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High Intensity Radiated Fields (HIRF) - Project Plan

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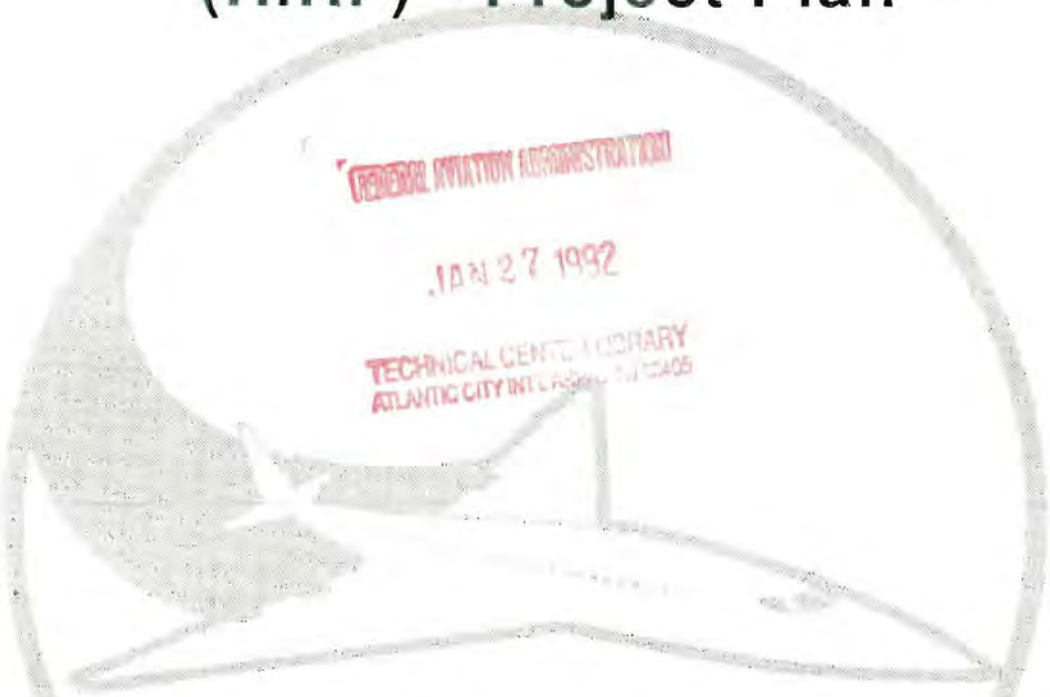

September 1991

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16. Abstract

This Plan addresses the Federal Aviation Administration's (FAA) approach to High Intensity Radiated Fields (HIRF) affecting the aviation community. It describes near- and far-term tasks, as well as identifying deliverables and addressing program management, schedule, and cost issues.

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ACRONYMS

BAC	British Aerospace Corporation
BCI	Bulk Cable Injection
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
ECAC	Electromagnetic Compatibility Analysis Center
EFIS	Electronic Flight Instrumentation System
EMCAB	Electromagnetic Compatibility Advisory Board
EMCAD	Electromagnetic Compatibility Analysis and Design
EME	Electromagnetic Environment
EMP	Electromagnetic Pulse
EMV	Electromagnetic Vulnerability
EUT	Equipment Under Test
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Controller
FDTD	Finite Differential Time Domain
GHz	Gigahertz
HERF	High Energy Radio Frequency Fields
HIRF	High Intensity Radiated Fields

HLDD	High-Level Direct Drive
INEL	Idaho National Engineering Laboratory
JAA	Joint Airworthiness Authorities
KHz	Kilohertz
LLNL	Lawrence Livermore National Laboratory
LLSC	Low-Level Swept Coupling
MHz	Megahertz
NASA	National Aeronautics and Space Administration
NATC	Naval Air Test Center
NEC	Numerical Electromagnetic Code
NPRM	Notice of Proposed Rulemaking
OTHB	Over the Horizon Backscatter Radar
RDT&E	Research, Development, Test and Evaluation
RF	Radio Frequency
RTCA	Radio Technical Commission for Aeronautics
SAE	Society of Automotive Engineers
TLM	Transmission Line Modeling
TSAR	Temporal Scattering and Response
V/m	Volts Per Meter

EXECUTIVE SUMMARY

This Plan addresses the Federal Aviation Administration's (FAA) approach to High Intensity Radiated Fields (HIRF) affecting the aviation community. It describes near- and far-term tasks, as well as identifies deliverables and addresses program management, schedule, and cost issues.

The "near-term" segment refers to testing, analysis, and demonstration of actual hardware which fulfills the immediate need to conduct a rapid response limited objective. A number of candidate systems/subsystems such as an S-76 glass cockpit helicopter, an Electronic Flight Instrumentation System (EFIS), and a Full Authority Digital Engine Controller (FADEC) will be considered. The S-76 is an operational FAA aircraft and the other two are flight-critical systems on current operational aircraft.

The "far-term" segment includes research tasks focused on verification of test procedures, modeling, knowledge base compilation and dissemination, training/seminars, and certification evaluations. The project establishes coordination for HIRF issues between the FAA and the foreign equivalents charged with regulating and monitoring new and/or planned emitters.

The "near-term" part of this research effort is directed primarily at a demonstration of HIRF susceptibility in certain existing operational commercial electronic avionic systems. The "far-term" effort has the objective of solving the HIRF issue and concern through engineering and scientific means.

1. INTRODUCTION

In response to the HIRF concern, the FAA initiated this broad-based RDT&E Project Plan to assure continued safe operation of aircraft in the existing electromagnetic environment. The need to define certain design practices to minimize electromagnetic susceptibility (HIRF) was pointed out by two FAA contracted studies; DOT/FAA/CT-86/40 "Aircraft Electromagnetic Compatibility,"[1] and DOT/FAA/CT-87/19 "Avionics Systems Design for High Energy."[2]

To carry out the intent of this broad-based effort, an FAA all-directorate team made up of representatives from the Regions, Headquarters, and the Technical Center was established to accomplish specific objectives. A comprehensive Program Plan[3] consisting of the following elements was developed:

- Research.
- Development of safety requirements.
- Designation of special use areas for high-power transmitters.
- Interim requirements for certification.
- Compliance criteria.
- Education.
- Rulemaking.
- Advisory materials.
- Environmental monitoring to characterize HIRF envelope.
- Establish international standards for HIRF certification.

The purpose of this document is to act as a vehicle for development of other RDT&E Projects that examine the role of the FAA in the future HIRF electromagnetic environment. This HIRF RDT&E Project Plan could, when applicable, follow an approach similar to the development of a basis for protection of aircraft against lightning phenomena, (note the published "Aircraft Lightning Protection

Handbook" - DOT/FAA/CT-89/22)[4]. As with other previous flight safety issues such as lightning, icing, etc., the FAA must define and bound the HIRF problem. The structure of the Society of Automotive Engineers (SAE)-AE4R Committee and the Radio Technical Commission for Aeronautics (RTCA)-SC135 have been the focal point for technical activities related to the development of safety criteria related to HIRF.

