AD-A032 474 GEORGIA INST OF TECH ATLANTA ENGINEERING EXPERIMENT --ETC F/G 9/3
ELECTROMAGNETIC COMPATIBILITY PROGRAM PLAN, (U)
APR 76 J C TOLER

UNCLASSIFIED DOT-FA74WA-3372
FAA-RD-76-75 NL

1 OF 1
ADA
032 474



END
DATE
FILMED
03-77
NTIS

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A032 474

ELECTROMAGNETIC COMPATIBILITY PROGRAM PLAN

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

APRIL 1976

335095

AD A032474

REPORT NO. FAA-RD-76-75

ELECTROMAGNETIC COMPATIBILITY PROGRAM PLAN

J. C. TOLER

DDC
RECEIVED
NOV 24 1976
C

APRIL 1976

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-76-75		

4. Title and Subtitle	5. Report Date
Electromagnetic Compatibility Program Plan	April 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
J. C. Toler	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Engineering Experiment Station Georgia Institute of Technology Atlanta, GA 30332	11. Contract or Grant No. DOT-FA74WA-3372 new
	13. Type of Report and Period Covered Research
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590	14. Sponsoring Agency Code ARD-350

15. Supplementary Notes

16. Abstract

This report summarizes recommendations to the Federal Aviation Administration (FAA) regarding management and engineering considerations of importance in establishing an agency-wide Electromagnetic Compatibility Program (ECP). → to page 2 →
Essential to the implementation of a satisfactory ECP is a clear understanding of terminology and philosophy. A Program terminology is therefore developed in which precise definitions are provided for commonly used terms, e.g., EC, Electromagnetic Interference, and Electromagnetic Susceptibility. These definitions show that each of these terms has a distinctive meaning and that any interchangeable use of them leads to misunderstandings. The Program philosophy is focused entirely on realizing the ultimate goal of system level compatibility. All management and engineering efforts must be related to achieving this ultimate goal or they have no justification. From an engineering point-of-view, strong and equal emphases on a priori design and a posteriori test efforts are recommended.
Management techniques and tools as they influence the EC organization and its responsibilities are also identified. Organizational guidelines include generalized responsibilities that should be handled by the EC Group and the location of this Group within an overall agency organization. Management tools available for implementing the ECP include Control Plans, Test Plans, Test Reports, and Waiver Requests. Finally, an outline of typical EC tasks is generated as a function of time and for an assumed system development program. These tasks identify both FAA and contractor responsibilities in implementing an effective ECP.

17. Key Words	18. Distribution Statement
Electromagnetic Compatibility Program Management	Document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	59	$4.50/3.00

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

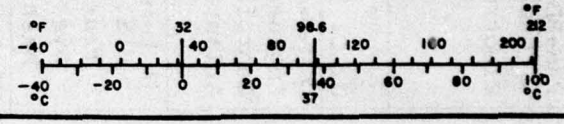
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.96	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FORWORD

This report was prepared within the Electronics Technology Laboratory of the Georgia Tech Engineering Experiment Station. The research program was in accordance with Contract No. DOT-FA74WA-3372 and was under the general supervision of Mr. D. W. Robertson, Laboratory Director. Mr. J. C. Toler, Head, Electromagnetic Compatibility Group, was the Project Director, and Mr. Edward J. Kaputa, FAA, had technical cognizance over the program. This report summarizes the activities directed to developing guidelines for an Electromagnetic Compatibility Program for implementation within the Federal Aviation Administration.

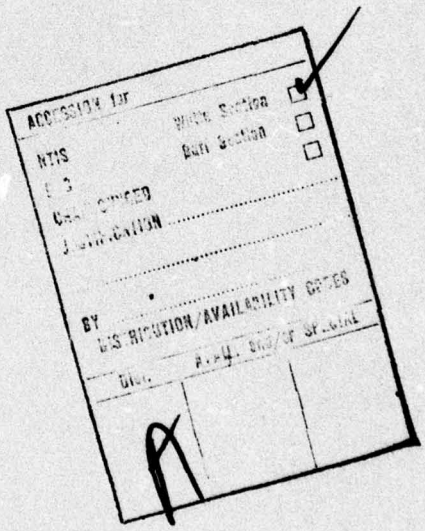


TABLE OF CONTENTS

		PAGE
1.	INTRODUCTION	1
	1.1 The Need for an Electromagnetic Compatibility Program Plan.	1
	1.2 Purpose of EMC Program Plan	1
2.	TERMINOLOGY.	3
3.	APPLICABLE DOCUMENTS	6
	3.1 FAA Documents	6
	3.2 Military Documents.	6
4.	EMC PHILOSOPHY	8
5.	MANAGEMENT TECHNIQUES AND TOOLS.	11
	5.1 EMC Organization.	11
	5.1.1 Responsibilities of EMC Organization	11
	5.1.2 Location of the EMC Organization	14
	5.1.2.1 Decentralized EMC Organization.	17
	5.1.2.2 Centralized EMC Organization.	19
	5.1.2.3 Other Types of EMC Organizations.	21
	5.2 EMC Management Tools.	23
	5.2.1 Control Plans.	23
	5.2.2 Test Plans	24
	5.2.3 Test Reports	26
	5.2.4 Waiver Requests.	27
	5.3 EMC Programs Tasks.	28
6.	SUMMARY.	35
7.	SELECTED BIBLIOGRAPHY.	36
APPENDIX A.		A-1
APPENDIX B.		B-1

LIST OF ILLUSTRATIONS

1.	Functional Relationship of Typical EMC Responsibilities	15
2.	Typical EMC Responsibilities Versus Program Phases.	16
3.	Decentralized EMC Organization.	18
4.	Centralized EMC Organization.	20
5.	Chronological Order of Typical EMC Tasks.	45

1. INTRODUCTION

1.1 The Need For An Electromagnetic Compatibility Program Plan

In a very real sense, facilities used by the Federal Aviation Administration (FAA) can be described as complex assemblages of mechanical, electrical, electronic, and architectural systems. These systems are highly interdependent in their functioning and have a direct influence on both safety and scheduling of air transportation. The design requirements imposed on all of these systems, and especially those of an electrical and electronic nature, are necessarily stringent. They include provisions for flexibility and modularity in operation, reliability in functioning regardless of whether a multiplicity of systems are co-located or distributed over several square miles, and interference-free operation in an increasingly hostile electromagnetic environment. Concurrently, electrical and electronic systems are continually being reduced in physical size, packaged with increased density, and operated in a digital mode. In view of this situation, it is not surprising that these systems are expensive to design, to install in facilities, to operate, and to maintain.

In order to provide electrical and electronic systems with maximum reliability and minimum cost, it is imperative that electromagnetic considerations be a part of all phases of the system's life cycle. These electromagnetic considerations must include radiated and conducted signal emission and susceptibility concerns integrated into design, fabrication, test, installation, operation, and maintenance activities. In order to accomplish this in a systematic and cost-effective manner, documented philosophies and methods of procedure need to exist and need to have management approval. These philosophies and methods of procedure establish the overall approach to an Electromagnetic Compatibility (EMC) Program Plan. Without this Plan, approved by management and communicated to all program personnel, EMC effects will necessarily be sporadic, inefficient, and inconsistently imposed.

1.2 Purpose of EMC Program Plan

This plan establishes guidelines for an overall EMC effort applicable to electrical and electronic systems (and elements thereof) used in FAA facilities. As such, it defines for FAA managers and engineers the authority and activities that comprise an effective EMC Program. When these

activities are authoritatively incorporated into designs and verified by tests, the result will be reflected by more reliable functioning, reduced operational and maintenance costs, and improved flight safety and scheduling.

Organizationally, this Plan establishes the applicable EMC Terminology and Applicable Documents in Sections 2 and 3, respectively. Section 4 then documents the EMC Philosophy that should underlie all program decisions. The type of FAA organization best suited for implementing the EMC Program is discussed in Section 5, and Section 6 identifies the tools available for use in Program implementation. Finally, a typical chronology of EMC activities appropriate for an assumed program is presented in Section 7.

2. TERMINOLOGY

A clearly defined and thoroughly understood terminology is essential for effective communications within any technical discipline. The EMC discipline has always had difficulty at this point because no such clearly defined and thoroughly understood terminology has been commonly adopted. Instead, what has evolved is a proliferation of both terms and definitions whose meaning is too often a function of the context within which they are being used. In order to avoid further proliferation, the terminology documented in MIL-STD-463 is adopted for this Program Plan. However, clarification of some of this terminology is provided by the examples cited in the following paragraphs.

In Directive 2333.2, Section III, dated 31 July 1967, the Department of Defense identified some EMC definitions for use in their programs. For example, the definition of EMC was as follows:

> Electromagnetic Compatibility (EMC) is the ability of communications-electronics (C-E) equipments, subsystems, and systems to operate in their intended operational environments without suffering or causing unacceptable degradation because of unintentional electromagnetic radiation or response. It does not involve a separate branch of engineering, but directs attention to improvement of electrical and electronic engineering knowledge and techniques to include all aspects of electromagnetic effects.

The Directive further emphasized that EMC is achieved only when Design Compatibility and Operational Compatibility are realized. In this context, Design and Operational Compatibility were defined as follows:

> Design Compatibility is EMC achieved by incorporation of engineering characteristics or features in all electromagnetic radiating and receiving equipments in order to eliminate or reject undesired signals, either self-generated or external, and enhance operating capabilities in the presence of natural or man-made electromagnetic noise.

Operational Compatibility is EMC achieved by the application of C-E equipment flexibility to ensure interference-free operation in homogeneous or heterogeneous environments of C-E equipments. It involves the application of sound frequency management and clear concepts and documents to maximize operational effectiveness. It relies heavily on initial achievement of design compatibility.

An emission, as referred to in this Plan, is electromagnetic energy emanating from a source via either air or wire coupling. This emission may be either desired or undesired insofar as its source is concerned; however, if it is coupled along a path to a receptor and performance degradation results, then electromagnetic interference has occurred. In order for performance degradation to occur, the emission level must overcome loss in the coupling path and exceed the susceptibility threshold of the receptor. Consequently, the factors of primary concern in EMC analysis are the emission source, the coupling path, and the receptor. The relationship between these factors can be expressed in a simplified equation format as follows:

$$EME - P_L \geq EMS \dashrightarrow EMI \text{ and}$$

$$EME - P_L < EMS \longrightarrow EMC$$

where: EME = electromagnetic emission level,

P_L = path loss,

EMS = electromagnetic susceptibility threshold,

EMI = electromagnetic interference, and

EMC = electromagnetic compatibility.

From this relationship, it is obvious that (1) individual terms have specific meaning and are not to be used interchangeably and (2) EMI and EMC are the antithesis of one another. In this usage, EMI and EMC tend to become primarily system (or perhaps subsystem) considerations because they involve two or more equipments. Similarly, EME and EMS tend to become primarily equipment (or subsystem) considerations.

