filter model.	Both functional and non-functional spectral models for several types of modulation.	Arbitrary and MIL STD selectivity curves based on power threshold and integrated margin.	Would be a good program for computing RF system antenna coupled interferences if models for gain pattern vs. frequency and in-line filter/VSWR considerations are added.
SEMCAP Specification and Electromagnetic Compatibility Analysis Program (TRW Systems Group)	Off-line computation or empirical data must be supplied. Only field transfer functions are available.	Off-line computations or empirical data on both antenna-to-field and field-to-antenna transfer function.	Conceptually, could be included in a receptor filter card using data from separate off-line analysis.	Limited spectral types for RF systems.	Limited definition of receiver selectivity, uses integrated voltage referenced to a threshold for susceptibility criteria.	Excellent program for interference in cables wire routing, limited applicability to RF system antenna coupled interferences.
DECAL Design Communications Algorithm (Naval Ocean Systems Center, Navy)	No coupling path model is provided, instead, antenna deficiency (required isolation) is the primary output of the program.	Antenna models are not necessary since required antenna isolation is the output of the program.	No apparent considerations of mismatch is included. Coupler insertion losses, however, are included.	Detailed consideration of functional emission spectrum, spurious signals, and broadband transmitter noise.	Detailed consideration of spurious responses of receiver. Receiver impedance versus frequency is not included.	Good detailed program, however, the issue of antenna coupling is not addressed. Evidently, antenna coupling is left entirely to off-line analysis.

	Modeling Attributes					
Program Name (Developer)	**Modeling Attributes**	**Program Name (Developer)**	**Modeling Attributes**	**Program Name (Developer)**	**Modeling Attributes**	**General Comments on Program Suitability**
COSAM Co-Site Analysis Model (Electromagnetic Compatibility Analysis Center, DOD)	No coupling models other than free space, far field gain models.	Simple user supplied antenna gain models.	Transmission line impedance mismatch effects are included.	Detailed consideration of functional type of interference signal. No consideration of spurious emissions in models.	No model for receiver impedance or threshold effects at front-end (Note: This is not the program's purpose) Spurious models are included.	Primarily a probability of interference program using detailed models for (S+I)/N of receiver demodulation processes. Antenna gain models may not be entirely accurate.
AFMAP AWACS Frequency Analysis Management Program (Boeing Company)	Uses an infinite cylinder model. Does not include capabilities for off fuselage models.	Uses generic monopole antenna models and specialized, user developed, subroutines for other antennas. Can include frequency dependant gains.	Includes separate models for VSR and in-line filters. Data, however, must be known form off-line sources.	Detailed discrete voltage spectral models form data computed off-line.	General selectivity cure based on power threshold.	Good program for RF subsystem antenna coupled interference. AFMAP primarily acts as a data handler/computational aid and does not include specific models.
SCAPS Scattering and Propagation Simulator (General Electric)	Can account for interposed objects in a cluttered environment but offers on specific models.	Antennas are modeled as a coupled pair with scattering matrices. Assumes conjugate match conditions.	Capable of including all transmission system losses. No specific models are available, these must be developed on an individual basis.	General discrete emission spectra specified by user.	Represents receiver as frequency dependent reflection coefficient.	Very good systematic approach (scattering matrix) to antenna coupling including many affects. Models for specific interactions are, however, lacking.

Appendix 3.2. Preliminary Electromagnetic Compatibility Analysis

Input Parameters

Table A.3.2. System Parameters

Co-Site transmitters and receivers			AMTI-RX GMTI-TX	GMTI-RX AMTI-TX	GMTI-RX IFF-TX	IFF-RX GMTI-TX
TX Frequency	fT	MHz	10000	1500	1030	10000
TX Power Output	PT	dBm	200	200	200	200
TX Antenna Gain	GT	dBm	60	60	25	60
TX Bandwidth	TBW	MHz	10	10	3	10
RX Frequency	fR	MHz	1500	10000	10000	1090
RX Intermediate Frequency	IF	MHz	60	100	100	70
RX Local Oscillator	LO	MHz	1560	10100	10100	1160
RX Fundamental Sensitivity	PR	dBm	-100	-100	-100	-84
RX Antenna Gain	GR	dBm	60	60	60	25
RX Bandwidth	RBW	MHz	10	10	10	8
Coverage		nmi	250	200	256	200
Distance between TX & RX	dTR	km	0.040889	0.040889	0.040889	0.040889
Distance between TX & RX	dTR	miles	2.54E-02	2.54E-02	2.54E-02	2.54E-02
Length between sensors on aircraft		km	4.00E-02	4.00E-02	4.00E-02	4.00E-02
Height between sensors (radius of A/C)		km	5.40E-03	5.40E-03	5.40E-03	5.40E-03

Co-Site transmitters and receivers			AMTI-TX HB-RX	AMTI-TX LB-RX	AMTI-TX SHF-RX	GMTI-TX HB-RX	GMTI-TX LB-RX	GMTI-TX SHF-RX
TX Frequency	fT	MHz	1500	1500	1500	10000	10000	10000
TX Power Output	PT	dBm	200	200	200	200	200	200
TX Antenna Gain	GT	dBm	60	60	60	60	60	60
TX Bandwidth	TBW	MHz	10	10	10	10	10	10
RX Frequency	fR	MHz	17	0.08	18000000	17	0.08	18000000
RX Intermediate Frequency	IF	MHz	5	0.03	20000000	5	0.03	20000000
RX Local Oscillator	LO	MHz	22	0.11	38000000	22	0.11	38000000
RX Fundamental Sensitivity	PR	dBm	-50	-50	-50	-50	-50	-50
RX Antenna Gain	GR	dBm	25	25	50	25	25	50
RX Bandwidth	RBW	MHz	25	100	30000000	25	100	30000000
Coverage		nmi	130	130	130	130	130	130
Distance between TX & RX	dTR	km	0.040889	0.040889	0.040889	0.040889	0.0400211	0.0400211
Distance between TX & RX	dTR	miles	2.54E-02	2.54E-02	2.54E-02	2.54E-02	2.49E-02	2.49E-02
Length between sensors on aircraft		km	4.00E-02	4.00E-02	4.00E-02	0.00E+00	0.00E+00	0.00E+00
Height between sensors (radius of A/C)		km	8.28E-04	8.28E-04	8.28E-04	0.004572	0.004572	0.004572