The elements of the Plan are:

1. Characterization and validation of HIRF environment.

2. Determination of aircraft susceptibility.

3. Identification of design/test signal levels.

4. Development and publication of test methods, analytical techniques, and procedures.

The HIRF environment, both in the U.S. and abroad, is being defined by the SAE-AE4R Committee. The severe environment has been agreed to and the normal environment is still being defined. This has resulted in the definition of a HIRF envelope in the form of an energy spectrum representing the maximum levels (worst case) to be used in the certification of aircraft and systems. Test methods and procedures are being defined and published in evolving documents, such as RTCA-DO-160C[5], SAE reports which will be used as the basis for an advisory circular, and the Hazards of Electromagnetic Radiation to Aircraft User's Manual[6]. These documents represent an international effort of many organizations in government and industry and are being developed to describe the design, analyses, and testing necessary for certification.

In other elements of the FAA Program Plan[3], interim standards for HIRF certification have been developed and applied as special conditions to the certification of a number of commercial aircraft[8,9]. To inform and educate government, industry, and any other interested parties HIRF Seminars[10] are presented by government and industry; the primary objective being to describe basic causes and means of protection from the effects of HIRF.

The FAA has initiated the rulemaking process with Notice of Proposed Rulemaking (NPRM) which is scheduled to be issued by the end of 1991. The AE4R Technical Committee has initiated a program for developing advisory material and establishing international standards as a cooperative effort with the European Joint Airworthiness Authorities (JAA) and other international entities. The SAE has traditionally been the focus of similar safety related complex technical activities.

The SAE, through Subcommittee AE4R, has proposed four technically accepted routes to perform a HIRF demonstration. The four methods are:

1. Coupling (microwave methods, or Bulk Cable Injection (BCI) programs, tests/analyses).

2. High power radiation tests.

3. Similarity (details undefined).

4. Alternate technologies.

Some of these methods have already been used at different government and industry entities, and have been proposed to the Subcommittee as a system approach to demonstrate compliance and obtain certification. The military program for system hardness to nuclear bomb generated Electromagnetic Pulse (EMP) has used both analysis, current injection and radiation for simulation of the threat and resolution of the concern. A validation effort is required to prove the several steps in the proposed routes to certification, identify limitations, and preclude unnecessary aviation community testing. The end product would be updated documentation of specific acceptable methods of test and analysis for FAA compliance and certification.

A normal HIRF environment is routinely encountered at airports during takeoff and landing. A more severe HIRF environment may be encountered during abnormal conditions and flight regimes at the edges of the flight envelope. The FAA has been working with the technical and scientific communities to develop methods of demonstrating that aircraft can fly safely while exposed to HIRF if proper protective measures are implemented. Ohio State University, under the direction of the FAA has coordinated an effort to define the HIRF threat in actual

field levels. The FAA has monitored activities within industry to test, simulate, and analyze aircraft and components for HIRF compliance.

For some time, the military has known of a HIRF threat from certain EM radiation. Commercial HIRF-related flight safety incidents have been reported world-wide. For instance, British Aerospace Corporation (BAC) has documented Carribean HIRF encounters. Newer aircraft designs are increasingly using computer/digital electronic control components. Digital fly-by-wire components may be more susceptible to HIRF intensities than analog components. Newer aircraft designs also make use of composite materials to replace metal enclosures, thus potentially reducing the level of HIRF protection. These design changes require evolution of the criteria for FAA certification. Industry needs acceptable and cost effective standards, design guidelines, and techniques to design against HIRF-related environments. Also, demonstration of compliance may result in the need for new test facilities, measuring equipment and data acquisition systems.

The Flight Safety Research Branch (ACD-230) of the FAA Technical Center, Aircraft Safety Division is providing overall RDT&E, coordination, and implementation on an ongoing basis in support of the FAA Aircraft Engineering Division (AIR-100), Technical Analysis Branch (AIR-120), and the National Resource Specialists (ANW-103), with participation by National Aeronautics and Space Administrations (NASA), Department of Defense (DOD), Department of Energy (DOE), and other selected U.S. Federal agencies, JAA, and the civil sector of the aviation industry.

Background for this effort being coordinated at the FAA Technical Center is founded in its tradition of solving similar technical challenges such as lightning and icing.

2. PURPOSE

For the FAA to adequately exercise their responsibility regarding HIRF aviation hazards, this Plan has been developed which, when implemented, will provide the technical basis for resolving the HIRF-related flight safety issues in a constantly changing environment. The purpose of this RDT&E Project Plan is to resolve these concerns. The research component of the program responsibly

addresses all of the HIRF flight safety issues and concerns. This multi-year plan, when completed, will provide both the technical basis for resolving the HIRF flight safety issues now and a vehicle to address future concerns. A major objective is to maintain adequate technical guidance to FAA certification specialists and aircraft industry system designers.

3. SCOPE

This RDT&E Project Plan addresses existing FAA regulations and aviation industry concerns, such as what equipment testing is appropriate to ensure adequate resistance to real-world HIRF emanation conditions. This document outlines a methodology for conducting laboratory up through a full-scale HIRF research projects.

- Support will be given to the SAE AE4R to determine the HIRF environment. Material will be provided to support aircraft certification and users manuals.
- Continued assessment of the HIRF aviation hazard issues and concerns will be of prime importance.
- Approaches to the pressing need for efficient and effective methods of testing and qualification of on-board flight-critical safety system components to HIRF in the frequency range above 400 MHz needs to be developed and documented.
- Unproven test and analysis methods are being developed and proposed by the SAE AE4R and RTCA Subcommittees. These will be validated by this RDT&E Plan.
- This document proposes a separate research program to develop new methods for partial system/subsystem testing, as well as HIRF qualification at the full up operational aircraft level.
- Modeling and analysis are alternate methods of assuming HIRF compliance. Research directed at presently available tools will be carried under this RDT&E Plan.
- A data base of HIRF-related information from unrestricted literature is needed. HIRF flight safety incidents, worldwide HIRF testing facilities and

testing capabilities, HIRF test data, and HIRF analysis techniques will be incorporated into such a data base.

- The foundation for development of a workshop/training/seminar program is needed for all parts of commercial aviation. This would include hardening of aviation equipment, airframe design information and other related HIRF issues.

- In-place aviation industry testing programs should be considered. These capabilities already exist in the U.S. Military and in the Euro/UK.

- Upgrade plans to ensure that flight incident/accident investigation teams are prepared to consider HIRF aviation hazards in their analyses is a possibility.

- A flight test demonstration to verify that HIRF will adversely affect existing avionics is needed. This will support the economic analysis of the NPRM.

4. HIRF RDT&E PROJECT PLAN

The FAA considers the HIRF environment during aircraft or system certification. The all-directorate team organized by the FAA has made considerable progress in many areas of HIRF certification requirements. However, some in the aviation industry are not satisfied with several aspects of the proposed HIRF certification requirements and subsequent costs. These and many other technical HIRF issues such as testing methodologies, attenuation, etc., must be resolved. The RDT&E Project Plan addresses these issues. The objective is to resolve HIRF issues and to provide the technical basis for design and qualification standards for the protection of flight-critical safety aircraft systems.

This RDT&E Project Plan addresses the more pressing HIRF issues in a near-term task plan, as well as maintaining an ongoing updating program for present and future HIRF issues in a far-term task plan.

The near-term tasks are planned to address the issue of correlating several flight-critical subsystem HIRF tests in the laboratory and in aircraft tests. These tasks address test methodology as well as test criteria. They are also designed to provide a data base that might be used to evaluate emerging testing and analysis technologies.