In the context of this Program Plan, the terms "system," "subsystem," and "equipment" are extensively used and have distinctive meanings. For example, a system is considered to be an assemblage of equipments and/or

subsystems, generally housed in a multirack configuration and interconnected to perform multiple interrelated and possibly sequential functions. Typical systems in FAA facilities include the Radar Display System (RDS), the Instrument Landing System (ILS), and the Automated Radar Terminal System (ARTS). On the other hand, an equipment is considered to consist of an assemblage of electrical and electronic components interconnected to perform a single function and housed in an individual chassis. An individual transmitter, receiver, regulated output amplifier or time code generator are examples of FAA equipments. Subsystems are considered somewhere between single chassis equipments and multirack systems; therefore, a subsystem consists of a limited number of individual equipments interconnected to perform a few identifiable functions. In each case, the normally used cabling and wiring is considered to be a part of the equipment, subsystem, or system.

For the purposes of this Program Plan, there is one additional aspect that must be considered regarding the definition of EMC. This has to do with what is commonly referred to as the "margin of safety." Electromagnetic compatibility is often defined not only in terms of satisfactory functional performance of a system, but goes an additional step and requires a margin of safety or a safety margin. Consider, for example, a regulated output amplifier and assume that it has a susceptibility threshold of x volts. When an undesired emission in excess of x volts impinges on the amplifier, performance degradation results; when an undesired emission of less than x volts impinges on the amplifier, it continues to function without degradation. The latter condition would, according to definitions which require no safety margin, represent EMC. This would be true even if the undesired emission level were almost, but not quite, x volts in magnitude. For definitions which include the safety margin, it would be necessary for the undesired emission level at the amplifier to be a specified level below x volts in order to realize EMC. This definition, therefore, not only requires compatible and satisfactory functional performance, but also provides assurance that an incompatibility is not imminent. A commonly used, but by no means universally applicable, safety margin requires that undesired emission levels be at least six dB below the threshold of susceptibility at all frequencies of interest.

3. APPLICABLE DOCUMENTS

The following documents, of the issue in effect at the time a procurement specification or request for proposal is released, are a part of this Plan to the extent specified herein.

3.1 FAA Documents

FAA-G-2100	Electronic Equipments, General Requirements
7340.1D	Contractions
FAA-RD-76-71	Handbook for Electromagnetic Compatibility Design of Electronic Equipments
FAA-RD-75-215	Grounding, Bonding, and Shielding Practices and Procedures for Electronic Equipments and Facilities
FAA-RD-76-69	Electromagnetic Compatibility Rationale Report, Conducted Test Requirements for Electronic Equipments in Air Transportation Facilities
FAA-RD-76-70	Electromagnetic Compatibility Rationale Report, Radiated Test Requirements for Electronic Equipments in Air Transportation Facilities
FAA-ER-350-023	Electronic Equipments Grounding, Bonding, and Shielding Practices, General Requirements

3.2 Military Documents

MIL-STD-449	Radio Frequency Spectrum Characteristics, Measurement of
MIL-STD-461	Electromagnetic Interference Characteristics, Requirements for Equipments
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-463	Definitions and System of Units, Electromagnetic Interference Technology
MIL-STD-469	Radar Engineering Design Requirements, Electromagnetic Compatibility

MIL-STD-1541	Electromagnetic Compatibility Requirements for Space Vehicles
MIL-STD-1542	Electromagnetic Compatibility and Grounding Requirements for Space System Facilities
MIL-E-6051	Electromagnetic Compatibility Requirements, Systems
MIL-I-6181	Interference Control Requirements, Aircraft Equipment
MIL-I-26600	Interference Control Requirements, Aeronautical Equipment

4. EMC PHILOSOPHY

The EMC philosophy recommended for FAA adoption and documented herein provides management and engineering directives for a program of EMC control that is broad enough to encompass systems, subsystems and equipments, yet sufficiently detailed to establish specific requirements for individual application. Its ultimate goal is to achieve both inter- and intra-system compatibility in FAA facilities housing electrical and electronic equipments. By this means, the EMC Program will contribute to flight safety, minimize flight scheduling problems and improve the cost-effective operation of the nation's air transportation system. The following management and engineering requirements represent the major components of the EMC philosophy:

(1) Since the ultimate goal of the EMC Program is system level compatibility, all EMC requirements imposed at other levels (such as subsystem and equipment levels) are subordinate. Consequently, these other requirements must influence the ultimate goal in some tangible way, or they have no justification for existence. This means that requirements imposed by equipment level EMC standards must have an identifiable relationship to the requirements imposed by system level EMC standards.

(2) At all levels, the EMC Program will require an equal emphasis on a priori design and a posteriori test requirements. This dictates that, for every electromagnetic design requirement, there must be a corresponding electromagnetic test requirement. Conversely, for every electromagnetic test requirement, there must be a corresponding electromagnetic design requirement.

(3) Specific EMC test requirements will be in accordance with system and/or equipment level standards, the most notable of which are currently MIL-E-6051 (systems) and MIL-STD-461/ MIL-STD-462 (equipments).

(4) Specific EMC design requirements for equipments will be in accordance with the guidelines provided in the document FAA-RD-76-71, "Handbook for Electromagnetic Compatibility Design of Electronic Equipments." It is noted that there is not presently a FAA design guideline applicable at the system level. (Until such a document is developed, those portions of MIL-STD-469 that are related to radar systems and those portions of MIL-STD-1541 and MIL-STD-1542 that are related to communications satellites may be helpful in the design of certain FAA systems.)

Although the above major components of the EMC philosophy are individually straightforward, their implementation on a consistent basis is a formidable task. In too many instances, the emphases on the overall EMC Program have been directed solely to either the equipment or the system level and to either a design or a test effort. Such emphases preclude any meaningful systems engineering effort. The attempts to justify such approaches can be summarized as follows:

(1) By concentrating all EMC efforts at the equipment level, essentially all emission and susceptibility problems can be satisfactorily resolved; consequently, there can be no system level problem. Why then should design and/or test efforts be expended at a level where no problems can exist?

(2) By concentrating all EMC efforts at the system level, the costly and time consuming equipment level design and test efforts are unnecessary. After all, it is system level compatibility that is of ultimate concern, so why not direct the effort to where the concern is? In fact, it matters little whether emissions from equipments or equipment susceptibility exists, because those emission and susceptibility characteristics that cause problems will show up at the system level and be handled there.

(3) By concentrating all EMC efforts in the design phase, provisions can be incorporated to assure that emission levels are low and susceptibility thresholds high. Therefore, tests are unnecessary as they can only confirm what is already known to be the case.

(4) By concentrating all EMC efforts in the test phase, design oversights will be identified and remedied. Since a test effort is necessary anyway, why bother with a design effort which cannot possibly solve all of the problems that will occur?

As should be obvious, none of the above emphases are satisfactory. In fact, the satisfactory EMC Program is one based on a philosophy requiring a cohesive effort at all levels of activity and in both design and test phases of system development. In the following section, an EMC organization plus management techniques and tools available for use in implementing such a Program are presented.

5. MANAGEMENT TECHNIQUES AND TOOLS

5.1 EMC Organization

An effective EMC Program, with its resulting benefits of improved flight safety, system costs, equipment performance, and schedules will not just happen; rather, it will be realized only through the functioning of a competent EMC organization which has the firm and thorough support of program management. In many respects, it would be correct to say that the effectiveness of an FAA EMC organization will be directly proportional to the support it receives from upper management. The major considerations that must be clearly defined as the FAA considers establishment of an EMC organization are the responsibility and authority to be assigned to and the location of the EMC organization within the framework of the overall organization. Each of these considerations are discussed in detail in the following paragraphs. In this discussion, the considerations are presented in a generalized format such that they are applicable regardless of whether the EMC organization is internal or external (contractor) to the FAA.

5.1.1 Responsibilities of EMC Organization

The responsibilities of the EMC organization span the entire program activity, beginning with the initial system concept phase and continuing through all installation and operational phases. In very broad terms, the EMC organization can be considered as responsible for assuring that the final system is electromagnetically compatible by placing into effect the necessary managerial and technical controls required during each and every phase of the program activity. The managerial and technical controls necessary to accomplish this responsibility assume various formats and forms, such as procedures, methods, standards, guidelines, etc. The form and format taken by the controls are a function of both the complexity of the program and the program phase to which the control must be applicable. The following are some typical basic controls that the EMC organization must have authority to accomplish as a part of its broadest responsibility:

(1) During the early system concept phase of program activity, the EMC organization must provide a single and well-documented definition of the entire EMC effort. This definition, used heavily by management and updated as program changes occur, is usually in the format of an EMC Control Plan and is the most important single document prepared by the EMC organization. Control Plan requirements are presented in detail in Paragraph 5.2.1 of this Plan. This Plan is the controlling and guiding set of EMC policies that communicate to each department head, each engineer, each contractor, and the procuring activity the work efforts, areas of emphasis, test and design philosophies, and methods to be utilized to preclude EMC problems. The EMC efforts to be accomplished as an integral function of program activity are also reflected in the Control Plan.

(2) The EMC organization must also provide the technical information needed for design and test engineering controls. For design engineering controls, the responsibilities of the EMC organization include generating, if necessary, and implementing technically valid guides or specifications which authoritatively delineate consistent methods to be followed in minimizing EME from and EMS within equipments. As noted earlier, these design guidelines are conspicuously absent in most large programs today. The resulting situation is one in which equipments are tested for compliance with requirements for which they were not designed. For test engineering efforts, numerous Government standards (for example, MIL-STD-461A and MIL-STD-462) and industry specifications defining specific EME and EMS tests are readily available to the EMC organization as control documents. In every case, the requirements of these documents must be carefully reviewed for applicability to the needs of the program. Modification of at least some of the specification requirements, generation of a new and different test specification, or adoption of MIL-STD-461A and MIL-STD-462 should be the expected result of this effort. In

both the test and design engineering areas, the EMC organization must assure that resulting guides and standards are directly relatable to the total electromagnetic environment in which the subsystems and equipments must finally operate.

(3) The EMC organization should be the single source for and have the authority to interpret and enforce EMC design and test engineering controls. It should also be responsible for final concurrence with any planned deviation or waiver of the applicable EMC design and test engineering controls.

(4) The methods to permit quantitative predictions of the amount of operational degradation resulting from mutual electromagnetic environments envisioned in operational situations should be developed and applied by the EMC organization. Accomplishment of this responsibility should fully utilize all available information regarding projected installation locations, frequency allocations and assignments, electromagnetic environment alterations due to new equipment or subsystem installations, design techniques, etc. in order to make possible electromagnetically compatible performance of the final systems.

(5) The EMC organization is responsible for assuring that an educational program, both formal and informal, as necessary, is initiated to inform all elements of the program organization concerning the various aspects of the EMC problem, its nature, its application to the specific program at hand, and the managerial, design, and test engineering factors involved in its solution. With this accomplished, the "black magic" attitude normally associated with EMC efforts will be eliminated. The educational program should make specifically clear the distinctive difference in meaning of the terms "electromagnetic compatibility" and "satisfactory functional performance". The educational program should also show that the basic electrical/

electronic theory daily used by all engineering disciplines is the same theory used in the EMC discipline; the only difference is in the fact that, in the EMC discipline, it is the undesired rather than the desired signal that is under consideration.