“Short Form Prediction” Tool

‘Quick-Look’ Analysis and Results

Table A.3.3.a. AMTI and GMTI Bandwidth Definition

				Generic	Make BW smaller work? Use defined BW in Parameters	Generic	Make BW smaller work? Use defined BW in Parameters
	Transmitter and Receiver Frequency Limits				**IF fST(min) > fSR(max)**		**IF fST(max) < fSR(min)**
Line	Parameter	Symbol	Equation - if needed	AMTI-RX GMTI-TX	AMTI-RX GMTI-TX	GMTI-RX AMTI-TX	GMTI-RX AMTI-TX
1	TX fundamental Freq	f OT		10000	10000	1500	1500
2	TX Minimum Spurious Freq	f ST (min)	0.1*f OT	1000	9995	150	1495
3	TX Maximum Spurious Freq	f ST (max)	10*F OT	100000	10005	15000	1505
4	RX fundamental Freq	f OR		1500	1500	10000	10000
5	RX Minimum Spurious Freq	f SR (min)	0.1*f OR	150	1495	1000	9995
6	RX Maximum Spurious Freq	f SR (max)	10*F OR	15000	1505	100000	10005
7	TX-RX Max Allowable Freq Separation for Fundamental EMI	delta f (max)	0.2*f OR	300	300	2000	2000

Table A.3.3.b. AMTI and GMTI EMC ‘Quick-Look’ Results

	Applicability of Four EMI Prediction Cases						
	SIM*: TX Harmonic & RX Spurious*						
			f ST (min) < f SR (max)	Yes	No	Yes	Yes
			f ST (max) > f SR (min)	Yes	Yes	Yes	No
	If NO then there is not an EMI Problem = STOP		SIM EMI Problem?	**Yes**	**No**	**Yes**	**No**

	RIM*: TX Harmonic & RX Fundamental*						
			f ST (min) < f OR	Yes	No	Yes	Yes
			f ST (max) > f OR	Yes	Yes	Yes	No
	If NO then skip RIM; enter N/A on line 38		RIM EMI Problem?	**Yes**	**No**	**Yes**	**No**

	TIM*: TX Fundamental & RX Spurious*						
			f OT < f SR (max)	Yes	No	Yes	Yes
			f OT > f SR (min)	Yes	Yes	Yes	No
	If NO, skip TIM; enter N/A on line 38		TIM EMI Problem?	**Yes**	**No**	**Yes**	**No**
	IF Both RIM & TIM were N/A, skip FIM and enter N/A on line 38						

	FIM*: TX Fundametnal & RX Fundamental*						
			abs(f OT - f OR) < delta f (max)	No	No	No	No
	If No, skip FIM; enter N/A on line 38		FIM EMI Problem?	No	No	No	No

Table A.3.4.a. GMTI and IFF Bandwidth Definition

				Generic	Make BW smaller work? Use defined BW in Parameters	Generic	Make BW smaller work? Use defined BW in Parameters
	Transmitter and Receiver Frequency Limits				**No**		**No**
Line	Parameter	Symbol	Equation - if needed	GMTI-RX IFF-TX	GMTI-RX IFF-TX	IFF-RX GMTI-TX	IFF-RX GMTI-TX
1	TX fundamental Freq	f OT		1030	1030	10000	10000
2	TX Minimum Spurious Freq	f ST (min)	0.1*f OT	103	1028.5	1000	10000
3	TX Maximum Spurious Freq	f ST (max)	10*F OT	10300	1031.5	100000	10000
4	RX fundamental Freq	f OR		10000	10000	1090	1090
5	RX Minimum Spurious Freq	f SR (min)	0.1*f OR	1000	9995	109	1090
6	RX Maximum Spurious Freq	f SR (max)	10*F OR	100000	10005	10900	1090
7	TX-RX Max Allowable Freq Separation for Fundamental EMI	delta f (max)	0.2*f OR	2000	2000	218	218

Table A.3.4.b. GMTI and IFF EMC 'Quick-Look' Results

	Applicability of Four EMI Prediction Cases						
	SIM: *TX Harmonic & RX Spurious*						
			f ST (min) < f SR (max)	Yes	Yes	Yes	Yes
			f ST (max) > f SR (min)	Yes	Yes	Yes	Yes
	If NO then there is not an EMI Problem = STOP		SIM EMI Problem?	**Yes**	**Yes**	**Yes**	**Yes**

	RIM: *TX Harmonic & RX Fundamental*						
			f ST (min) < f OR	Yes	Yes	Yes	Yes
			f ST (max) > f OR	Yes	Yes	Yes	Yes
	If NO then skip RIM; enter N/A on line 38		RIM EMI Problem?	**Yes**	**Yes**	**Yes**	**Yes**