4.1 Near-Term Task Description

There is an immediate need to conduct rapid response and limited HIRF testing on a number of candidate items such as EFIS and FADEC equipment/ subsystems. It is planned that these candidate equipment/subsystems will be provided to the FAA Technical Center by the respective manufacturer (contributions), who would then participate in the tests. It is desirable that any manufacturer modeling, analysis, and test data accompany the equipment/ subsystems to the government/industry test facilities.

A detailed test plan will be coordinated with the FAA all-directorate HIRF team and the associated National Resource Specialists.

4.1.1 Objective

The main objectives of the near-term projects are to provide baseline HIRF test data and to prove, by test, the technical adequacy of the coupling and radiated test methodologies for demonstration of compliance with the FAA HIRF rule. Another objective of the near-term program is to verify or improve all documentation that applies to certification.

4.1.2 Scope

The scope will involve BCI and radio frequency (RF) radiation tests of a FADEC and EFIS system. Modeling and analysis can also be used on a FADEC and EFIS. The projects will be executed at a U.S. facility and sponsored by the FAA Technical Center. Additional scope to the near-term testing is a review and/or improvement of all certification documentation, such as guidelines and rules.

4.1.3 Technical Tasks

Task A: Sikorsky (S-76) Flight Tests

The FAA Technical Center S-76 Helicopter is available for near-term testing. The S-76 has a cockpit display system representative of those employed in the newer commercial transport aircraft. This aircraft could be modeled and its most susceptible HIRF-related weaknesses identified. The next logical step would be to fly the S-76 EFIS equipped, against available HIRF sources such as the biconical antenna at the FAA Technical Center, the DOD Over-the-Horizon

Backscatter (OTHB) radar facility at Moscow, Maine, the Pave Paw system at Otis Air Force Base Massachusetts, or the Voice of America transmitter located in South Carolina. The flight tests of the S-76 would conclude with high intensity RF tests in a large anechoic chamber (such as the Naval Air Test Center (NATC) located at Patuxant River, MD). In all flight tests, upset, failure, false indicators, etc., would be monitored and recorded.

Task B: DO-160C[5] Test

The purpose of this task is to verify and validate the initial version of DO-160C[5]. The DO-160C[5] test of the FADEC and EFIS will be performed. A test plan and test results report will be the deliverable documentation.

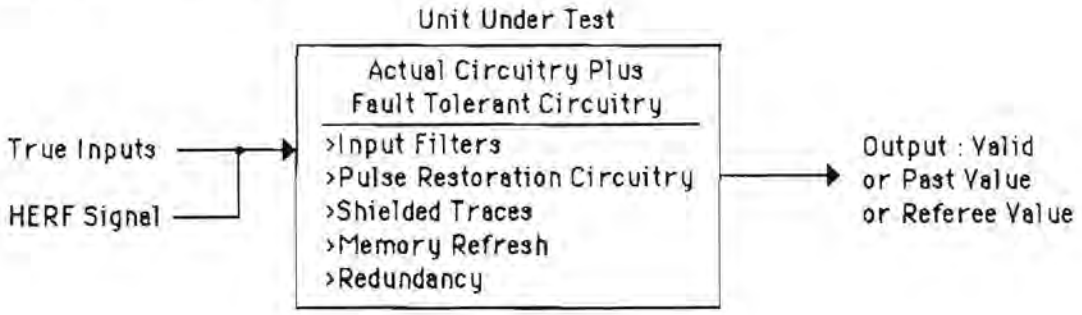
Task C: Test Plan

The purpose of this task is to adequately plan a realistic short-term test program complete with schedule, cost, and deliverables. A Master Test Plan will be developed which describes the technical requirements of each test. A method of test, the test interrelationships, and test limitations to be evaluated will be stated. The Master Test Plan, coupled with the background study, will form the framework for all further tasks.

Task D: Testing Assessment Methodology for Extrapolation and Verification of HIRF Full Threat

The purpose of this task is to test an electronic unit via Low-Level Swept Coupling (LLSC) to determine if there is a malfunction signature in the frequency range to 400 MHz. From this data, estimate the malfunction protection provided at higher frequencies, and verify for the appropriate number of selected frequencies. The pass/fail criteria must be determined. The outputs will be examined while the microprocessor, inside the unit under test, may be upset or subjected to questionable data as a result of the HIRF disturbed input parameters. Without opening or modifying the unit and thus destroying its certified construction, correct diagnostics must be established. A typical Component/ Subsystem Test Configuration and desired results are shown in Figures 1 and 2, respectively.

Test Setup Example



Candidate Test Items:

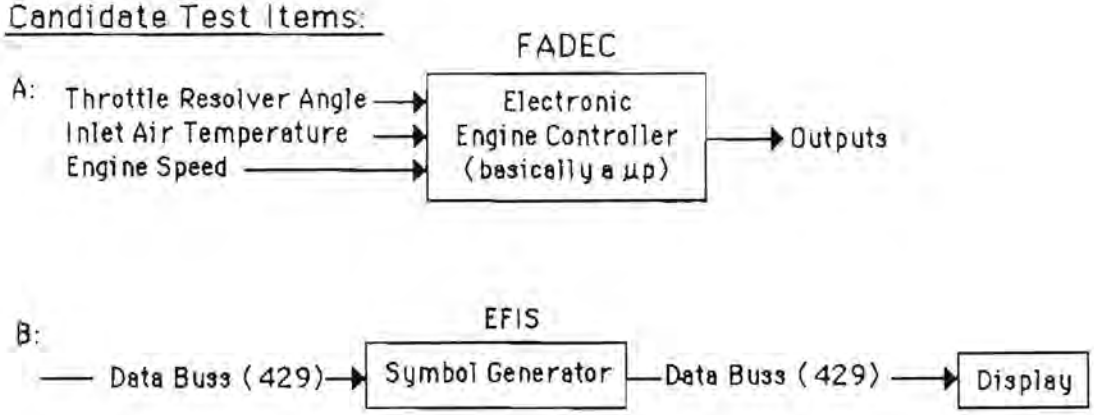
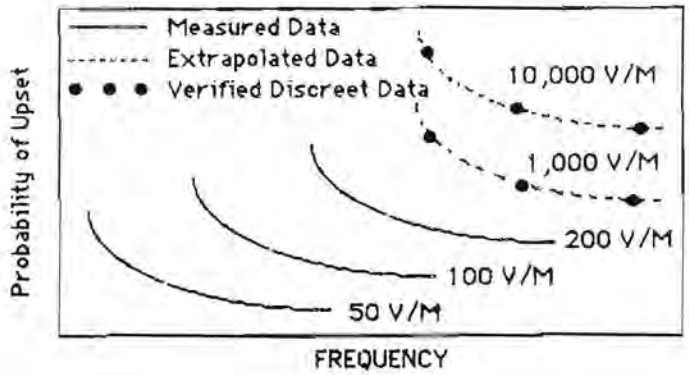
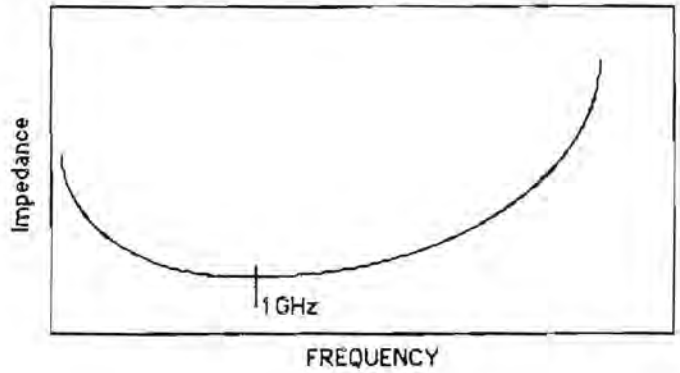


Figure 1 - Typical Component/Subsystem Test Configuration

Also, determine if a 1 KHz square wave at 50% duty cycle modulation results in an overtest of the equipment in the 30 MHz to 18 GHz radiated test as compared to more realistic radar modulations (i.e., 1 µs pulse at 1 KHz and selection of other real modulations as shown in users guide). What percentage of overtest, if any, should be determined?