When these five basic responsibilities are thoroughly understood and put into effect, the major EMC Program requirements for the FAA will be encompassed. These responsibilities will provide (1) for the development of an authoritative document defining the total EMC effort, (2) the establishment and/or generation of detailed standards and procedural controls to be implemented during design and test engineering phases of the program, (3) the interpretation and enforcement of these design and test engineering controls, (4) the establishment of a capability to predict and preclude EMC problems before they occur, and (5) adequate instruction of all personnel involved with the EMC effort. Figure 1 depicts the functional relationship between typical EMC responsibilities while Figure 2 shows typical EMC responsibilities as a function of program phases.

The above considerations should provide a foundation insofar as basic responsibilities and authorities of an FAA EMC organization are concerned. The location of the EMC organization in the overall program organization is considered in the following paragraphs.

5.1.2 Location of the EMC Organization

There have been many discussions as to where the EMC organization belongs within the overall program organization. None of these discussions has resulted in a single concise answer that will readily fit all cases. It is recognized from the outset that no such single answer will be provided here either; however, some of the various advantages and disadvantages related to EMC organization locations will be presented and can serve as a guideline for organizational decisions.

Obviously, the EMC organization must be well integrated into the overall program activity and, at the same time, located organizationally where it can best perform its assigned responsibilities. Numerous situations exist in which an EMC organization has rather clearly assigned responsibilities,

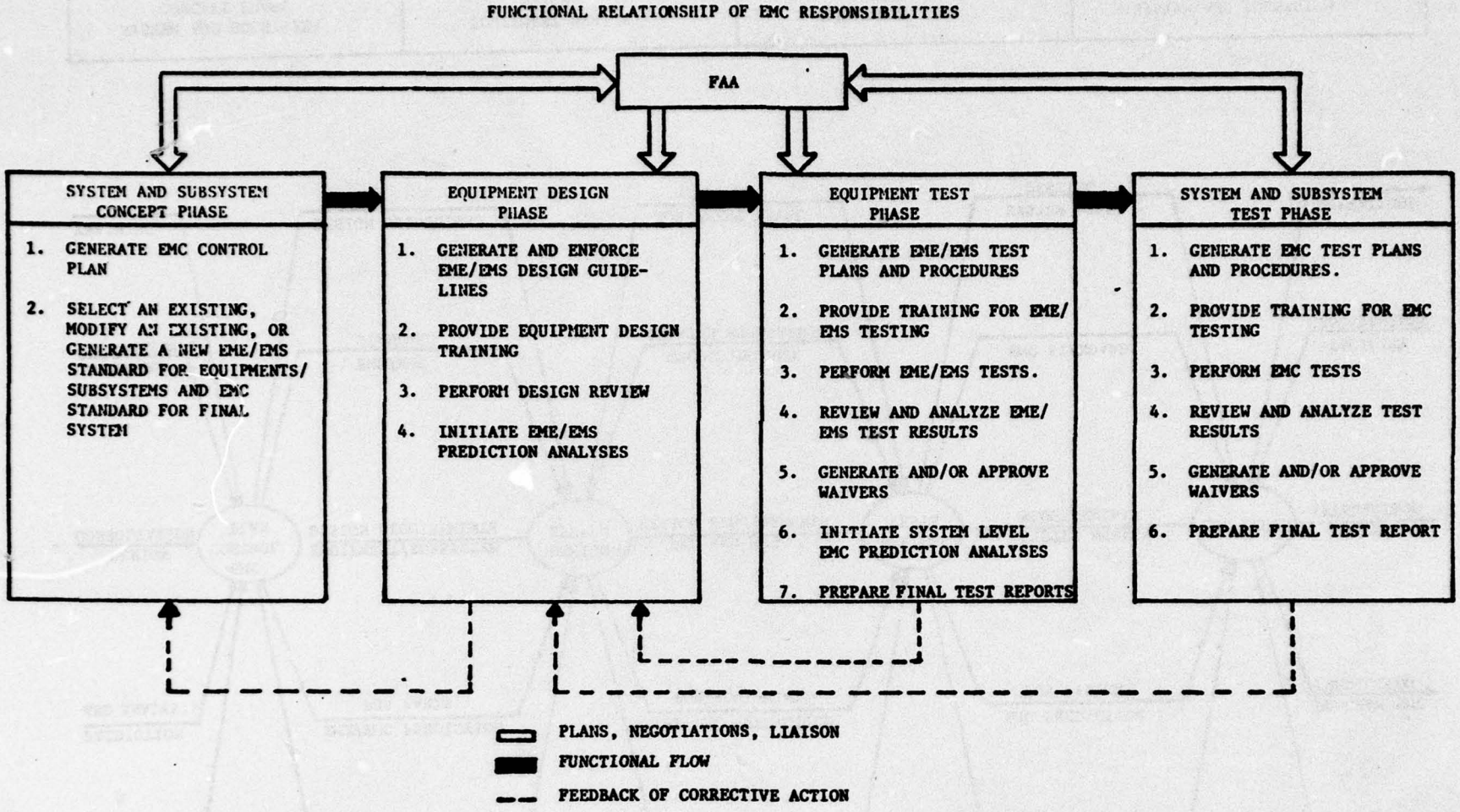


Figure 1. Functional Relationship of Typical EMC Responsibilities.

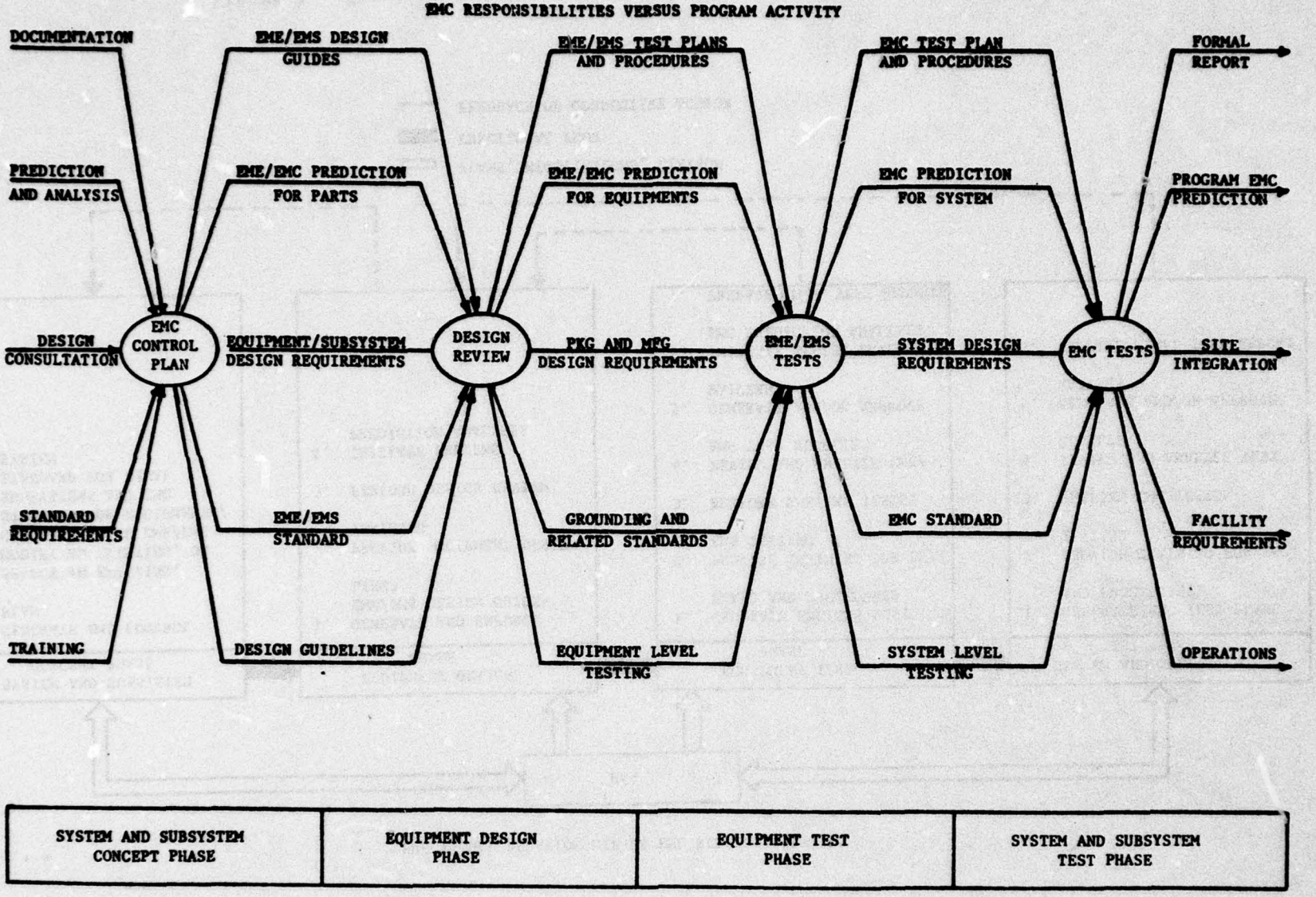


Figure 2. Typical EMC Responsibilities Versus Program Phases.

but is essentially nonexistent because of restraints resulting from organizational location. This is a primary reason for many ineffective EMC organizations. Therefore, in considering organizational locations, major emphasis will be placed on precluding this problem. There are basically two different approaches commonly taken in locating an EMC organization. For lack of a better designation, these two different approaches will be called decentralized and centralized EMC organizations, and each will be considered separately.

5.1.2.1 Decentralized EMC Organization

In this type of EMC organization, which is shown in Figure 3, there is generally no distinctive EMC organization as such. Sometimes an individual in a staff position at a reasonably high organizational level serves as "Head" of the EMC organization. Other members of the organization are either assigned to or designated within the various organizations already in existence. For example, an individual at the program staff level is often assigned the responsibility for overall EMC. He, in turn, designates an individual in each design organization, each test organization, and perhaps the facilities organization to provide him with EMC status, methods, problems, etc. This group of individuals would then meet, either periodically or as the need arises, to work out their EMC control effort. In this type of organization, EMC is almost always a part time job for the individuals involved.

This approach to locating an EMC organization has a single advantage, and that is the fact that the persons responsible for the EMC effort are very well integrated into the various program activities. This is obvious since they are a part of the design, test, etc. organizations. This advantage is not be weighed lightly, especially in view of the difficulty in finding individuals who have strong background experience in both EMC and various aspects of design, test, etc.