	TIM: *TX Fundamental & RX Spurious*						
			f OT < f SR (max)	Yes	Yes	Yes	Yes
			f OT > f SR (min)	Yes	Yes	Yes	Yes
	If NO, skip TIM; enter N/A on line 38		TIM EMI Problem?	**Yes**	**Yes**	**Yes**	**Yes**
	IF Both RIM & TIM were N/A, skip FIM and enter N/A on line 38						

	FIM: *TX Fundametnal & RX Fundamental*						
			abs(f OT - f OR) < delta f (max)	No	No	No	No
	If No, skip FIM; enter N/A on line 38		FIM EMI Problem?	No	No	No	No

Table A.3.5.a. AMTI and HB, LB, and SHF Bandwidth Definition

				Generic	Make BW smaller work?	Generic	Generic
	Transmitter and Receiver Frequency Limits				**No**		
Line	Parameter	Symbol	Equation - if needed	AMTI-TX HB-RX	AMTI-TX HB-RX	AMTI-TX LB-RX	AMTI-TX SHF-RX
1	TX fundamental Freq	f OT		1500	1500	1500	1500
2	TX Minimum Spurious Freq	f ST (min)	0.1*f OT	150	1500	150	150
3	TX Maximum Spurious Freq	f ST (max)	10*F OT	15000	1500	15000	15000
4	RX fundamental Freq	f OR		17	17	0.08	18000000
5	RX Minimum Spurious Freq	f SR (min)	0.1*f OR	1.7	17	0.008	1800000
6	RX Maximum Spurious Freq	f SR (max)	10*F OR	170	17	0.8	180000000
7	TX-RX Max Allowable Freq Separation for Fundamental EMI	delta f (max)	0.2*f OR	3.4	3.4	0.016	3600000

Table A.3.5.b. AMTI and HB, LB, and SHF EMC ‘Quick-Look’ Results

	Applicability of Four EMI Prediction Cases						
	SIM*: TX Harmonic & RX Spurious*						
			f ST (min) < f SR (max)	Yes	Yes	No	Yes
			f ST (max) > f SR (min)	Yes	Yes	Yes	No
	If NO then there is not an EMI Problem = STOP		SIM EMI Problem?	**Yes**	**Yes**	**No**	**No**

	RIM*: TX Harmonic & RX Fundamental*						
			f ST (min) < f OR	No	No	No	Yes
			f ST (max) > f OR	Yes	Yes	Yes	No
	If NO then skip RIM; enter N/A on line 38		RIM EMI Problem?	**No**	**No**	**No**	**No**

	TIM*: TX Fundamental & RX Spurious*						
			f OT < f SR (max)	No	No	No	Yes
			f OT > f SR (min)	Yes	Yes	Yes	No
	If NO, skip TIM; enter N/A on line 38		TIM EMI Problem?	**No**	**No**	**No**	**No**
	IF Both RIM & TIM were N/A, skip FIM and enter N/A on line 38						

	FIM*: TX Fundametnal & RX Fundamental*						
			abs(f OT - f OR) < delta f (max)	No	No	No	No
	If No, skip FIM; enter N/A on line 38		FIM EMI Problem?	No	No	No	No

Table A.3.6 GMTI and HB, LB, and SHF EMC Bandwidth Definition and 'Quick-Look' Results

	Transmitter and Receiver Frequency Limits					
Line	Parameter	Symbol	Equation - if needed	GMTI-TX HB-RX	GMTI-TX LB-RX	GMTI-TX SHF-RX
1	TX fundamental Freq	f OT		10000	10000	10000
2	TX Minimum Spurious Freq	f ST (min)	0.1*f OT	1000	1000	1000
3	TX Maximum Spurious Freq	f ST (max)	10*F OT	100000	100000	100000
4	RX fundamental Freq	f OR		17	0.08	18000000
5	RX Minimum Spurious Freq	f SR (min)	0.1*f OR	1.7	0.008	1800000
6	RX Maximum Spurious Freq	f SR (max)	10*F OR	170	0.8	180000000
7	TX-RX Max Allowable Freq Separation for Fundamental EMI	delta f (max)	0.2*f OR	3.4	0.016	3600000

	Applicability of Four EMI Prediction Cases					
	SIM*: TX Harmonic & RX Spurious*					
			f ST (min) < f SR (max)	No	No	Yes
			f ST (max) > f SR (min)	Yes	Yes	No
	If NO then there is not an EMI Problem = STOP		SIM EMI Problem?	**No**	**No**	**No**

	RIM*: TX Harmonic & RX Fundamental*					
			f ST (min) < f OR	No	No	Yes
			f ST (max) > f OR	Yes	Yes	No
	If NO then skip RIM; enter N/A on line 38		RIM EMI Problem?	**No**	**No**	**No**

	TIM*: TX Fundamental & RX Spurious*					
			f OT < f SR (max)	No	No	Yes
			f OT > f SR (min)	Yes	Yes	No
	If NO, skip TIM; enter N/A on line 38		TIM EMI Problem?	**No**	**No**	**No**
	IF Both RIM & TIM were N/A, skip FIM and enter N/A on line 38					

	FIM*: TX Fundametnal & RX Fundamental*					
			abs(f OT - f OR) < delta f (max)	No	No	No
	If No, skip FIM; enter N/A on line 38		FIM EMI Problem?	No	No	No