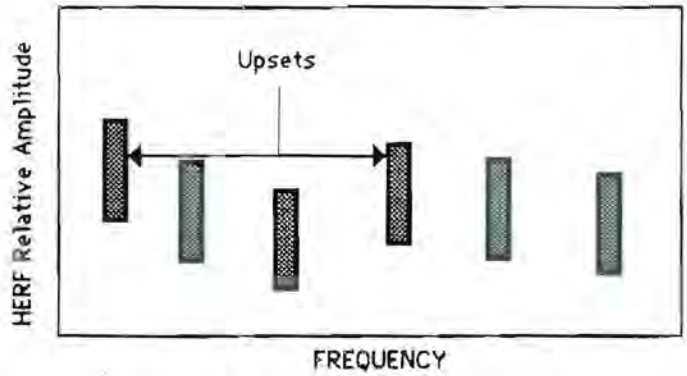


Figure 2 - Desired Statistical Results

Task E: Design and Integration

The purpose of this task is to conduct a HIRF subsystem test using an actual airframe or a test-bed. The FADEC and EFIS will be installed into the test aircraft. The accompanying engineering will include all aspects of planning and the electrical, physical, structural, and integration need for the systems to function similar to an operational aircraft. HIRF hardening considerations and engineering practices will be used. The installation will include the physical installation, connection, and checkout of the system on the aircraft. Deliverables will include installation drawings and a functional test report.

Task F: Low-Level Swept Coupling

The purpose of this task is to verify LLSC techniques and validate the assumption that it can be extrapolated to full threat. This task will include conducting all forms of LLSC on the aircraft. Each LLSC test type will be a subtask. The subtask tests are:

- 3D Modeling Transmission Line Modeling (TLM)
- Numerical Electromagnetic Code (NEC)
- Low Level Direct Drive
- Low Level Swept Coupling

Deliverables will include three test plans and three test reports.

Task G: High Level Injection

The purpose of this task is to verify the existing BCI and High-Level Direct Drive (HLDD) test methodologies.

Task H: High-Field Equipment Test

The purpose of this task is to develop a method of full-threat evaluation without actually radiating at high-level outside of an aircraft. The FADEC and EFIS, while installed in the aircraft, will be subjected to HIRF (reduced by the airframe

attenuation). The radiating antenna will be placed in front and around the systems rather than outside the aircraft as in Task I.

Task I: Whole Aircraft Test

The purpose of this task is to duplicate actual HIRF full-threat conditions on an aircraft in flight. A test will be conducted to radiate the HIRF-predicted external environment to an aircraft and evaluate the performance of a FADEC and EFIS.

Task J: Electromagnetic Vulnerability (EMV) Assessment/Certification and Interim Report

The purpose of this task is to summarize the vulnerabilities, or lack thereof, of flight-critical safety systems or equipment. This task will collate the data from all the tasks. The data will be collectively analyzed. The EMV of the EFIS and FADEC will be established. Recommendations as to the certifiability of the system will be provided. Conclusions and recommendations will be made regarding the validity of the two test approaches. Limitations, benefits, and lessons learned will be included in the documentation.

Task K: Investigate Additional Methods for Qualification Above 400 MHz

Task L: Develop Detailed Analysis and Test Methods for Establishing Similarity

Verify predictions by installation analysis and test of the same equipment in turn or more different installations, (i.e., different airplanes or same airplane with different installation techniques).;

Task M: Background Data Study

The purpose of this task is to gather all available, applicable HIRF-related test data and analytical information and make it available. A FADEC/EFIS and aircraft to be tested will be identified. An extensive data search and collection of information regarding the systems will be conducted. The data will be analyzed and reduced. Conclusions and recommendations will be made regarding the viability of these systems. Characteristics of the systems and applicability of available data to the validation program will be documented.

4.2 Far-Term Task Description

The far-term tasks of this RDT&E Project Plan continue to address each of the elements of the FAA all-directorate Program Plan, namely:

- Research.
- Data base development and dissemination.
- Training/seminars/workshops/conferences.
- Technical publications.
- FAA certification criteria updates.
- Test Plan guidance.

These far-term tasks will provide the technical basis to update the HIRF certification process and requirements on an ongoing basis. These tasks will resolve the known HIRF issues and provide a mechanism to resolve any future HIRF issues. To keep current, the known HIRF issues require the following ongoing efforts:

- Identify HIRF emitters and accurately quantify related HIRF threat levels.
- identify candidate areas for consideration for HIRF special use airspace.
- Validate HIRF levels and effects on flight-critical aircraft equipment in airframe conditions. Measure hardening provided by several different aircraft, publish results and expand similarity analysis methods.
- Provide a handbook of HIRF-hardening design examples for aircraft equipment and airframes.
- Evaluate and validate various new HIRF testing schemes for use in the laboratory and on airframe-installed equipment.
- Establish requirements for HIRF testing facilities and equipment.
- HIRF modeling and analysis techniques.

- Establish, maintain, and make available data bases of HIRF-related information.
- Identify government and industry test facilities and laboratories.
- Record and review all HIRF-related incidents.
- EME certification of technicians, engineers and laboratories.
- Provide more information, technical publications, and training on HIRF design and testing.
- Continue to provide a forum for HIRF issues through FAA sponsorship of seminars, conferences, and industry coordination.
- Improve, validate, and update HIRF certification requirements.

A comprehensive far-term effort is delineated which will flow from test definition, modeling, and analysis to an equipment/subsystems, system, and full-scale aircraft test procedure. This section describes an overview of this ambitious effort by the FAA and industry which addresses HIRF issues and concerns.

4.2.1 Research

The far-term tasks are divided into two groups; those tasks of a technical nature that can be described as technical research tasks, and those tasks that are educationally related.

Research is planned which will focus on refining component/subsystem test definition and verification of the approach to modeling and analysis, leading to a full-scale aircraft test procedure. The continuing objective of this program to be conducted by the FAA and industry is the improvement of RTCA DO-160[5] and the SAE-AE4R User's Manual[6].

4.2.1.1 HIRF Modeling and Analysis

The purpose of HIRF modeling and analysis is to develop a cost-effective alternative to testing. This effort will complement and support testing as well as specification development. It is predictive in nature and, as such, will forecast

HIRF-related "soft-spots". One objective is to develop the analytical approach to the point where air frame testing measurement requirements can be reduced.