In contrast to the single advantage, the decentralized EMC organization has many disadvantages. Individuals working within any organization are strongly inclined to be concerned with their organization's primary mission

DECENTRALIZED EMC ORGANIZATION

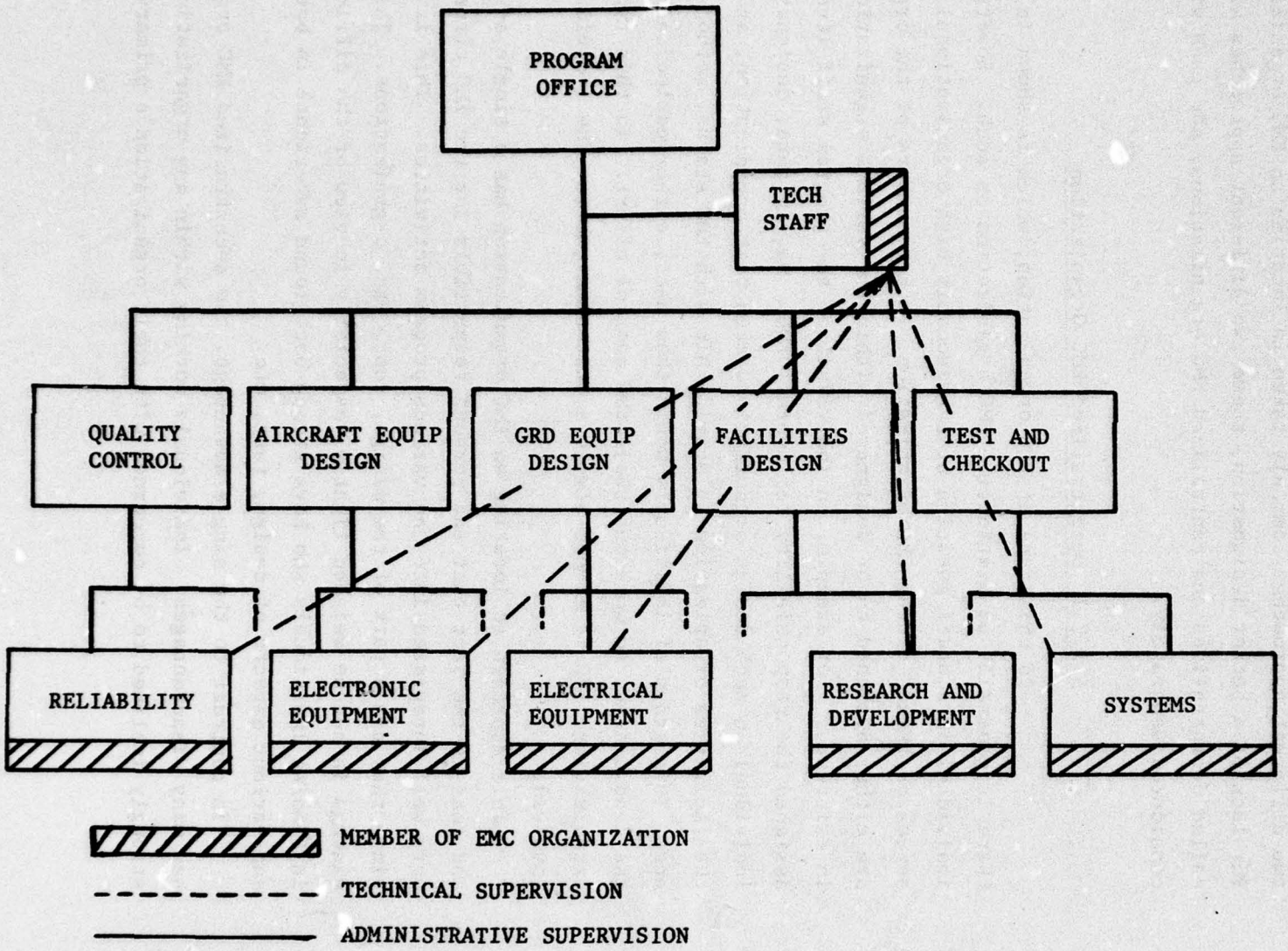


Figure 3. Decentralized EMC Organization.

much more so than to any secondary mission. EMC, therefore, tends to become at best a secondary concern; and the effectiveness of the EMC effort quickly reflects this. In matters involving the interpretation of the key design and test engineering controls, several different positions are likely on any one controversial issue. In many cases, the person responsible for the overall EMC effort does not have the authority to formulate the most valid interpretation for the program as a whole; consequently, each member of the EMC organization implements his own particular idea as to the best approach. In some cases where there is a person with the authority to determine and dictate the EMC policy, important elements of the EMC Program are not enforced because of the lack of time to review the efforts of each member of the EMC organization. As a result, the individual members of the EMC organization still implement their own ideas, resulting in a highly inconsistent EMC effort. This disadvantage is primarily the result of persons reporting administratively and technically to two different organizations. There is also the tendency within the decentralized type of EMC organization to meet only when serious problems arise. Such meetings completely eliminate the possibility of preventing problems before they occur. Further, the meetings of the EMC organization tend to become less and less formal as the program problems become more and more complex. These informal type meetings tend to accomplish less and breed misunderstandings resulting from semantic problems and the lack of communications. The result is to gradually begin holding fewer and fewer of these informal meetings. All of these factors reduce the effectiveness of the EMC organization, and an ineffective EMC effort does not result in program benefits.

5.1.2.2 Centralized EMC Organization

The EMC organization, as shown in Figure 4, is very distinctive as a centralized type of organization. The manager of the EMC effort has several individuals who report, administratively and technically, directly to him and routes of communications and authority can, therefore, be clearly defined.

The major disadvantages of this type of organization is the difficulty the EMC engineer experiences in first understanding the problems of the design

CENTRALIZED EMC ORGANIZATION

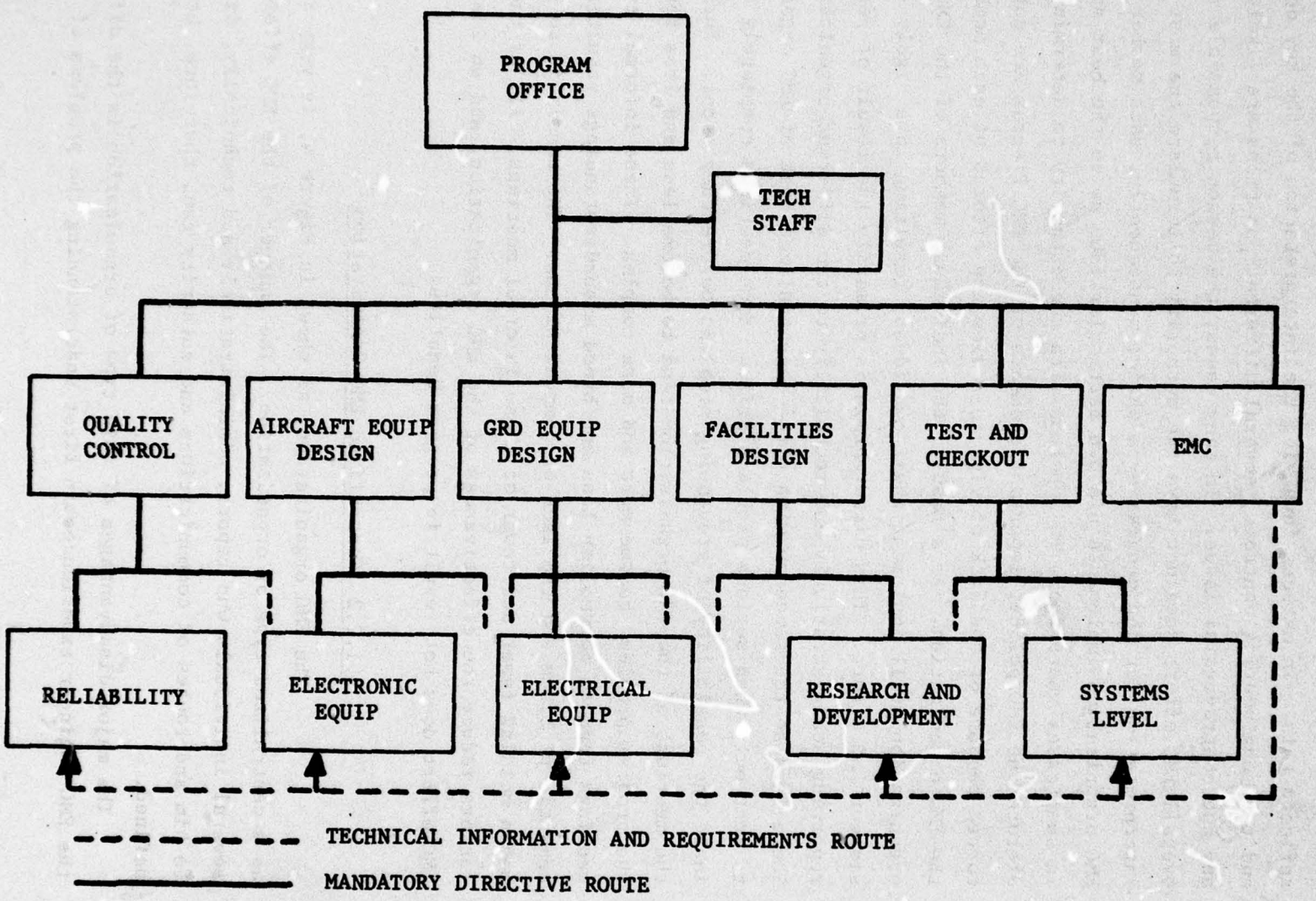


Figure 4. Centralized EMC Organization.

and test engineers and, secondly, having his technical opinion accepted by the design and test engineers. There is a tendency on the part of the design and test engineers to try solving their EMC problems themselves without calling attention to the fact that their equipment has resulted in an EMC problem; however, if the schedule becomes adversely impacted or when the problem has grown so complex as to almost defy solution, then the EMC engineers are called in. They are expected to solve the most complex of problems overnight after a short notice and essentially no technical briefings. If they cannot accomplish this, it "proves" that EMC organizations are not needed anyway. This example is admittedly exaggerated, but it does depict some of the difficulty that EMC engineers face in having their opinions and consultations accepted.

The advantages of the centralized type of EMC organization are numerous. A consistent EMC effort is obtained much easier because the interpretation and enforcement of various requirements is accomplished under the technical and administrative leadership of a single manager. Much greater standardization of procedures, methods, equipments, etc. is possible since it is not necessary to satisfy the whims of numerous supervisory persons. Since EMC engineers work side by side on a daily basis, they can share and exchange technical ideas readily, thereby expanding their EMC experience. Various EMC problems can now be precluded since both the personnel and information are available for before-the-fact analysis. The ability to develop new EMC methods and techniques is also more readily available because of the ease with which research and study efforts can be initiated under a central EMC organization.

5.1.2.3 Other Types of EMC Organizations

There are, of course, many different variations to the decentralized and centralized types of EMC organization previously discussed. One variation which is sometimes used involves merging the EMC and Reliability organizations together. It is argued that they both have the same function, i.e., reduction of failures and long-range cost improvement to both customer and contractor by precluding major fixes and mission failures. Further

argument for this organizational merger usually states that neither Reliability Engineering nor EMC should be in-line functions, but should serve in an advisory capacity. This is supposed to free the design engineers to do design work and the test engineers to do test work. The Reliability Engineering and EMC organizations would generate design and test limits and would review designs for compliance with these limits. The recourse available when design and test results do not comply with these limits would be to report to upper management.

Another rather frequent variation to the centralized and decentralized types of EMC organization involves incorporating EMC efforts in a Systems Engineering effort concerned primarily with characteristics of signals at interfaces. Too often, the signal characteristics of concern are those voltages, currents, impedances, waveforms, etc. necessary for the receptor circuit. Little or no concern is given to undesired characteristics of signals which are generally the source of EMC problems. Under these conditions, EMC control is highly ineffective.