Table A.3.7. AMTI and GMTI Amplitude Culling

Amplitude and Frequency Culling

					AMTI-RX GMTI-TX				GMTI-RX AMTI-TX			
Line	Parameter	Symbol	Unit	Recommended Value/Equation If Needed	FIM	TIM	RIM	SIM	FIM	TIM	RIM	SIM
	AMPLITUDE CULLING				NA				NA			
8	TX Power	PT (f OT)	dBm			200	XXX	XXX		200	XXX	XXX
9	TX Spurios Power Output	PT (f ST)	dBm	PT(f OT)-60dB	XXX	XXX	140	140	XXX	XXX	140	140
10	TX Antenna Gain in RX Direction	GTR (f)	dB	or 0dB		0	0	0		0	0	0
11	RX Antenna Gain in TX Direction	GRT (f)	dB	or 0dB		0	0	0		0	0	0
12	Propagation Loss Using Freq No.	L			#1	#1	#4	#2	#1	#1	#4	#2
			MHz			10000	1500	1000		1500	10000	150
	Loss from Fig No. 2.7, (pg2.36,Vol7) Duff (Function of freq, distance)		dB	all negative		82	64	61		64	82	44
13	Unintentional Power Available	PA (f)	dBm	PT + L	0	282	204	201	0	264	222	184
14	RX Fundamental Susceptibility	PR (f OR)	dBm	sensitivity		XXX	-100	XXX		XXX	-100	XXX
15	RX Spurious Suscept	PR (f SR)	dBm	PR (f OR) + 80dB	XXX	-20	XXX	-20	XXX	-20	XXX	-20
16	Preliminary EMI Prediction		dB	line 13-14 or 13-15	0	302	304	221	0	284	322	204

IF EMI margin < -10 dB, EMI Highly Improbable = STOP
IF EMI margin > -10 dB, Start Frequency Culling

Table A.3.8.a. AMTI and GMTI Frequency Culling

					AMTI-RX GMTI-TX				GMTI-RX AMTI-TX			
Line	Parameter	Symbol	Unit	Recommended Value/Equation If Needed	FIM	TIM	RIM	SIM	FIM	TIM	RIM	SIM
	FREQUENCY CULLING											
	Bandwidth Correction											
17	TX PRF (if pulse)		pps			100	100	100		100	100	100
18	TX Bandwidth	BT		2/PI * t if pulse; t=width		6.366	6.37	6.37		6.366	6.366	6.37
19	RX Bandwidth	BR				10	10	10		10	10	10
20	Adjustment	lines 17 to 19	dB	Use Fig 2.8/2.9		-92	-92	-92		-92	-92	-92
21	Bandwidth Corrected	EMI Margin	dB	line 16+20	0	210	212	129	0	192	230	112
	(BT+BR)/2				####	8.183	8.18	8.18	###	8.183	8.183	8.18
	IF EMI MARGIN <= -10 dB, EMI HIGHLY IMPROBABLE = STOP											

Table A.3.8.b. AMTI and GMTI Frequency Correction

					AMTI-RX GMTI-TX				GMTI-RX AMTI-TX			
	Frequency Correction											
22	RX Local Oscillator Frequency	f LO	dBm			1560				10100		
23	RX Intermediate Frequency	f IF	dBm			60				100		
24	TX-RX Freq Separation:			delta f=abs((1)-(4)		XXX	XXX	XXX		XXX	XXX	XXX
25	delta f > (BT+BR)/2			line (24), fig 2.10		XXX	XXX	XXX		XXX	XXX	XXX
26	f OT/ f LO +/- f IF to nearest integer				XXX	6	XXX	XXX	XXX	0	XXX	XXX
27	multiply lines (22) & (26)		MHz		XXX	9360	XXX	XXX	XXX	0	XXX	XXX
28	delta f =abs((1)-(23)-(27))				XXX	732	XXX	XXX	XXX	1592	XXX	XXX
28	delta f =abs((1)+(23)-(27))				XXX	548	XXX	XXX	XXX	1408	XXX	XXX
29	select smaller delta f from (28)		MHz		XXX	548	XXX	XXX	XXX	1408	XXX	XXX
30	delta f>(BT+BR)/2		dB	line (29), fig 2.10	XXX	-100	XXX	XXX	XXX	-100	XXX	XXX
31	calculate f OR/f OT to nearest integer				XXX	XXX	0	XXX	XXX	XXX	7	XXX
32	multiply lines (1) X (31)		MHz		XXX	XXX	0	XXX	XXX	XXX	10500	XXX
33	delta f=abs((4)-(32))		MHz		XXX	XXX	1500	XXX	XXX	XXX	500	XXX
34	delta f > (BT+BR)/2		dB	line (33), fig 2.10	XXX	XXX	-100	XXX	XXX	XXX	-100	XXX
35	calculate minimum delta f		MHz	form A	XXX	XXX	XXX	0	XXX	XXX	XXX	0
36	delta f>(BT+BR)/2		dB	line (35), fig 2.10	XXX	XXX	XXX	0	XXX	XXX	XXX	0
	EMI Frequency Corrected Summary											
37	Add line 21 to line				25	30	34	36	25	30	34	36
38	Total		dB		0	110	112	129	0	92	130	112