The ability to effectively analyze HIRF issues is still evolving. Current models and codes, such as TSAR, 3-D FDTD[11], the U.S. Army's Solid Modelling Code[12] and others, are not widely used for design or certification. At the same time, test methodology, test instrumentation, and test specifications are evolving. An effect of this situation is that specifications for tests and protective designs frequently are uncertain resulting in, perhaps, overly expensive protective designs, complex test methodologies, and an expensive certification process.

Verified and validated engineering models and codes for components, subsystems, systems, and full-up aircraft on HIRF-related problems are needed. In general, the analysis of a HIRF problem proceeds in the following logical series of steps:

- Define the external environment and boundary conditions.
- Determine the HIRF internal environment, HIRF entry points, and methods of coupling.
- Identify flight-critical and flight-essential components and systems that might be vulnerable to interference or damage.
- Establish protective pass/fail criteria.
- Design protective measures for vulnerable systems.
- Verify protection adequacy.

Engineering models and codes are used at selected points in the analysis to represent the aircraft, wire bundles, selected circuits, etc.

Properly verified and validated, engineering models and codes will be a cost-effective method for qualifying installed avionics to HIRF; determining which HIRF phenomena are of importance and why; studying basic coupling mechanisms; conducting extensive parameter studies; determining how best to represent the important physical phenomena; demonstrating understanding of a HIRF problem(s) through the use of verified and validated models (e.g.,

determining the response of critical circuits); and studying effects of new sources and materials. In particular, the codes will be useful aids in areas such as providing specifications for purposes of developing protective designs, performing safety analyses of critical and essential systems, investigating scaling issues, conducting corrective action modeling, predicting adverse effects, preparing test specifications, pre- and post-test analyses, and developing operational procedures, maintenance procedures, and training.

The most important issue to be resolved in order to achieve the advantages discussed above is to collect and evaluate current information on the status of HIRF codes and modeling worldwide, Note: "A Program Plan for the Transfer of DOD Methodology for High Power Electromagnetic Susceptibility Assessments to the Civil Aircraft Industry"[13]. A number of crucial questions need to be formulated and answered before the FAA undertakes research into the analytical codes and modeling aspects of HIRF, such as:

- What is the status of the codes relative to capability, applicability, and acceptability of the available codes which are classified, proprietary, or in the open literature?
- What is the status of the verification and validation effort for the codes?
- What is the capability of the codes to represent the HIRF phenomena of interest?
- Do the codes conform to industry and government software standards?
- Are the codes user friendly and cost effective to use?

Lawrence Livermore National laboratory (LLNL), in cooperation with NASA, is assisting the FAA in Electromagnetic (HIRF) Modeling. LLNL's System, Temporal Scattering and Response Software (TSAR) is an electromagnetic modeling system consisting of a family of related codes. These codes have been designed to work together to provide the user with a practical way to set up, run, and interpret the results from a complex three-dimensional (3D) electromagnetic simulation.

The various codes in the TSAR system have been in development at LLNL since 1987 and in active use since 1988. TSAR is presently being investigated by the FAA as part of this RDT&E plan.

4.2.1.2 Detailed HIRF Test Plan

HIRF issues require testing to validate, establish, and correlate HIRF testing data for equipment, airframe, and aircraft complete with equipment. This project will identify and quantify test procedures and criteria in support of the far-term research segments of the project. A detailed outline of the approach to a detailed HIRF test is presented in Appendix A of this Plan.

4.2.1.3 In-Service Qualification of System Components

A major area of concern, which is not presently addressed, is the need for continuing validation of critical and essential system components' performance in a HIRF environment. An objective of this task will be to establish procedures for qualification of system components which maintain the requirements established in the original bench-test approach defined in DO-160C.

4.2.1.4 Rapid Recovery (Hardened) HIRF Digital System Development

Industry has indicated that state-of-the-art systems are available which tolerate HIRF by sensing the RF disturbance, automatically "freezing" system outputs, and resuming normal operation following the event. The objective of this task is to explore and evaluate the applicability of this technology relative to commercial flight electronic systems.

4.2.2 Data Base Development and Dissemination

An important element of the far-term component directed at building and disseminating a knowledge base of resources, events, literature, and test data relating to HIRF flight safety issues. This capability will be on-line and maintained by the FAA Technical Center.

This element consists of four tasks:

- Identify the data to be included in the data base such as HIRF tests performed to date, test facilities available, test facility capabilities, actual HIRF aircraft incidences, etc.
- Obtain relevant information for the data base.
- Organize the information into a formal data base structure.
- Make the data base information available for analysis.

4.2.2.1 Identify the Data to be Included in the Data Base

A global community of people and organizations that are concerned with and working on HIRF issues exists and has regular formal meetings. One of the expressed needs of this network or support community is to have access to information on HIRF issues. A major goal is to determine the information resource needs and priorities of the HIRF community so as data collection begins, the right data is sought. The following examples are indicative of the kind of data that might be useful to the community as a whole.

- A listing of government and commercial industry capabilities such as:
  - facilities
  - test equipment
  - availability/work load
  - staff capabilities and size
  - upgrade potential
  - costs for utilization
- Information about events on in-service aircraft relating to HIRF caused:
  - flight safety impairments
  - flight delays
  - nuisance occurrences or events
  - corrective actions taken

- Literature and bibliography of all relevant papers, books, standards, etc., relating to HIRF flight safety

- Test data from HIRF tests on aviation equipment and airframes.

4.2.2.2 Obtain Relevant Information for the Data Base

In order to obtain the information identified in Subsection 4.2.2.1, several issues must be addressed:

- Identify and establish an organization to obtain the information.

- Obtain the information needed from the HIRF support community - address proprietary issues.

- Set formats and procedures for collecting the information.

- Set procedures and requirements for obtaining all future data. This might include revision of reporting/recording requirements for in-service aircraft.

4.2.2.3 Organize the Information into a Formal Data Base Structure

This effort involves decisions about formats, size, storage media, and structure of the technical data. An organization must be identified along with computer equipment and facilities requirements. Procedures must be established, and availability and access rules must be identified.

4.2.2.4 Disseminate the Data Base Information

The first generation of data base shall be made available within one year. The data may be distributed as a self-contained software system with search and retrieval capabilities in a generic MS-DOS format on low-density (360 kilobyte) floppy disks. This approach will accommodate the "lowest common denominator" in terms of readily available hardware and user friendly systems operation. The built-in search and retrieval capability will minimize compatibility issues and the necessity for users to already possess a particular software system.

Updates to the data base can be distributed semi-annually or more often depending on the need for updating the data. The floppy disk system will include a data capture module to permit members of the user community to input information about changes to equipment or facilities and new work in their organizations using their own personal computers. This information will be conveniently recorded by users, transferred to a diskette, and mailed back to the data collection facility about one to two months prior to the next general distribution of new data.

The long-term availability of the data and the methods of making the data accessible will evolve from this initial effort.