A third and final variation tends to combine the decentralized and centralized types of EMC organization in a rather straightforward manner. With this variation, there is a very small central EMC organization, usually within the overall program organization, and with EMC representatives scattered throughout the program activities. All of these EMC personnel meet in what is typically called a "Working Committee" meeting. Meetings are normally held when a problem arises although they may meet periodically. For the most part, this variation combines all of the disadvantages of both the decentralized and centralized types of organization without sharing many of the advantages of either. Exceptions can be found to each of these types of EMC organizations.

Much of the eventual success of any FAA EMC organization can be attributed to the persons comprising it. The centralized organization, or some minor variation thereof, generally seems to work most effectively. In any case, the EMC organization must be supported by and have access to upper management. Then, and only then, will the EMC effort be effective, thereby resulting in benefits to the overall program.

5.2 EMC Management Tools

Once a satisfactory EMC philosophy has been developed, approved by management, and readied for implementation, there are numerous tools which can be used in initiating the EMC Program. The availability of these tools assumes that suitable EMC standards applicable at the system and/or equipment levels have been imposed at the time of procurement. With this being the case, the most commonly available management tools are EMC Control Plans, Test Plans, Test Reports, and Waiver Requests.

5.2.1 Control Plans

Within the FAA Electromagnetic Compatibility Program, the Control Plan will be the most significant document prepared, and its importance cannot be over-emphasized. Simply stated, the purpose of the Control Plan is to define how the EMC Program, required by contractual documents, is to be accomplished. The Control Plan, therefore, becomes the basic document from which all EMC Program requirements are derived. Without a thorough and comprehensive Control Plan, the EMC Program requirements, for engineering as well as managerial personnel, are not technically established or authoritatively documented. As such, enforcement of requirements is virtually impossible.

In view of this Plan's purpose, it is necessary that EMC requirements, scope of activity, organizational responsibilities, implementation procedures, etc. be thoroughly defined prior to Control Plan submittal for FAA approval. The requirements in Appendix A are presented as guidelines which, if followed in the preparation of an EMC Control Plan, will help to obtain approval by assuring thorough and comprehensive requirements for EMC Control. The Control Plan should be submitted by the contractor within 90 days after the contract is awarded.

It should be noted that portions of the Control Plan guidelines will be defined only as the EMC Program progresses; therefore, these portions cannot be included in the initial submittal of the Control Plan, but instead, should be added during subsequent reviews and updatings. The format in which these guidelines are submitted is not necessarily intended as a requirement for the Control Plan format.

5.2.2 Test Plans

Test Plans represent another type document which, when effectively implemented, will appreciably enhance the management of an FAA EMC Program. Because of their nature, they complement the Control Plan but are considerably more influenced by "levels" of applicability than are Control Plans. Since the Control Plan is the overall document that defines the EMC effort in its entirety, it can be prepared as applicable to either the system or equipment level; however, it is much more common for a single Control Plan to be all-encompassing and, therefore, prepared for both the equipment and system levels. In this way, a single Control Plan can define all EMC efforts associated with a particular system. The Test Plan may also be prepared to cover both system and equipment levels, but this format is seldom, if ever, satisfactory. This unsatisfactory condition results primarily because of the extensive difference between test requirements for systems and equipments. It is, therefore, more satisfactory and common to prepare separate system level Test Plans and equipment level Test Plans. Additionally, individual Test Plans are usually prepared for each major equipment or subsystem within a system. Whether or not these individual Test Plans are prepared is determined largely by how nearly identical the various subsystems and/or equipments are.

As with the Control Plan, the purpose of Test Plans varies as a function of applicability. In a very broad sense, it is to assure that, for every design requirement, there is a corresponding test requirement, and conversely, for every test requirement, there is a corresponding design requirement. This precludes a strong EMC emphasis on design without a subsequent emphasis on EMC testing that assures design goals have been met. Further, it also precludes the much more likely event of an EMC test effort on systems or equipments for which there was no EMC design emphasis.

In a somewhat more specific sense, the purpose of a Test Plan is to assure that the contractor has given thoroughly adequate consideration to every aspect of the forthcoming EMC test. Typical of these aspects of the planned test are the test environment; system, subsystem, or equipment

configuration, installation, and mode of operation; applicable test procedures and limits; etc.

In MIL-E-6051D, the stated purpose of the Test Plan is "to provide the contractor a means by which his EMC Test Program (EMCTP) can be submitted to the customer". MIL-STD-461A presents the Test Plan purpose as being to "detail the means of implementation and application of the test procedures to be performed to verify compliance with the applicable EMI/EMC requirements". It is noted that in an older EMC standard (MIL-I-26600) the applicability of the Test Plan was limited "to the equipment being procured" and, therefore, the purpose of the Test Plan did not apply to equipments that were developed in-house by the FAA or to those provided to a contractor by the FAA. This standard also required a level of detail that was not common to the detail required in other Test Plans. This resulted from the requirement that "the Test Plan shall be sufficiently detailed so that a qualified technician can, with little additional information, use the Plan to conduct tests". Other specifications not requiring this level of detail depend on the generation of Test Procedures for use prior to test performance.

In view of the above purposes of EMC Test Plans, it is obvious that they are extremely important tools for any effective EMC effort. In essentially every respect, Test Plans are to the test effort (whether at the system, subsystem, or equipment level) what the Control Plan is to the program management effort. As such, Test Plans are normally subservient to the Control Plan; and, as a matter of fact, the Control Plan often stipulates that Test Plans must be prepared. In this context, a comprehensive and thorough Test Plan remains an essential and mandatory document, and its importance relative to the Control Plan--and, hence, the total program--is established. That Test Plans are important is indicated by the fact that essentially every EMC standard and specification requires their generation.

Requirements related to Test Plan submittal date and approval are as varied as the Test Plans themselves; however, it is recommended that the FAA retain approval authority over Test Plans and that this approval be formally received prior to performance of the test. MIL-STD-461A requires that "approval of the Test Plan shall precede any formal testing" (para. 4.3); but if MIL-E-6051D is imposed by the FAA on system procurements, no Test Plan submittal or

approval prior to test performance is required. This requirement must, therefore, be separately incorporated into the Procurement Specification. It is noted that earlier EMC specifications such as MIL-I-6181D and MIL-I-26600 did not state that the customer had approval authority over Test Plans. In numerous cases, contractual problems arose over this point when the schedule began to bind and funds became short. This situation was subsequently corrected by requirements in later documents such as MIL-STD-461A.

As has been indicated earlier, Test Plan contents will vary widely depending on not only the level of their applicability, but also on the particular system or equipment to which they are applicable. Consequently, it is not possible to present Test Plan contents in any detail that is universally applicable. To circumvent this problem and still provide needed guidelines for preparation of Test Plans, Appendix B has been prepared. This appendix assumes a particular type of system for which the primary contents of a representative Test Plan are presented. Selection of a system level rather than an equipment level Test Plan is made because it is felt that system level Test Plan requirements may be more easily downgraded to the equipment level than vice versa. Also, system level Test Plan contents will be representative of the type of content necessary in an equipment level Test Plan. This selection will also preclude the problem of identifying an equipment type for which Test Plan contents are presented. Such a problem would exist because of the tremendously wide variety in electrical/electronic equipments used by the FAA. Consideration of the guidelines in Appendix B should help substantially in obtaining FAA approval of Test Plans.

5.2.3 Test Reports

Control and Test Plans are essential in initiating EMC activity; however, the final determination of whether the goal of the EMC Program has been achieved or not is made based on test results documented in Test Reports. Consequently, Test Reports are important and their submittal in a timely manner is essential. As in the case of Test Plans, Test Reports are applicable for both the equipment and system level efforts. Unlike Test Plans,

however, the type of information required in Test Reports is similar regardless of whether the test item was a system or equipment.

It is recommended that, as a minimum, the FAA require Test Reports to be submitted for evaluation prior to accepting equipments and/or systems. In the case of complex electronic systems that perform functions critical to safe air transportation, it is recommended that FAA approval of the Test Report be a condition of system acceptance.

A suitable format for Test Reports submitted to the FAA is presented in Appendix D of MIL-HDBK-237. This format includes the usual Cover Page followed by Administrative Data such as the contract number, description of the equipment or system tested, test location, definition of the ambient electromagnetic environment in the test area and a list of the tests conducted. Then appendices are added in sufficient number to describe in detail each test. This detailed description must include the test procedures used as well as data sheets, graphs, illustrations, and photographs. Where applicable, daily log sheets that document sequential efforts must also be provided in these appendices. A separate appendix for terminology is required if specialized words or terms are used. In the appendices for individual tests, special attention must be devoted to reporting results of the data analysis and the comparison of measured signal levels with acceptable performance limits. Whether or not an equipment or system is electromagnetically compatible must be specifically specified.

5.2.4 Waiver Requests

In the case of a complex system, it is doubtful that all EMC requirements will have been met even when an adequate EMC organization has approved an acceptable Control Plan and Test Plan. Therefore, it is likely that Waiver Requests will be received from the contractor and must be dealt with in a manner that does not degrade overall EMC.

A point of extreme importance in the review of Waiver Requests is that requests to delete tests (as opposed to accept test data that exceed specified performance limits) should be strongly discouraged. Also, it is important that the same EMC organization review and act on all Waiver Requests so the cumulative effects of a multiplicity of approved waivers can be

assessed. The EMC organization that reviews Waiver Requests should compare susceptibility thresholds with emission levels in determining whether a waiver can be granted. It is noted that, in many cases, granting approval for requested waivers will represent an action that is cost-effective and not technically degrading for the FAA. It is recommended, however, that Waiver Requests clearly indicate that the contractor's failure to comply with applicable EMC requirements is not the result of neglecting basic EMC principles during any phase of equipment or system development. Typical of the information needed in order to adequately judge the merits of a Waiver Request is the following:

(1) the number of equipments or systems involved,

(2) the installed location of these equipments or systems and their criticality relative to safe and reliable air transportation,

(3) the impact on program cost and schedule,

(4) the measured data (emission levels and susceptibility thresholds) compared to applicable performance levels, and

(5) the contractor's assessment of degradation that would result if the waiver were granted, and the rationale for this assessment.

5.3 EMC Programs Tasks

To this point, various recommendations regarding EMC organizations and management tools have been presented. With these recommendations in mind, a hypothetical development program can be assumed and specific tasks, as a function of time, that must be accomplished by the EMC organization can be defined. Accomplishment of these tasks with firm management support will virtually assure the implementation of an effective EMC Program.

The hypothetical program is assumed to require the design, assembly, test, and delivery of a large electrical/electronic system. The FAA is procuring the system from a large contractor and is, therefore, serving in a program management function only. The program is assumed to be 15 months in duration. Typical tasks constituting an effective EMC effort are chrono-

logically defined for both the FAA and contractor. The FAA EMC responsibilities are designated with an asterisk, and the chronological order is shown in Figure 5. The individual program tasks are as follows:

*a. Assure incorporation of the EMC requirements in the Procurement Specification before it is issued as a Request for Quotation.