IF EMI Margin < -10dB, EMI Highly Improbable

Table A.3.9. GMTI-IFF, IFF-GMTI, and AMTI-HB Amplitude Culling

					GMTI-RX		IFF-TX		IFF-RX GMTI-TX				AMTI-TX RJ-HB-RX			
Line	Parameter	Symbol	Unit	Recommended Value/Equation If Needed	FIM	TIM	RIM	SIM	FIM	TIM	RIM	SIM	FIM	TIM	RIM	SIM
	AMPLITUDE CULLING				NA				NA				NA			
8	TX Power	PT (f OT)	dBm			200	XXX	XXX		200	XXX	XXX		200	XXX	XXX
9	TX Spurios Power Output	PT (f ST)	dBm	PT(f OT)-60dB	XXX	XXX	140	140	XXX	XXX	140	140	XXX	XXX	140	140
10	TX Antenna Gain in RX Direction	GTR (f)	dB	or 0dB		0	0	0		0	0	0		0	0	0
11	RX Antenna Gain in TX Direction	GRT (f)	dB	or 0dB		0	0	0		0	0	0		0	0	0
12	Propagation Loss Using Freq No.	L			#1	#1	#4	#2	#1	#1	#4	#2	#1	#1	#4	#2
			MHz			1030	10000	103		10000	1090	1000		1500	17	150
	Loss from Fig No. 2.7, (pg2.36,Vol7) Duff (Function of freq, distance)		dB	all negative		61	82	41		82	61	58		57	20	40
13	Unintentional Power Available	PA (f)	dBm	PT + L	0	261	222	181	0	282	201	198	0	257	160	180
14	RX Fundamental Susceptibility	PR (f OR)	dBm	sensitivity		XXX	-100	XXX		XXX	-84	XXX		XXX	-50	XXX
15	RX Spurious Suscept	PR (f SR)	dBm	PR (f OR) + 80dB	XXX	-20	XXX	-20	XXX	-4	XXX	-4	XXX	30	XXX	30
16	Preliminary EMI Prediction		dB	line 13-14 or 13-15	0	281	322	201	0	286	285	202	0	227	210	150

IF EMI margin < -10 dB, EMI Highly Improbable = STOP
IF EMI margin > -10 dB, Start Frequency Culling

Table A.3.10.a. GMTI-IFF, IFF-GMTI, and AMTI-HB Frequency Culling

					GMTI-RX IFF-TX				IFF-RX GMTI-TX				AMTI-TX RJ-HB-RX			
Line	Parameter	Symbol	Unit	Recommended Value/Equation If Needed	FIM	TIM	RIM	SIM	FIM	TIM	RIM	SIM	FIM	TIM	RIM	SIM
	FREQUENCY CULLING															
	Bandwidth Correction															
17	TX PRF (if pulse)		pps			100	100	100		100	100	100		100	100	100
18	TX Bandwidth	BT		2/PI * t if pulse; t=width		1.91	1.91	1.9		6.366	6.37	6.37		6.37	6.4	6.4
19	RX Bandwidth	BR				10	10	10		8	8	8		25	25	25
20	Adjustment	lines 17 to 19	dB	Use Fig 2.8/2.9		-92	-92	-92		-92	-92	-92		-92	-92	-92
21	Bandwidth Corrected	EMI Margin	dB	line 16+20	0	189	230	109	0	194	193	110	0	135	118	58
	(BT+BR)/2				####	5.955	5.955	6	###	7.183	7.18	7.18	##	15.7	16	16

IF EMI MARGIN <= -10 dB, EMI HIGHLY IMPROBABLE = STOP

Table A.3.10.b. GMTI-IFF, IFF-GMTI, and AMTI-HB Frequency Correction

					GMTI-RX IFF-TX				IFF-RX GMTI-TX				AMTI-TX RJ-HB-RX			
	Frequency Correction															
22	RX Local Oscillator Frequency	f LO	dBm			10100				1160				22		
23	RX Intermediate Frequency	f IF	dBm			100				70				5		
24	TX-RX Freq Separation:			delta f=abs((1)-(4)		XXX	XXX	XXX		XXX	XXX	XXX		XXX	XXX	XXX
25	delta f > (BT+BR)/2			line (24) & fig 2.10		XXX	XXX	XXX		XXX	XXX	XXX		XXX	XXX	XXX
26	f OT/ f LO +/- f IF to nearest integer				XXX	0	XXX	XXX	XXX	9	XXX	XXX	XXX	68	XXX	XXX
27	multiply lines (22) & (26)		MHz		XXX	0	XXX	XXX	XXX	10440	XXX	XXX	XXX	1496	XXX	XXX
28	delta f =abs((1)-(23)-(27))				XXX	1122	XXX	XXX	XXX	348	XXX	XXX	XXX	96	XXX	XXX
28	delta f =abs((1)+(23)-(27))				XXX	938	XXX	XXX	XXX	532	XXX	XXX	XXX	88	XXX	XXX
29	select smaller delta f from (28)		MHz		XXX	938	XXX	XXX	XXX	348	XXX	XXX	XXX	88	XXX	XXX
30	delta f>(BT+BR)/2		dB	line (29), fig 2.10	XXX	-100	XXX	XXX	XXX	-100	XXX	XXX	XXX	-100	XXX	XXX
31	calculate f OR/f OT to nearest integer				XXX	XXX	10	XXX	XXX	XXX	0	XXX	XXX	XXX	0	XXX
32	multiply lines (1) X (31)		MHz		XXX	XXX	10300	XXX	XXX	XXX	0	XXX	XXX	XXX	0	XXX
33	delta f=abs((4)-(32))		MHz		XXX	XXX	300	XXX	XXX	XXX	####	XXX	XXX	XXX	17	XXX
34	delta f > (BT+BR)/2		dB	line (33), fig 2.10	XXX	XXX	-100	XXX	XXX	XXX	-100	XXX	XXX	XXX	###	XXX
35	calculate minimum delta f		MHz	form A	XXX	XXX	XXX	0	XXX	XXX	XXX	0	XXX	XXX	XXX	0
36	delta f>(BT+BR)/2		dB	line (35), fig 2.10	XXX	XXX	XXX	0	XXX	XXX	XXX	0	XXX	XXX	XXX	0
	EMI Frequency Corrected Summary															
37	Add line 21 to line				25	30	34	36	25	30	34	36	25	30	34	36
38	Total		dB		0	89	130	109	0	94	93	110	0	35	18	58