4.2.3 Training/Seminars/Workshops/Conferences

4.2.3.1 Objectives

Education and information exchange are of strategic importance in accomplishing the objectives of the Flight Safety RDT&E Project Plan when addressing HIRF. Technical awareness throughout the aviation industry, both nationally and internationally, is prerequisite to practical resolution of HIRF issues and concerns. In the near-term, the Flight Safety Research Branch of the FAA Technical Center wishes to foster an open and cooperative spirit among regulators, manufacturers, airlines, and researchers. This is prerequisite to the far-term efforts necessary to achieve an adequate level of safety relative to the hazards of HIRF interference. Workshops currently available and supported by the FAA include "Advisory Circular Compliance," "HIRF Workshop for Installer," "HIRF vs Printed Circuit Boards," and others.[10]

4.2.3.2 Conferences

Technical conferences scheduled and coordinated by the FAA are the primary near-term activities and will serve to focus attention on HIRF issues and concerns. These conferences serve as a forum for information exchange and include technical seminars on specific areas related to data collection and risk quantification, as well as equipment design and certification. A more detailed far-term strategy will evolve from the coordination and interaction among conference participants. It is hoped that these conferences will be jointly

sponsored by the FAA. Specific topics to be reviewed and addressed in the technical seminars at these conferences include:

- Evolving high-tech equipment evaluation (sponsoring symposia, seminars, expositions, etc.).
- Candidate EFIS and FADEC equipment and subsystem testing results.
- Experience gained from the SAE-AE4R User's Manual[6] and RTCA DO-160C.
- Updated information in the HIRF events data base (including classification).
- Comments on proposed rulemaking related to HIRF safety requirements and aircraft certification.
- Research and development test evaluation and sharing of test results.
- Availability of RDT&E resources such as laboratory/facility equipment, test rigs, HIRF generators, analysis techniques, etc.
- Relevance of testing methods, procedures, and scaling relationships related to BCI and high energy radiation.

The following approach is suggested for arranging these conferences:

- Solicitation of technical papers related to the topics mentioned above.
- Selection of key speakers from the regulatory, industry, and research communities.
- Scheduling and venue arrangements.
- Selection of seminar topics and seminar leaders.
- Promotion and advertising to the global community involved or affected by HIRF aviation hazards.

4.2.4 Technical Publications

The Flight Safety Research Branch of the FAA Technical Center will actively promote the publication of any relevant technical information related to HIRF events, testing, research and development, etc. Presentation of technical papers for information exchange, as well as review and discussion in an open forum such as the annual technical conferences discussed above, is strongly encouraged. Proceedings from conferences and other technical society meetings will be consolidated and disseminated by FAA in an annual report summarizing HIRF-related activities. These publications will not only serve to coordinate efforts toward the resolution of HIRF issues and concerns within the aviation industry, but also serve to expand and enhance awareness of HIRF interference hazards in other government agencies in the U.S. and overseas. A far-term coordinated project strategy will evolve from the interaction of key participants at the annual conferences. This strategy will be documented and promulgated in the form of a detailed program plan to members of the global community involved in HIRF research and eventual resolution of HIRF issues and concerns. Annual updates of the RDT&E Project Plan will be based on the results and proceedings of the annual conferences. A major objective of this element will be the development of a handbook addressing HIRF sources, hazards, protection, training, and maintenance including requalification issues for critical system components.

4.2.5 FAA Certification Criteria Updates

Modeling, analysis and test results may warrant modifications in design and/or verification methods. As necessary, when significant changes occur, certification criteria shall be updated. Appropriate coordination for certification updating will be a continuous part of this project.

4.2.5.1 Description of the System

Describe the system's installation configuration, any unusual or unique features, the operational aspects being addressed, zone locations, HIRF environment, HIRF design level(s), and approaches.

4.2.5.2 Description of the Protection

State the methods of HIRF mitigation and the process to be used to verify the effectiveness of the design. Typically, the verification method includes a combination of analytical procedures and tests. If analytical procedures are used, the methodology for verification of these procedures shall be described.

4.2.5.3 Pass/Fail

The pass/fail level will be identified and will apply to testing and analysis of all systems, including electrical/electronic equipment. The pass/fail level for an electronic system, for example, might include the following:

- The equipment HIRF design level for upset and/or damage.
- The levels of test (100 V/m, 200 V/m, etc.).
- The margin between tested levels and upset/damage.
- Interference with analog or digital data due to the exposure to HIRF environment.

Upset effects on system performance and flight safety will consider parameters such as time duration of upset, the effects of upset on the operation of the system, and the time of occurrence during the various flight modes of the aircraft.

4.2.6 Test Plan Guidance

The objective is to assist industry in protecting against the HIRF environment and certifying their respective airframes at the lowest cost and within desired schedules.

When HIRF tests are to be a part of the certification process, plans for each test will be prepared which describe or include the following: purpose of the test; production or test article to be utilized; article configuration; test drawing, as required; method of installation that simulates the production installation; applicable HIRF environment; lightning simulation method; test fields to be

used; diagnostic methods; pass/fail criteria; and the appropriate schedule(s) and location(s) of proposed test(s).

Some of the procedural steps that will be taken include:

- Obtain FAA concurrence that the test plan is adequate.

- Obtain FAA concurrence on details of part conformity of the test article and installation conformity of the test setup.

  Part conformity and installation conformity will be judged from the viewpoint of similarity to the production parts and installation. Development parts and simulated installations are acceptable, provided they can be shown to adequately represent the electrical and mechanical features of the production parts and installation for the specific HIRF tests. Adequacy will be justified by the applicant and receive concurrence from the FAA.

  Exploratory HIRF tests are often conducted early in the development cycle; a process both recognized and encouraged. These development data shall be considered for certification purposes provided the development parts and simulated installations meet the criteria stated above. If it is contemplated that results from development test results will become candidates for certification data, adequate advance notice of this approach will be given to the FAA for review and acceptance.

5. PROGRAM MANAGEMENT

The FAA Technical Center, Aircraft Safety Division, Flight Safety Research Branch, ACD-230, is providing overall program development, coordination, and implementation continuity in support of the FAA Aircraft Engineering Division, AIR-100, Technical Analysis Branch, AIR-120, and the National Resource Specialists, ANW-103.

DOE, Idaho Falls Operations, Idaho, and their technology resource, SCIENTECH, Inc., are supporting FAA Flight Safety Research Branch in a technology and consulting role.

NASA, (Langley Research Center), Department of Commerce (DOC), other DOE laboratories, such as Sandia National Laboratory, Lawrence Livermore

National Laboratory (LLNL), Idaho National Engineering Laboratory (INEL), and various selected federal agencies, international organizations, and the aircraft/systems industry, etc., are participating (see Figure 3). DOD resources, such as the NATC (Patuxant River, MD) and others will be called on to use their expertise which is already in-place and developed. European experts will be utilized as applicable in the program development (note Reference 14).