(1) Include the requirement for an electromagnetically compatible system as a major performance requirement in the Procurement Specification.

(2) Include the required systems level and equipment/subsystem level EMC, EME, and EMS standards in the Applicable Documents portion of the Procurement Specification.

(3) Include the required EME and EMS standards in the equipment/subsystem level Design Requirements portion of the Procurement Specification and the required EMC standards in the systems level Design Requirements portion of the Procurement Specification.

(4) Include the required equipment/subsystem level EME and EMS standards in the Qualification Test portion of the Procurement Specification.

(5) Include the required systems level EMC standard in the Integrated Systems Test portion of the Procurement Specification.

*b. Assure that the required EMC, EME, and EMS standards are properly included in the final contract after all quotations have been reviewed and a contractor selected. This requires a review of the formal Procurement Specification to determine that the required EMC documents are properly included from both a legal and technical point-of-view.

*c. Provide the contractor with broad requirements for the EMC Control Plan. Generation and submittal of this plan must be a contractual requirement, and the FAA must have approval authority.

QUARTERS	STEP NUMBER	ACTION REQUIRED
1	*a	INCORPORATE EMC REQUIREMENTS IN PROCUREMENT DETAILED SPECIFICATION
	*b	ASSURE EME, EMS, AND EMC REQUIREMENTS ARE IN FINAL CONTRACT
	*c	PROVIDE CONTRACTOR EMC CONTROL PLAN REQUIREMENT
	d	SUBMIT EMC CONTROL PLAN
2	*e	PROVIDE CONTRACTOR EME AND EMS TEST PLAN REQUIREMENTS
	*f	PERFORM EME AND EMS DESIGN REVIEW
3	*g	PROVIDE CONTRACTOR EMC TEST REQUIREMENTS
	h	SUBMIT EME AND EMS TEST PLAN
4	*i	PROVIDE CONTRACTOR EMC TEST PLAN REQUIREMENTS
	j	PROCURE EME AND EMS TEST FACILITIES
	k	SUBMIT EME AND EMS TEST PROCEDURES
	l	INITIATE EME AND EMS TESTING EFFORT
	m	SUBMIT EMC TEST PLAN
5	n	PROCURE TEST EQUIPMENT FOR EMC TEST
	p	PERFORM EMC QUALIFICATIONS TEST
	q	INCORPORATE REMEDIAL FIXES
	r	REPEAT EMC QUALIFICATION TEST ON MODIFIED EQUPIMENTS/SUBSYSTEMS
	s	SUBMIT FINAL EMC TEST REPORT

Figure 5. Chronological Order of Typical EMC Tasks

The requirements provided to the contractor should define the nature and type of EMC information to be included in the Control Plan. Minimum suggested portions of the Control Plan include Introduction, Definition of Terms, Applicable Documents, Program Management Requirements, Design Requirements, Test Requirements, and Standard Interpretations.

d. Submit an acceptable EMC Control Plan within three months after contract award. The submitted plan should cover the areas outlined in Step c. and should specify a semi-annual review requirement during which any applicable program redirections or changes can be included in the Control Plan.

*e. Provide the contractor with broad EME and EMS Test Plan requirements. Preparation and generation of this Test Plan will define the equipment/subsystems level testing to be performed, and should be a contractual requirement over which the FAA has approval authority.

(1) Include criteria to be used in determining which equipments/subsystems should be EME and EMS tested.
(2) Require identification, by name and serial number, of the equipments/subsystems to be tested.
(3) Include criteria to be used in determining the extent of the EME and EMS tests to be performed.
(4) Require submittal of a projected test schedule and test location.

*f. Perform an EME and EMS design review to assure that the equipment/subsystems have complied with the applicable design requirements portion of the EMC Control Plan.

*g. Provide contractor with broad systems level EMC test requirements.

(1) Include the type and nature of the system level EMC test to be performed.
(2) Include the prerequisites that must be satisfied prior to the systems level EMC test.

(3) Include the criteria to be used in selection of equipment/subsystem points to be monitored during the EMC test.

(4) Include the criteria for system EMC acceptance and/or rejection.

h. Submit an acceptable EME/EMS Test Plan that adequately covers at least the areas covered in Step e.

*i. Provide contractor with broad EMC Test Plan requirements. Preparation and generation of this Test Plan will define the systems level EMC testing to be performed and should be a contractual requirement over which the FAA has approval authority.

(1) Include the overall systems level EMC test philosophy to be followed.

(2) Require designation of the system to be EMC tested and its test locations.

(3) Require submittal of projected system level EMC tests, including the sequence of tests which will depict the EMC testing relative to other systems level testing.

(4) Require designation of the organization responsible for performance of the various phases of the system level EMC test.

(5) Require block diagrams and identification of the equipment to be used to perform the EMC test.

j. Procure equipment/subsystems level test facilities including screen rooms, test equipments, screen room filters, etc.

k. Submit equipment/subsystem level EME and EMS Test Procedures. These procedures should include operating modes, configurations, test methods, etc.

l. Initiate equipment/subsystem level EME and EMS tests in accordance with the Step k. Test Procedures and Step h. Test Plan.

m. Submit an acceptable systems level EMC Test Plan covering the areas outlined in Steps g. and i.

n. Procure the equipment to be used in performing the system level EMC test.

o. Submit acceptable EMC Test Procedures delineating the test equipment configuration and calibration, equipment/subsystem points to be monitored within the system, applicable limits for each test point, operational mode of the system during various test phases, etc.

p. Perform a complete and comprehensive EMC System Compatibility Test on the first system representing final configuration. The test will be in accordance with the Step o. Test Procedures and the Step m. Test Plan.

q. Incorporate any required remedial fixes.

r. Repeat the EMC General Acceptance Test on all changed or modified portions of the system to assure the adequacy of the Step q. remedial fixes.

s. Submit a final systems level EMC Test Report.

This outline of EMC program tasks does not, of course, satisfy all of the needs of every large electrical/electronic system. Exceptions to these tasks and to their time sequence will exist and are, in fact, expected. These expected exceptions are the result of system complexity, nature of the system's final mission, various program philosophies and approaches assumed by management, etc. However, in spite of all exceptions, these tasks represent a large percentage of the efforts needed in order for an FAA procurement to benefit as a result of an effective EMC Program. For procurements with a duration either longer or shorter than 15 months, the time frame of the task outline can be expanded or compressed to suit particular needs.

Several results and conclusions are obvious from an analysis of this outline of EMC tasks. First, of the twenty major tasks outlined, seven are the responsibility of the FAA. The nature of these tasks is to define requirements and to survey the contractor's response to these requirements. It should, therefore, be recognized that an effective EMC organization must

exist within the FAA, as well as within the contractor, organization. This is true even though the primary role of the FAA is one of managing the program rather than doing the actual design, assembly, and test. In some cases in the past, this need for a customer EMC effort has been overlooked with the result being a diminished EMC Program for the final system. Secondly, it should be noted that the FAA will have a definite responsibility to provide requirements, at least in broad terms, to the contractor with a sufficient lead time before contractor documentation is expected. Otherwise, a time consuming period of documentation submittal, rejection, resubmittal, etc. can be expected. Situations commonly exist on large programs in which the time period between documentation rejection and resubmittal is six months. Thirdly, there is some specific and well defined documentation required that is peculiarly EMC oriented. This documentation consists of the Control Plan, the system level and equipment/subsystem level Test Plans and Test Procedures, etc. In some cases, situations may exist in which it is easier to obtain the required EMC information through already-established documentation channels. This situation is, of course, satisfactory so long as the desired EMC information is received in a timely manner.

6. SUMMARY

To even the casual observer, it is obvious that the number of industrial and commercial aircraft in service is increasing and that the electronic systems used to control air transportation are complex assembledges of an advanced nature. Also true but not so obvious is the fact that this air transportation system is highly dependent on and influenced by electromagnetic signals. This situation has evolved to the point that there is now a need for a formalized EMC Program within the FAA. This document has presented management and engineering factors that must be thoroughly considered as formalization of this EMC Program is undertaken. Recommendations have been made, especially in the areas of control documentation and organizational aspects of the EMC Program. It is firmly believed and respectfully submitted that (1) the complement of electronic devices in use by the FAA demands a coordinated program of EMC control and (2) the recommendations made herein encompass the major tenets of an effective EMC Program.

7. SELECTED BIBLIOGRAPHY

The following reference documents are listed as sources of additional information regarding implementation of an effective program of EMC control:

(1) White, Donald R. J., "A Handbook Series on Electromagnetic Interference and Compatibility," Vol. 1, Chapter 7, Don White Consultants, Inc., Germantown, MD, 1973.

(2) White, Donald R. J., "A Handbook Series on Electromagnetic Interference and Compatibility,", Vol. 3, "EMC Control Methods and Techniques," Don White Consultants, Inc., Germantown, MD, 1973.

(3) Hoffart, H. and Ball, N., "EMC Control Effort on the ACE-S/C System (Apollo Program)," Tenth Tri-Service Conference on EMC, November 1964, pp. 58-76.

(4) Nichols, F. J., "Management Responsibility in Obtaining an Electrical/Electronic Compatible Weapon System," Eighth Tri-Service Conference on EMC, October 1962, pp. 44-58.

(5) Weinstock, G. L., "Electromagnetic Interference Control Within Aerospace Ground Equipment for the McDonnell Phantom II Aircraft," IEEE Trans. on EMC, Vol. EMC-7, June 1965, p. 85.

(6) Fousel, V. L., "On Achieving Compatibility Between Management and EMC Specialties," 1970 IEEE EMC Symposium Record, July 1970, p. 120.

(7) Osburn, J. D. and Morris, F. J., "Reliability Techniques for Design Control of EMC," 1970 IEEE EMC Symposium Record, July 1970, p. 124.

(8) Cummings, J. R., "Harpoon Missile EMC Management," 1975 IEEE EMC Symposium Record, October 1975, p. 6AIa1.

(9) Robertson, D. W. and Toler, J. C., ed., Electromagnetic Compatibility Short Course Lectures, August 1969, Chapters 17, 32, 33.

(10) NASA, Electromagnetic Compatibility Principles and Practices (Apollo Program), National Aeronautics and Space Administration, Washington, DC, 1965, Chapters 2, 3, 15.

APPENDIX A

GUIDELINES FOR CONTROL PLAN PREPARATION

INTRODUCTION

A brief and concise Introduction should be provided to identify the system and/or facility to which the Control Plan is applicable, and the purpose of the Control Plan with respect to the overall EMC Program. The Introduction should also state whether the Control Plan is submitted in response to paragraph 3.2 of MIL-E-6051D, paragraph 4.2 of MIL-STD-461, or Appendix A of Reports FAA-RD-76-69 and FAA-RD-76-70 (if called out in the contract). It is recommended that the requirements for both documents be covered in a single Control Plan, and the subsequent requirements are so written. However, if generation of the information necessary to satisfy the requirements of both a MIL-E-6051D and a MIL-STD-461 Control Plan causes an undue delay in submittal, the Control Plan requirements of MIL-STD-461 should be prepared first. A second Control Plan, satisfying the requirements of MIL-E-6051D, should be submitted within three months after submittal of the MIL-STD-461 Control Plan.