IF EMI Margin < -10dB, EMI Highly Improbable

Alternate EMI Evaluation

Table A.3.11.a. AMTI – GMTI and GMTI – IFF Analog EMC Prediction Combinations

Out of Band Interference; separations of >10% operating frequency

Line	Parameter	Symbol	Unit	AMTI-RX GMTI-TX	GMTI-RX AMTI-TX	GMTI-RX IFF-TX	IFF-RX GMTI-TX
	Transmitter Harmonic to Receiver Fundamental; fR > f Tq						
1	RX Frequency	fR	MHz	1500	10000	10000	1090
2	TX Frequency	fT	MHz	10000	1500	1030	10000
3	(1)/(2) and round off to nearest integer	N		0	7	10	0
4	TX Harmonic Frequency; (3)*(2)	NfT	MHz	0	10500	10300	0
5	Frequency Separation; abs((4)-(1))		MHz	1500	500	300	1090
6	Receiver Bandwidth			10	10	10	8
	If (5)>(6), No Harmonic Interference; If (5)<(6) Continue			No	No	No	No
7	TX Power	PT	dBm	200	200	200	200
8	Harmonic Corection (from table 8.2)		dB	0	0	0	0
9	Harmonic Power	PT	dBm	200	200	200	200
10	Propagation Constant			32	32	32	32
11	20 log dTR		km	-27.767868	-27.767868	-27.7679	-27.7679
12	20 log fR		MHz	63.5218252	80	80	60.74853
13	Propagation Loss; (10)+(11)+(12)	L	dB	67.7539568	84.2321317	84.23213	64.98066
14	RX Antenna Gain	GR	dB	60	60	25	60
15	Power Available at RX; (9)-(13)+(14)		dBm	192.246043	175.767868	140.7679	195.0193
16	RX Susceptibility Level	PR	dBm	-100	-100	-100	-84
17	Interference Margin; (15)-(16)	IM	dB	292.246043	275.767868	240.7679	279.0193

Table A.3.11.b. AMTI – GMTI and GMTI – IFF Analog EMC Prediction Combinations

Transmitter Fundamental to Receiver Spurious; fT > fR

18 (2)/(1) and round off to nearest integer	P		6.66666667	0.15	0.103	9.174312
19 Local Oscillator Frequency	fLO	MHz	10100	10100	1160	22
20 Intermediate Frequency	fIF	MHz	60	100	100	70
21 abs(PfLO+/-fIF-fT; (18)*(19) + (20)-(2)			57393.3333	115	810.52	9728.165
abs(PfLO+/-fIF-fT; (18)*(19) - (20)-(2)			57273.3333	85	1010.52	9868.165
If (21+) or (21-) > (6) No Spurious Interface; If (21+) or (21-) <(6) Continue	line (6)		No	No	No	No
22 TX Power	PT	dBm	200	200	200	200
23 TX Antenna Gain	GT	DB	60	60	25	60
24 Propagation Constant			32	32	33	33
25 20 log dTR		km	-27.767868	-27.767868	-27.7679	-27.7679
26 20 log fT		MHz	80	63.5218252	60.25674	80
27 Propagation Loss; (24)+(25)+(26)	L	dB	84.2321317	67.7539568	65.48888	85.23213
28 Power Available at RX; (22)+(23)-(27)		dBm	175.767868	192.246043	159.5111	174.7679
29 RX Fundamental Susceptibitlity	PR	dBm	-100	-100	-100	-84
30 Spurious Correction (from Table 8.3)		dBm				
31 Spurious Susceptibility; (29)+(30)		dBm	-100	-100	-100	-84
32 Interference Margin; (28)-(31)	IM	dB	275.767868	292.246043	259.5111	258.7679

IM<-10dB, EMI Highly Improbable -10dB<IM<10dB, EMI Marginal IM>10dB, EMI Probable

Table A.3.12.a. AMTI and GMTI Combinations with HB, LB, and SHF Analog EMC Prediction

Out of Band Interference; separations of >10% operating frequency

Line	Parameter	Symbol	Unit	AMTI-TX HB-RX	AMTI-TX LB-RX	AMTI-TX SHF-RX	GMTI-TX HB-RX	GMTI-TX LB-RX	GMTI-TX SHF-RX
	Transmitter Harmonic to Receiver Fundamental; fR > f Tq								
1	RX Frequency	fR	MHz	17	0.08	1.8E+07	17	0.08	18000000
2	TX Frequency	fT	MHz	1500	1500	1500	10000	10000	10000
3	(1)/(2) and round off to nearest integer	N		0	0	12000	0	0	1800
4	TX Harmonic Frequency; (3)*(2)	NfT	MHz	0	0	1.8E+07	0	0	18000000
5	Frequency Separation; abs((4)-(1))		MHz	17	0.08	0	17	0.08	0
6	Receiver Bandwidth			25	100	3E+07	25	100	30000000
	If (5)>(6), No Harmonic Interference; If (5)<(6) Continue			Yes	Yes	Yes	Yes	Yes	Yes
7	TX Power	PT	dBm	200	200	200	200	200	200
8	Harmonic Corection (from table 8.2)		dB	0	0	1	2	3	4
9	Harmonic Power	PT	dBm	200	200	200	200	200	200
10	Propagation Constant			32	32	32	32	32	32
11	20 log dTR		km	-37.646	-37.6461	-37.6461	-30.458	-30.458	-30.4576
12	20 log fR		MHz	24.609	-21.9382	145.105	24.609	-21.938	145.1055
13	Propagation Loss; (10)+(11)+(12)	L	dB	18.9629	-27.5843	139.459	26.1514	-20.396	146.6479
14	RX Antenna Gain	GR	dB	60	60	60	60	60	60
15	Power Available at RX; (9)-(13)+(14)		dBm	241.037	287.584	120.541	233.849	280.396	113.3521
16	RX Susceptibility Level	PR	dBm	-50	-50	-50	-50	-50	-50
17	Interference Margin; (15)-(16)	IM	dB	291.037	337.584	170.541	283.849	330.396	163.3521