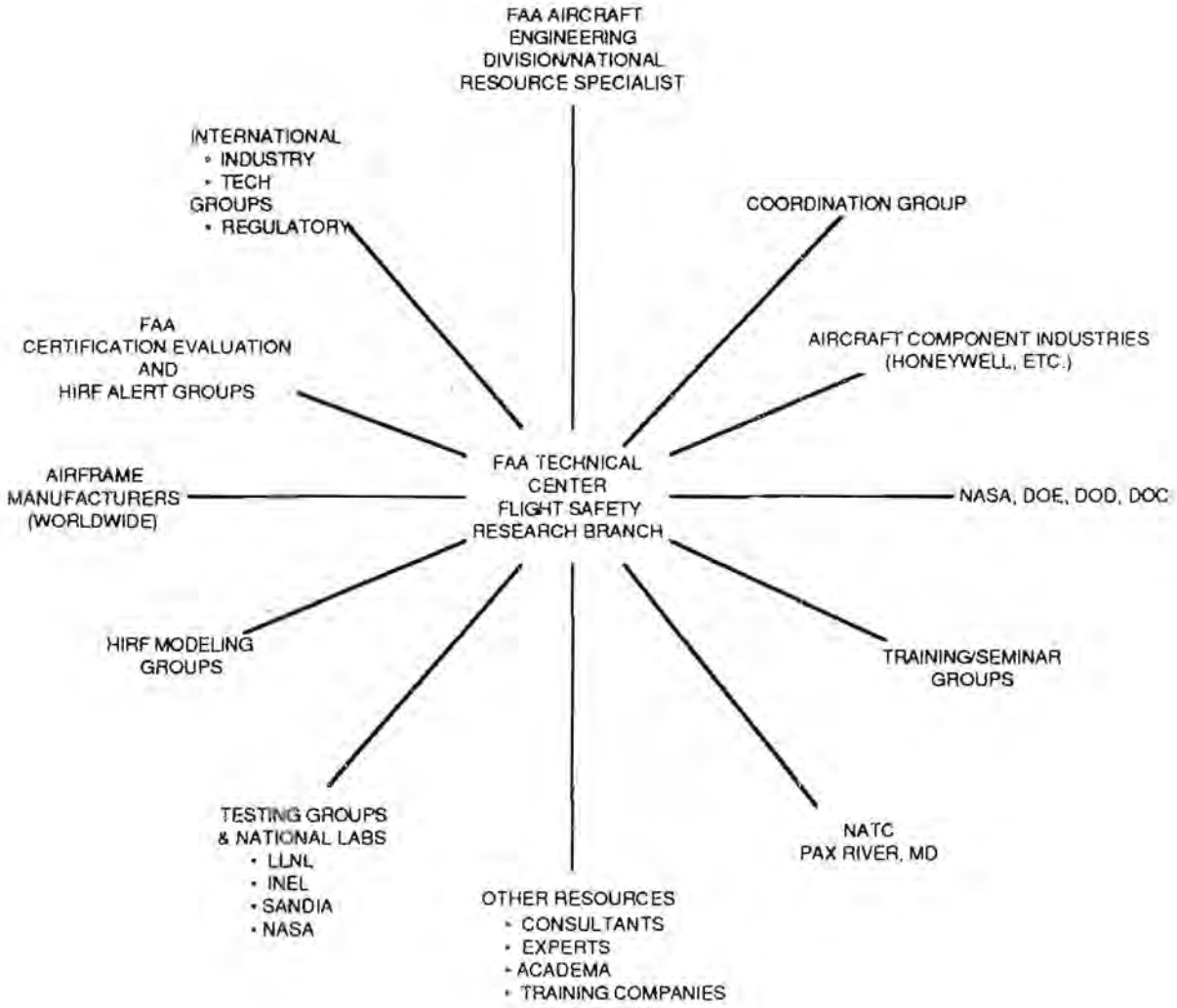


Figure 3 - Program Participants

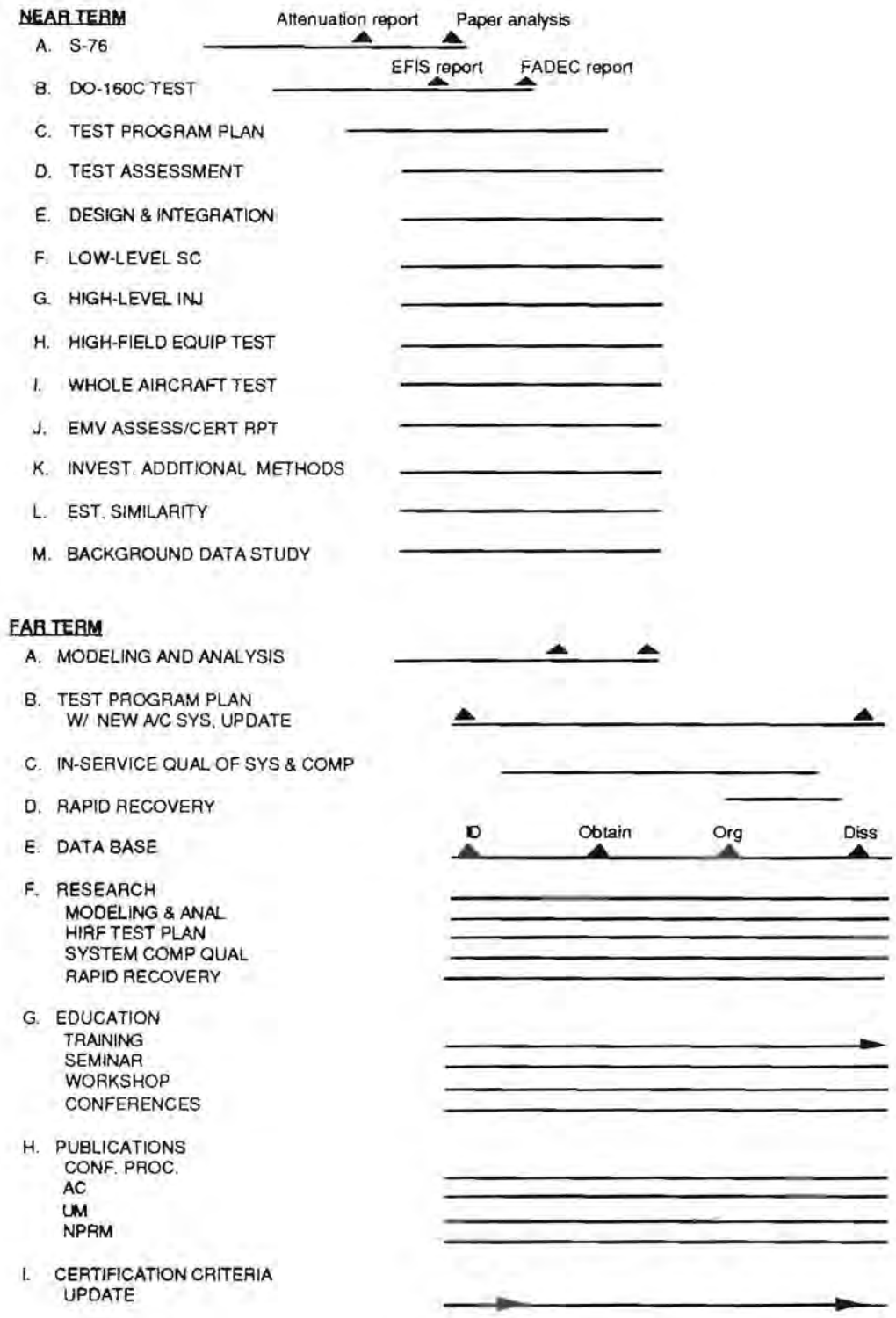


Figure 4 - Schedule and Deliverables

6. PRODUCTS/DELIVERABLES

The resulting data from the tasks in Section 4 will contribute to the needs of certification specialists and industry in response to the purpose (Section 2) and scope (Section 3) of this RDT&E Project Plan. The technical data, reports, guidelines and procedures, etc., listed below, will be available in accordance with program schedules.