The Introduction should also specifically stipulate a time period for Control Plan review and updating by the contractor. If the review indicates that there have been no program changes that affect the EMC Program defined in the Control Plan, no updating or revision is necessary. A time period not exceeding six months is generally acceptable for these periodic reviews.

The relationship between requirements of the imposed EMC standards should also be clearly shown in this portion of the Control Plan. The relationship shown between standard requirements will, in effect, be the broad policy statement on which the remainder of the contractor's EMC Program rests. Since MIL-E-6051D, MIL-STD-461, and MIL-STD-462 are the applicable EMC documents, systems level electromagnetic compatibility is the ultimate goal of the EMC Program. The requirements of MIL-STD-461 and MIL-STD-462, as defined in subsequent portions of the Control Plan, are reasonable and mandatory steps taken at the equipment/subsystem level to assure accomplishment of the EMC Program goal. The necessity of MIL-STD-461 test results for defining the MIL-STD-6051D test should also be clearly stated. Recognition of these facts in the Introduction to the Control Plan, and throughout the EMC Program, is of paramount importance.

Also in the Control Plan Introduction should be strong and concise statements to the effect that the contractor's EMC Program will emphasize "before-the-fact" design of compatibility into the electrical/electronic equipments. "After-the-fact" testing of equipments for EME/EMS without the "before-the-fact" EME/EMS design emphasis is, in effect, equivalent to testing equipments for performance for which they were not designed. EMC design emphasis is, therefore, mandatory.

APPLICABLE DOCUMENTS

Documents which influence the EMC Program, either directly or indirectly, should be listed in this portion of the Control Plan. These documents could be categorized as government or contractor standards, specifications, plans, drawings, reports, etc. Effective dates, if applicable, of the listed documents and all restrictions or limitations affecting the incorporation of the documents should be included. If EMC related documents are classified into various levels such that some are submitted for approval, others for review, and maybe others are available upon request for information, these levels should specifically be stated. Special attention should be directed to assuring that EMC documentation is submitted within a satisfactory time interval.

DEFINITIONS

This portion of the EMC Control Plan is necessary in order to determine the extent and scope of effort. Many words or phrases have various meanings to different organizations. Some of the most frequently misused terms and, therefore, terms requiring definition are: bonding, contractor's preliminary tests, design qualification tests, type tests, production tests, type acceptance procedures, ground, interference, susceptibility, system, subsystem, equipment, ambient environment, compatibility, and safety margin. These, plus any other contractor peculiar terms, require thorough definition and must be used in their defined context throughout the Control Plan. (See Section 2, TERMINOLOGY, of this Program Plan for suggested nomenclature.)

MANAGEMENT OF EMC PROGRAM

The effectiveness with which an EMC Program can be implemented is obviously affected by all restrictions that are placed on the Program initiators. These restrictions may take the form of poor management decisions, ineffective organizations, lack of technical capability, etc. For these reasons, this portion of the Control Plan should contain positive statements of Program Management's intent to fully support an effective EMC Program and sufficient organizational information to assure that the EMC Program can be readily implemented. Normally, this portion of the Control Plan will present a chart or work statement presenting organizational elements and responsibilities such as:

(1) The central EMC coordination organization. This single, authoritative organization should be the central contact for all EMC Program matters and should have authority for making final decisions in all EME/EMS/EMC policies, concepts, philosophies, and specification interpretations. This organization should also prepare the EMC Control Plan.

(2) The organization(s) responsible for preparation of EME/EMS/EMC procedures, plans, reports, and other associated documentation such as the Test Plan, Test Procedures, Process Specifications, Waiver Requests, etc. Where more than one organization provides inputs to documentation, the organizational chart should reflect this.

(3) The organization(s) responsible for EME/EMS/EMC testing at all levels. This organization chart should show equipment/subsystem level (MIL-STD-461 and MIL-STD-462) testing activity, such as development, qualification, and engineering, as well as system level (MIL-E-6051D) testing activity, such as qualification, acceptance, and compliance. Additionally, this chart should indicate the organization responsible for the ambient electromagnetic environment at the test site.

(4) The organization(s) which will provide EME/EMS/EMC representation during the various system and equipment level reviews. These reviews should logically be concurrent with the program conceptual phase, equipment design phase, and various testing phases. If the review is performed by a designated team, one of the team members should be an EMC engineer.

(5) The organization(s) responsible for the preparation, approval, and submittal of Deviation Requests against EME/EMS/EMC requirements or standards. As a general rule, the responsible design organization prepares needed Deviation Requests, and the central EMC coordination organization provides approval or disapproval prior to any formal submittal to the FAA.

IMPLEMENTATION OF THE EMC PROGRAM

This portion of the EMC Control Plan should present the means by which EMC control is to be assured. The control means presented must be applicable at the equipment/subsystem design, development, assembly, and test phases as well as at the final system assembly and test phases.

In applying MIL-STD-461 and MIL-STD-462 at the equipment/subsystem level, the Control Plan should obligate the contractor to:

(1) Perform a technical review of all electrical/electronic equipments for the purpose of defining characteristics which influence the propensity for EME and EMS. Typical characteristics include equipment/subsystem complexity, extent of miniaturization, sequence and mode of operation, location, etc.

(2) Establish equipment categories using the results of the above technical review and the equipment classification table in MIL-STD-461. Factors considered in this category assignment are: (a) expected EME and EMC characteristics of the equipments, (b) where and when are the equipments used, (c) what EME/EMS designs are being incorporated into the equipments, (d) what equipment is essentially identical, from an electro-

magnetic point-of-view, to other equipments, (e) the equipment complexity, and (f) criticality of the equipment with respect to the mission of the FAA facility where it is to be installed.

(3) Review equipments, using the categories established above, to define (a) which equipments will and will not require testing, (b) the level at which the test will be performed (chassis, subsystems, facility, etc.), (c) the extent of testing relative to frequency ranges, limits, etc., (d) the serial number of the equipments/subsystems to be tested, and (e) the projected testing schedule.

(4) Define all requirements for equipment/subsystem level EME/EMS Control Plans and Test Plans required by Paragraphs 4.2 and 4.3 of MIL-STD-461 or by Appendix A in FAA reports FAA-RD-76-69 or FAA-RD-76-70. Any equipment/subsystem level Control Plan should be heavily oriented toward specific design requirements. As stated in the Introduction, separate MIL-E-6051D and MIL-STD-461 Control Plans are not recommended; therefore, equipment and system design requirements should be thoroughly documented and included in the Design Requirements portion of this Control Plan. Test Plans should be generated for each EME/EMS test performed at the chassis level or higher.

(5) Review both MIL-STD-461 and MIL-STD-462 for applicability to FAA equipments. Where the requirements of these standards do not apply, specific deletions should be proposed in the Control Plan. In cases where the intent of the specified requirement is desirable but the requirement is unsatisfactory, the Control Plan should propose a recommended change to the standard requirement. All requirements considered necessary for adequate EMC control but not specifically required by the applicable standard should also be included in the Control Plan.

(6) Define the means by which satisfactory grounding (FAA-ER-350-023) and EME/EMS (MIL-STD-461) design controls are to be imple-

mented. This includes (a) a listing of the design guidelines that will be applicable, (b) the means by which these guidelines are to be effectively presented to the design organizations, (c) the control used to assure that the design guidelines are followed, and (d) the participation, responsibility, and authority of the EMC representative during the various design reviews.

In applying MIL-E-6051D at the system level, the Control Plan should obligate the contractor to the following:

(1) Categorize all of the equipments/subsystems comprising the system into EMC oriented criticality categories. These criticality categories will be based on the mission of the individual system as a part of an air transportation facility. Facility criticality categories should be based on equipments whose improper operation will result in (a) compromised flight safety and (b) adverse influence on flight schedules.

(2) Use the EME/EMS characteristics obtained during the equipment/subsystem level testing to define the test points and limits for the system level test. This requires that the susceptibility characteristics of each critical equipment be compared to the emission characteristics of the other equipments such that potential EMC problem areas can be defined and resolved. Equipment characteristics used during this comparison will include signal levels and frequencies. The results of the comparison of characteristics will determine whether or not potential incompatibilities exist at the system level; whether the mode of potential incompatibilities is radiated or conducted; on which conductor, in the case of conducted signals, the incompatibility will occur; and the limits that must be tested for in order to allow a sufficient margin of safety.

(3) Perform the following three types of EMC tests: (a) Unacceptable Response Tests to detect all unacceptable responses

and/or malfunctions at the outputs of critical equipments, (b) Transient Tests to assure that no transient voltages across DC inputs to transistorized equipment exceed a level that is 50% greater than the nominal power supply voltage, and (c) Safety Margin Tests to assure that interfering signals appearing at the susceptible points of critical equipments are six dB below the minimum signal that would result in operation, activation, or malfunctioning of the equipment.

(4) Review MIL-E-6051D for applicability insofar as an adequate EMC test on the system is concerned. Where requirements of the standard do not apply, specific deletions should be proposed in the Control Plan. In cases where the intent of the standard requirement is desirable, but the stated requirement is unsatisfactory, the Control Plan should propose recommended changes. All requirements considered necessary for adequate EMC control but not specifically required by MIL-E-6051D should also be included in the Control Plan. Typical of these requirements needed but not currently required by MIL-E-6051D are: (a) monitoring of system level transients to determine not only amplitude, but also rise time and duration, (b) analysis of the six dB margin of safety to assure its applicability for the particular equipment being monitored, and (c) deviating from this six dB safety margin requirement if sufficient justification exists, etc.

(5) Designate the systems for which a formal EMC Test Plan will be prepared. It is recommended that EMC Test Plans be prepared for the first installation system and for all subsequent systems that are significantly different, from an electromagnetic point-of-view, from this first installation system. For subsequent systems essentially identical, from an electromagnetic point-of-view, to the first installation system, the EMC test information from the first system should

be included in the Test Report for subsequent systems. The time at which the EMC Test Plan will be submitted for approval should also be designated. A time of six months before the EMC test is recommended (this six months time period represents a significant change from MIL-E-6051D, but is realistic when the Test Plan Requirements of this Program Plan are reviewed).

(6) Prepare formal EMC Test Procedures to be used in the performance of various EMC tests. The time at which these EMC Test Procedures will be submitted for approval should also be included. A time of eight weeks prior to the EMC test is recommended.

(7) Provide a test area ambient electromagnetic environment that does not exceed the susceptibility threshold of any critical equipment within the system. Major efforts to be expended in the suppression of facility equipments and in providing an adequate ground reference plane should also be delineated.

(8) Specify the various EMC tests to be performed at each location in cases where tests and evaluations are performed at more than one location.

(9) Integrate EMC testing with other functional performance testing such that a majority of the EMC tests are in parallel, rather than in series, with the overall testing schedule.

(10) Perform a System Compatibility Test, in accordance with paragraph 4.3.1 of MIL-E-6051D, on the first installation system. This test should be considered the EMC Qualification Test.