Table A.3.12.b. AMTI and GMTI Combinations with HB, LB, and SHF Analog EMC Prediction

Transmitter Fundamental to Receiver Spurious; fT > fR

18 (2)/(1) and round off to nearest integer	P		88.2353	18750	8.3E-05	588.235	125000	0.000556
19 Local Oscillator Frequency	fLO	MHz	0.11	3.8E+07	0	0	0	0
20 Intermediate Frequency	fIF	MHz	5	0.03	2E+07	5	0.03	20000000
21 abs(PfLO+/-fIF-fT; (18)*(19) + (20)-(2)			1485.29	7.1E+11	2E+07	9995	9999.97	19990000
abs(PfLO+/-fIF-fT; (18)*(19) - (20)-(2)			1495.29	7.1E+11	2E+07	10005	10000	20010000
If (21+) or (21-) > (6) No Spurious Interface; If (21+) or (21-) <(6) Continue	line (6)		No	No	Yes	No	No	Yes
22 TX Power	PT	dBm	200	200	200	200	200	200
23 TX Antenna Gain	GT	DB	60	60	60	60	60	60
24 Propagation Constant			33	33	33	33	33	33
25 20 log dTR		km	-37.646	-37.6461	-37.6461	-30.458	-30.458	-30.4576
26 20 log fT		MHz	63.5218	63.5218	63.5218	80	80	80
27 Propagation Loss; (24)+(25)+(26)	L	dB	58.8758	58.8758	58.8758	82.5424	82.5424	82.54243
28 Power Available at RX; (22)+(23)-(27)		dBm	201.124	201.124	201.124	177.458	177.458	177.4576
29 RX Fundamental Susceptibitlity	PR	dBm	-50	-50	-50	-50	-50	-50
30 Spurious Correction (from Table 8.3)		dBm						
31 Spurious Susceptibility; (29)+(30)		dBm	-50	-50	-50	-50	-50	-50
32 Interference Margin; (28)-(31)	IM	dB	251.124	251.124	251.124	227.458	227.458	227.4576

IM<-10dB, EMI Highly Improbable -10dB<IM<10dB, EMI Marginal IM>10dB, EMI Probable

Bibliography

Beam, Walter R. *Command, Control, and Communications Systems Engineering*. New York: McGraw-Hill Publishing Co., 1989.

Blanchard, Benjamin S. *System Engineering Management*. New York: Wiley-Interscience Publications, 1991.

Buede, Dennis. *The Engineering Design of Systems*. New York: Wiley-Interscience Publications, 2000.

Coskuner, Nevin. *Multimission Aircraft Design Study - Operational Scenarios*. MS thesis, AFIT/GSE/ENY/03-1. School of Aeronautics and Astronautics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2003.

Defense Electronics. *The C3I Handbook* (3rd Edition). California: EW Communications, Inc., 1988.

Department of the Air Force. *Concept of Operations For The MC2A 707 Testbed*. Langley AFB: AC2ISRC/A-85, 7 December 01.

Department of the Air Force. *Concept of Operations For The Multi-Sensor Command and Control Aircraft*. Langley AFB: AC2ISRC/A-8, 8 May 01.

Department of the Air Force. *Mission Need Statement (MNS), AC2ISRC (USAF) 001-01, Multi-Sensor Command and Control, ACAT I, Draft*. Langley AFB: AC2ISRC/A-8, 18 December 01.

Duff, William and Donald R.J. White. *Electromagnetic Interference and Compatibility (Vol 5), A Handbook on EMI Prediction and Analysis Techniques*. Gainesville: Don White Consultants, Inc., 1972.

Duff, William. *A Handbook Series on Electromagnetic Interference and Compatibility (Vol 1), Fundamentals of Electromagnetic Compatibility*. Gainesville: Interference Control Technologies, Inc., 1988.

Duff, William. *A Handbook Series on Electromagnetic Interference and Compatibility (Vol 7), Electromagnetic Compatibility in Communications*. Gainesville: Interference Control Technologies, Inc., 1988.

Fulghum, David A. “Key Decisions Remain For New Intel Aircraft,” *Aviation Week and Space Technology*, 178-181 (22 July 2002).

Fulghum, David A. “Paul Revere Designers Critique New Configuration,” *Aviation Week and Space Technology*, 52-53 (23 September 2002).

Fulghum, David A. "Sigint, Jamming Joined In Single Package," *Aviation Week and Space Technology*, 34 (23 December 2002).

Fulghum, David A. "Test of MC2A Reveal Problems an Promise," *Aviation Week and Space Technology*, 48-49 (23 September 2002).

Global Security. "*E-767 Multi-Mission Command and Control Aircraft (MC2A)*." Excerpt from unpublished article. n. pag. http//www.globalsecurity.org/military/systems/aircraft/e-767-mc2a.htm. 28 October 2002.