- HIRF Protection Handbook
- Pass/fail criteria guidance
- Approach to modeling and analysis
- Training programs
- Technical meetings/seminars/workshops/conferences
- Detailed test plans
- HIRF test procedures, techniques, and standards
- HIRF information updates
- HIRF research data base
- HIRF commercial data base
- HIRF alerts
- Technical data packages
- Guidance criteria/material
- Reports/proceedings, etc.
- Draft Advisory Circular
- Users Manual
- Input to NRPMs

7. REFERENCES

1. DOT/FAA/CT-86/40, "Aircraft Electromagnetic Compatibility," Boeing Commercial Airplane Company.

2. DOT/FAA/CT-87/19, "Avionics Systems Design for High Energy," CK Consultants.

3. U.S. Department of Transportation FAA Aircraft Certification Service "The High Energy Radio Frequency Fields Program Plan."

4. DOT/FAA/CT-89/22, "Aircraft Lightning Protection Handbook," Federal Aviation Administration, dated September 1989.

5. RTCA Report, DO-160C, "Environmental Conditions and Test Procedures for Airborne Equipment," Section 20, (Radio frequency susceptibility).

6. DOT/FAA/CT-90/XX, "User's Manual for Hazards of Electromagnetic Radiation to Aircraft," SAE-AE4R, Aircraft Radiated Environment Subcommittee Report, dated January 29, 1990.

7. Advisory Circular, AC-20/XX, "Hazards of Electromagnetic Radiation to Flight," dated February 20, 1990.

8. U.S. Department of Transportation, Federal Aviation Administration, Memorandum from John K. McGrath, "Action: High Energy Radiated Electromagnetic Fields. Interim Policy Guidelines on Certification Issues," dated Dec. 5, 1989.

9. U.S. Department of Transportation, Federal Aviation Administration, Draft Memorandum from J. Treacy to A. Rizvi - Comments on Proposed Advisory Circular or Interim Policy Guidelines - "Protection of Aircraft Electrical Systems Against RF Environment," Jan. 1990 in response to J. K. McGrath Memorandum of Dec. 5, 1989.

10. Chris Kendall Consultants, "HIRF Seminars."

11. Lawrence Livermore National Laboratory, EM Coupling Code.

12. U.S. Army Solid Modeling Code (EM Coupling Application).

13. "A Program Plan for the Transfer of DOD Methodology for High Power Electromagnetic Susceptibility Assessments to the Civil Aircraft Industry," Federal Aviation Administration, dated April 1990 (Draft).

14. EUROCAE WG33 Subgroups 2&3, "User's Guide for AC No. XX, Protection of Aircraft Electrical and Electronic Systems Against the Effects of the External Radio Frequency Environment."

15. S76 Project Test Plan DOT/FAA/CT - TN 91/26 "S76 High Intensity Radiated Fields Test Plan" (Draft), Federal Aviation Administration, dated July 1991.

16. EFIS/FADEC Project Test Plan

APPENDIX A

DETAILED OUTLINE OF HIRF TEST PLAN

HIRF issues require testing to validate, establish, and correlate HIRF testing data for equipment, airframe, and aircraft complete with equipment. The Test Plan will identify and quantify test procedures and test criteria in support of the far-term research segments of the program. A detailed outline of the approach to a detailed HIRF test is presented below.

A. Select and define equipment configuration in typical airframe installation

   1. Develop system schematic diagram

      a. Modify to reflect mock-up condition

      b. Vendor approval

   2. Identify required subsystems

      a. Sensors

      b. Feedback

      c. Data formats

      d. Bus support/host requirements

B. Initial failure/upset criteria

   1. Identify flight -critical operations/outputs

   2. Vendor concurrence

   3. FAA concurrence

C. Identify certification requirements

D. Coordinate/define participant's input

E. Identify resources, costs, etc. (who, where, $), by developing equipment test plan, logistics, etc. (schedule). This will entail development of resource reference through query regarding

experience, equipment, work load, staff (resources/work summary), and rates (estimates). Identify proposed/qualified laboratories/facilities/equipment requirements.

F. Identify and characterize measurement parameters for test matrix

G. Develop applicable tests and identify resources

1. Finalize specific test procedures and priorities

2. Match test with best resource

3. Data collection requirements

a. Standards (accuracy, precision)

b. Formats

c. Archive requirements

H. Develop equipment test schedule

1. Define test procedure

2. Identify site/resource availability/schedule

3. Identify logistics constraints

4. Set equipment/test log schedule

I. Develop and validate data analysis plan for test output

1. Preliminary analysis plan; mathematical support

2. Coordinate data with analysis, units, conversions, etc.

3. Evaluate data requirements, portability between tests

4. Develop/qualify test/data reference standards

5. Confirm calibration requirements and status

6. Test/data discipline requirements

   a. Forms

   b. Procedures

   c. Data safeguards

7. Final test specifications, procedures

   a. Draft

   b. Approvals

J. Equipment/bench testing of subsystems

1. Set up equipment and data collection system for defined tests

   a. Physical installation

      1) Install probes

      2) Reference antenna

      3) Cabling

   b. Set up - data acquisition system

      1) Initial installation/configuration as required

      2) System calibration/verification

      3) Probes; reference qualifications

      4) Initial benchmark data

   c. Set up - equipment-under-test (EUT)

      1) Initial installation/configuration

      2) Initial power-up

3) Debug/stabilize to normal operation

d. Benchmark data background with acquisition + EUT

e. Set up sources/excitation

f. Calibration fields/excitation

2. LLSC tests - equipment without power

a. Configure equipment, probes, antenna

b. Reference data run

c. Data collection - test execution

d. Closing data convergence run

e. Data closure - repeat 'c' as necessary

3. Equipment terminal impedance measurements - without power

a. Fabricate/install cable measurement fixture, network analyzer

b. Normalize/calibrate fixture

1) 10 KHz to 400 MHz

2) 400 MHz to 40 GHz

c. Take impedance data - repeat three times

d. Compare average impedance with engineering data

e. Final term impedance with engineering error bars

4. Conduct cable/line impedance measurements through measurement for cable bundles, i.e., line - line, line - x - line, line - ground (installed configuration)

5. Conduct BCI-induced terminal voltages - equipment without power

6. Perform LLSC tests - full simulation

7. Measure BCI-induced terminal voltages - full simulation

8. Conduct medium-level radiated exposure at selected frequencies (200 V/m)

9. Determine upset/failure levels (up to the maximum defined threat)

K. Perform airframe testing

1. Define test setup, logistics, etc. (who, where, $, test plan, schedule)

   a. Assign responsibilities

   b. Define equipment verification test plans

2. Conduct airframe low-level sweep tests - cavity coupling

3. Perform equipment low-level sweep tests on installed system

4. Measure cable/line impedances

5. Conduct BCI-induced terminal voltage measurements

6. Perform low-level sweep tests - full simulation (powered in airframe)

7. Conduct medium-level radiated exposure (200 V/m at selected frequencies)

8. Determine upset/failure level qualification

L. Reduce and analyze data in order to prepare a final report and recommendations for DO-160C[5] and User's Manual[6] qualification criteria