(11) Incorporate remedial measures where incompatibilities are detected during the System Compatibility Test. The effectiveness of these remedial measures should be demonstrated by tests, in accordance with the General Acceptance Test requirement in paragraph 4.3.2 of MIL-E-6051D, prior to installation of the first system. For obvious reasons, the General Acceptance Test should be performed on the first installation system at its manufacturing location; however,

if schedules will not allow this, performance of this test at a different location or on another system identical to the first system could reluctantly be accepted. If there are no incompatibilities during the System Compatibility Test, there is no requirement for a General Acceptance Test.

(12) Perform a General Acceptance Test, in accordance with paragraph 4.3.2 of MIL-E-6051D, on all subsequent systems which are not electromagnetically identical to the first installation system.

(13) Prepare a final report on each system level EMC test. The time for submittal of the report for approval should also be designated. A time not exceeding 45 days after completion of the EMC test is recommended. The report should specifically identify all/any follow-up EMC tests that should be performed at the installation site.

In addition to the requirements dealing with implementation of the applicable standards, several other requirements should be included in the Control Plan in order to implement overall and effective EMC control. These requirements include the following:

(1) The Control Plan should include the milestones and target dates for the EMC Program relative to the schedules applicable to the entire system. Typical EMC Program milestones are (a) preparation and submittal of the Control Plan, (b) preparation of the various equipment level EME/EMS Test Plans, (c) qualification testing of equipment to applicable EME/EMS requirements, (d) preparation of the systems level EMC Test Plan, (e) preparation of the various equipment level EME/EMS Test Procedures, (f) preparation of the systems level EMC Test Procedures, (g) initiation of the System Compatibility Test, (h) initiation of the General Acceptance Test, and (i) other milestones dependent on the system being developed.

(2) The Control Plan should include a delineation of the means by which design, test, and management personnel will be in-

formed of the EMC Program requirements and guidelines. These means should include formal and/or informal training sessions, periodic informative publications prepared and distributed by the EMC organization, and/or EMC committee meetings held regularly with representatives from various affected organizations. The total purpose of this effort is to assure that every possible EME/EMS control measure is incorporated as a "before-the-fact" design feature rather than an "after-the-fact" test fix.

(3) When several different organizations are involved in testing equipments, subsystems, and/or systems, the Control Plan should reflect the particular tests to be performed by each organization and how the test results, conclusions, and recommendations will be followed up and acted upon. The technical liaison between testing organizations performing equipment/subsystem (MIL-STD-461 and MIL-STD-462) and system (MIL-E-6051D) tests should be clearly shown. Additionally, requirements should be defined for situations in which technical liaison system level tests are performed at one location and the results are used to define test requirements at another location, and where test results obtained at several locations are combined to show compliance with the applicable system level specification. When this technical liaison is adequately defined, it should eliminate test duplication, reduce test performance time, and provide added confidence in the EMC of the system.

APPENDIX B

GUIDELINES FOR TEST PLAN PREPARATION

The system assumed for the purposes of this appendix is a multi-rack configuration containing a significant number of state-of-the-art electrical/electronic devices that have taken several years in their development, design, and fabrication. The applicable EMC documents will be assumed as follows:

MIL-STD-461A	Electromagnetic Interference Characteristics, Requirements for Equipment
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
MIL-E-6051D	Electromagnetic Compatibility Requirements, Systems
FAA-ER-350-023	Electronic Equipments Grounding, Bonding, and Shielding Practices, General Requirements

Representative information to be presented in each major heading of the Test Plan are presented in the following paragraphs.

INTRODUCTION

This portion of the Test Plan should be specific and detailed in areas pertaining to the purpose and/or objective of the proposed EMC Test Plan. Submittal of a Test Program Plan as a requirement of paragraph 4.2 of MIL-E-6051D should also be stated. Applicable portions of the EMC Control Plan or other related documents as well as broad EMC compliance philosophies and policies should be identified.

TEST DESCRIPTION

The test description should be a detailed presentation of the physical aspects of the proposed EMC test. As such, several separate but interrelated

aspects of the EMC test should be covered. The geographical location of all system level EMC testing should be presented. Also, it should be clearly indicated how the EMC tests will be integrated into the total system testing activity. It is suggested that a PERT or bar graph of the system test activity be included in which planned EMC testing is shown with respect to other system tests. Sufficient detail should exist to thoroughly reflect all series and parallel EMC test time. The various organizations performing either directly or indirectly related EMC test functions should also be indicated. These organizations should include those preparing the Test Plan, preparing the EMC Test Procedures, operating the EMC test equipment, analyzing the data to determine electromagnetic incompatibilities, and preparing the final Test Report. The EMC Test Procedures, or the procedures by which EMC testing is delineated, should be referenced by title and number, regardless of whether or not such procedures have been released at the time of Test Plan submittal. A thorough description of the system being tested should also be provided. This description should include the system and all associated equipment designations, any EMC testing accomplished on previous systems, prior out-of-tolerance EMC conditions detected and corrective actions incorporated, and a list of any MIL-STD-461A/MIL-STD-462 and FAA-ER-350-023 waivers that have been granted. If the effort to list previous EMC problems and remedies becomes excessive, appropriate Test Report numbers may be referenced.

This portion of the Test Plan should also stipulate all prerequisites that must be fulfilled prior to EMC testing. Additionally, equipment operating modes or status during the recording of EMC data and the basis for selecting these particular operational modes should be presented. Any effects anticipated or precautions to be exercised as a result of the ambient electromagnetic environment in the test area should also be thoroughly noted.

TEST POINT SELECTION

In this portion of the Test Plan, a list of points selected for monitoring during the EMC test should be provided. The criterion followed in se-

lecting these test points should also be included. A list of candidate test points not monitored is recommended in order to indicate the thoroughness with which the contractor analyzed the system for EMC. Criterion for selecting and/or omitting test points will typically include criticality of the equipment with which the monitored circuit is associated, MIL-STD-461A/MIL-STD-462 emission and susceptibility characteristics, design factors incorporated to eliminate electromagnetic incompatibilities, previous results from tests performed on identical or similar systems, and test point accessibility. Also presented in this portion of the Test Plan should be the out-of-tolerance limits for each test point and the rationale of the out-of-tolerance limits. Considerations followed in establishing test point limits should include MIL-STD-462 emission and susceptibility threshold characteristics, applicable design parameters, and response of the equipment function being monitored. The limits should clearly indicate the safety margin to be verified by the EMC test. Each test point should be defined by function description, applicable EMC test equipment channel assignment, and connector and/or pin number from referenced system schematics.

MEASUREMENT TECHNIQUES

A detailed description of the test equipment and measurement techniques should be presented in this portion of the Test Plan. The test equipment list plus an accompanying block diagram of all instrumentation from test point through recording device is suggested as a means of providing test equipment description. In describing measurement techniques, sensitivities, frequency responses, recording device scaling factors, types of data obtained and recorded, means of calibration, and test channel verification requirements should be included. It is mandatory that the measuring equipment capabilities be consistent with requirements specified in the TEST REQUIREMENTS section of the Test Plan.

TEST REQUIREMENTS

This portion of the Test Plan is exceptionally important and it is mandatory that as much detailed information as possible be included. A

description of each type of EMC test to be performed on the system should certainly be provided. As an example, a description of the audio frequency, radio frequency, and transient recording portion of any EMC test on the major power distribution systems should be provided. Description of the test type must be extensive enough to assure that the radiated and conducted EMC tests performed internal to the system (intra-system tests) and at all external connections to the system (interface tests) are adequate. The following are requirements and prerequisites that should be satisfied prior to the system level EMC test:

(1) All outstanding Engineering Orders, unincorporated configuration changes, missing equipments or subsystems, etc. should be incorporated/installed prior to EMC testing so that the system for test will represent actual final configuration. Results from any EMC tests performed on a non-final configuration system will (a) thoroughly identify that portion of the system that is not final configuration and (b) state that the EMC test results do not define characteristics of a final configuration system. Engineering Orders, configuration changes, equipments, etc. implemented or installed subsequent to the EMC test will be thoroughly coordinated with the EMC test personnel.

(2) All of the electrical/electronic equipments and subsystems comprising the system will be categorized into EMC-oriented criticality categories. These categories will be based on the mission or ultimate utilization of the system in its installation environment, i.e., air route traffic control center, air traffic control tower, flight service station, etc. The purpose of these criticality categories will be to define equipments and subsystems that should be monitored during the subsequent EMC test.

(3) All subsystems and equipments comprising the system should have been verified as operating satisfactorily within their design parameters prior to performance of any EMC test, the results of which will be used to indicate system level EMC.

(4) The electrical/electronic equipments and subsystems comprising the system should have complied with MIL-STD-461A/MIL-STD-462 or had approved Deviation Requests granted. Data from the MIL-STD-461A/MIL-STD-462 tests must be thoroughly analyzed to define the test points and limits applicable for the system level EMC test.

(5) An EMC Test Plan and EMC Test Procedure defining the EMC test and its integration with the other system tests should have been approved and distributed to all concerned organizations.

(6) The ambient electromagnetic environment of the test area in which the system is to be EMC tested should be thoroughly defined on permanent records prior to the EMC tests. This definition will be obtained with all test area equipments and subsystems capable of contributing to the test area ambient environment operating. Equipment and subsystem operation will be in a mode most likely to generate undesired emissions. The electromagnetic environment survey should cover a frequency spectrum of at least 0.15 to 1000 megaHertz. All signals with an amplitude of ten dB above the test receiver background level should be identified as to their source. All equipments and subsystems which contribute to the electromagnetic environment in sufficient magnitude to possibly cast doubt on the validity of EMC test data should be suppressed. If suppression is not incorporated, the equipment or subsystem should not be operated during EMC testing.

(7) The frequency response of the EMC test instrumentation must exceed the response of the equipments and/or subsystems being monitored.

System level EMC testing, in accordance with MIL-E-6051D, basically requires performance of the following two types of tests that should be described in the Test Plan:

(1) System Compatibility Test--Paragraph 4.3.1 states that "the contractor shall perform a complete EMC test on the system

designated and approved by the procuring activity. The system tested shall be typical of the production configuration and shall preferably be the first article."

(2) General Acceptance Test--Paragraph 4.3.2 states that "each production system shall be given a limited test as outlined in the contractor's approved Test Plan to ensure production compliance with EMC requirements."

It is also noted that MIL-E-6051D requires (paragraph 4.3.4 and paragraph 4.3.5) lightning and static electricity tests for sites and space vehicles; however, these are not generally applicable for the efforts undertaken by this investigation.

In performing the System Compatibility and General Acceptance Tests, the contractor is required to determine conclusively and correctly the causes of electromagnetic incompatibilities such as undesired/unacceptable response, and/or malfunction. Additionally, there are specific requirements regarding transients on power lines. Therefore, the Test Plan must describe how tests that reveal unacceptable response, malfunction, and excessive transients are to be conducted.

The Test Plan should also require that all data obtained during EMC tests will be permanently recorded. A test setup and equipment operation verification of EMC test instrumentation typically is required prior to recording EMC data. All EMC data records should have an on-record calibration and channel verification. Recording of EMC data 100 percent of the time is preferable. All EMC data will be recorded with a real-time correlation to the programmed test sequence of the system.