Hatley, D, P. Hruschka, and I. Pirghai. *Process For System Architecture and Requirements Engineering*. New York: Dorset House Publishing, 2000.

Jumper, John P. and James G. Roche. *Air Force Handbook*. Washington: Department of the Air Force, 107th Congress, Second Session.

Kahraman, Ahmit. *Multimission Aircraft Design Study - Payload*. MS thesis, AFIT/GSE/ENY/03-2. School of Aeronautics and Astronautics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2003.

Keiser, Bernhard. *Principles of Electromagnetic Compatibility* (3rd Edition). Massachusetts: Artech House Inc., 1987.

Paone, Chuck. *Joint Expeditionary Air Force Experiment '02 Begins*. Hanscom AFB: Electronic Systems Center Public Affairs. Excerpt from unpublished article. n. pag. http/www.af.mil/news. 24 July 2002.

Paone, Chuck. *Jumper Stresses 'Results at C2ISR Summit*. Hanscom AFB: Electronic Systems Center Public Affairs. Excerpt from unpublished article. n. pag. http/www.af.mil/news. 26 April 2002.

Paul, C. R. "EMC Analysis at the Equipment Level," *AGARD Lecture Series 116, Electromagnetic Compatibility*. 3-1 – 3-23 (August 1991).

Rackham, Peter. *Janes's C4I Systems* (10th Edition). Surrey: Jane's Information Group Limited, 1998.

Rechtin, E. and M. Maier. *The Art of Systems Engineering*. New York: CRC Press, 1997.

Roche, James G, Secretary of the Air Force. "Acquisition and Logistics Excellence—Exactly," Address to Acquisition and Logistics Excellence Day Hanscom AFB: Acquisition and Logistics, Wright-Patterson AFB OH. Excerpt from unpublished speech. n. pag. http/www.af.mil/news/speech. 21 October 2002.

Spina, John F. "The EMC Concept for Weapon Systems," *AGARD Lecture Series 116, Electromagnetic Compatibility*. 1-1 – 1-8 (August 1991).

Trimle, Stephen. "MC2A Program Splits into Two Fleets; Faces Two-Year Delivery Delay," *Aviation Week's Aerospace Daily*. Excerpt from unpublished article. n. pag. http//www.aviationnow.com/avnow/news. 21 November 2002.

Tuttle, Rich. "Aerospace Daily: Air Force Set To Release RFP For MC2A Program," *Aviation Week's Aerospace Daily*. Excerpt from unpublished article. n. pag. http//www.aviationnow.com/avnow/news. 8 November 2002.

Violette, J. L. Norman, Donald R.J. White, Michael F. Violette. *Electromagnetic Compatibility Handbook*. New York: Van Nostrand Reinhold Company Inc., 1987.

Weiner, D. D. "EMC Analysis at the System Level," *AGARD Lecture Series 116, Electromagnetic Compatibility*. 2-1 – 2-22 (August 1991).

Weston, David A. *Electromagnetic Compatibility: Principles and Applications*. New York: Marcel Dekker, Inc., 1991.

Wertz, J. and W. Larson. Space Mission Analysis and Design (3rd Edition). Boston: Space Technology Library, 1999.

White, Donald R. J. *Electromagnetic Interference and Compatibility (Vol 1), A Handbook on Electrical Noise and EMI Specifications (6th Printing).* Virginia: Don White Consultants, Inc., 1985.

Wilson, J. and M. Jolly. *C3I System Modification and EMC Methodology*. Technical Report. Rome Air Development Center, Griffiss AFB NY, January 1984 (RADC-TR-83-237).

(Category and Distribution Statement)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. REPORT DATE *(DD-MM-YYYY)* 25-03-2003	**2. REPORT TYPE** **Master's Thesis**	**3. DATES COVERED** *(From – To)* Jun 2002 – Mar 2003

4. TITLE AND SUBTITLE

MULTIMISSION AIRCRAFT DESIGN STUDY:
ELECTROMAGNETIC COMPATIBILITY

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

DAVIS, JENNA M., CAPTAIN, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
BLDG 642
2950 Hobson Way
Wright Patterson AFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GAI/ENY/03-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AF/XOI
Attn: Mr. Mike Burgan & Lt. Col. Charlie Bartlett
ADDRESS: 1480 Air Force Pentagon DSN: 225-8065
WPAFB OH 20330-1480 e-mail:

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The multi-mission aircraft (MMA) technical feasibility study will look at replacement of the aging fleet of C-135 and C-130 theater based command & control (C2) and intelligence, surveillance and reconnaissance (ISR) fleet. It is proposed that the MMA be out-fitted to combine some or all the functions of existing AWACS, JSTARS, RIVET JOINT, COMPASS CALL, and ABCCC platforms. It would also have links to other manned or unmanned ISR aircraft, as well as satellites. The objective of the proposed feasibility study is to examine the technical risks involved in combining multiple functions onto one aircraft that currently reside on separate aircraft. This Thesis will specifically focus on the risks that are due to electromagnetic interference between transmitters and interference between active and passive sensors. These risks will be outlined in detail and a recommendation as to which functions could be combined with minimal technical risk will be made.

15. SUBJECT TERMS

Systems Engineering, Multimission Aircraft, MMA, Multimission Command and Control Architecture, MC2A, Electromagnetic Compatibility, Electromagnetic Interference, EMI, EMC

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Curtis H. Spenny, PhD (ENY)
U	U	U	UU	129	**19b. TELEPHONE NUMBER** *(Include area code)* (937) 255-7777, ext 3296; e-mail: Curtis.Spenny@afit.edu