AD A139783

AFFTC-TIH-84-1

ELECTRICAL SUBSYSTEMS FLIGHT TEST HANDBOOK

AFFTC

Kenneth J. Lush

Final Report

January 1984

This document has been approved for public release and resale; it's distribution is unlimited.

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

This handbook, TJM-84-1, Electrical Subsystems Flight Test Handbook, was submitted under Job Order Number SC6322 by the Commander, 6520 Test Group, Edwards Air Force Base, California 93523.

This handbook has been reviewed and cleared for open publication and/or public release by the AFFTC Office of Public Affairs in accrodance with AFR 190-17 and DODD 5230.9. There is no objection to unlimited distribution of this handbook to the public at large, or by DDC to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public including foreign nationals.

Prepared by:

KENNETH J. LUSH
Aerospace Engineer

This handbook has been reviewed and is approved for publication:

RONALD W. MAHLUM, Chief
Flight Test Technology Branch

EDWARD B. RUSSELL, Colonel, USAF
Commander, 6520 Test Group

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A139 783

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	3. DISTRIBUTION/AVAILABILITY OF REPORT This document has been approved for public release and resale: It's distribution is unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFFTC-TIH-84-1	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION 6520 Test Group 6b. OFFICE SYMBOL (If applicable) ENMT	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Air Force Flight Test Center Edwards AFB, CA 93523	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE (Include Security Classification) Electrical Subsystems Flight Test Handbook (U)	
12. PERSONAL AUTHOR(S) Kenneth J. Lush	
13a. TYPE OF REPORT Final 13b. TIME COVERED FROM 6-83 TO 1-84	14. DATE OF REPORT (Yr., Mo., Day) 84-1 15. PAGE COUNT
16. SUPPLEMENTARY NOTATION	

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Aircraft Equipment; Flight Testing; Electrical
2	1C		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This Handbook provides engineers with guidelines for the testing of aircraft electrical subsystems. Future technological advances, characteristics of individual aircraft and test programs and cost constraints may necessitate other methods being used in some cases. A background is provided on aircraft electrical subsystems and the requirements to which they are designed. Details are provided of individual tests, test support requirements and evaluation criteria and suggestions made for presentation of results.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Kenneth J. Lush	22b. TELEPHONE NUMBER (Include Area Code) Autovon 350-3301 22c. OFFICE SYMBOL ENMT

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

PREFACE

This handbook presents the methods used in testing and evaluating aircraft electrical subsystems at the Air Force Flight Test Center (AFFTC), Edwards AFB, California. The work was done under the authority of the Study Plan for Development of a Handbook for Aircraft Electrical Subsystem Testing.

The format of this handbook is chosen to make it easily used by project engineers of the Subsystems Branch, Airframe Systems Division of Flight Test Engineering, AFFTC. It is designed to introduce a newly assigned flight test engineer to the subject and provide a working reference for planning and conduct of electrical subsystems flight tests and analysis, evaluation and reporting of results.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

	PAGE NO.
LIST OF ILLUSTRATIONS	6
LIST OF TABLES	7
INTRODUCTION	8
OBJECTIVES AND ENVIRONMENT OF ELECTRICAL SYSTEM TESTS	9
Position of AFFTC in the Development and Evaluation Process	9
Agencies Involved	9
Multi-purpose Flight Tests	11
Reporting	11
FUNCTIONS & ELEMENTS	12
Generators & Generator Control	13
Conventional 400 Hz	13
Cycloconverter	13
Direct Current Link	15
270 Vdc	15
Variable Voltage, Variable Frequency	15
Permanent Magnet Generators	15
Cooling	20
Power Distribution & Management	20
Purpose & Functions	20
Conventional Approach	23
New Approaches	23
Examples of Current Systems	28
F-15 Electrical System	28
B-1B Electrical System	28
Primary Generator Channels	35
Emergency Generator Channel	36
AC Power Distribution	36

PAGE NO.

Generator and Bus Control Operation 36

DC Power Supply System 37

External Power 37

Circuit Breakers 38

SYSTEM REQUIREMENTS 39

Introduction 39

Electric Power Characteristics 39

Modes of Operation 39

Normal Operation 39

Transfer Operation 39

Starting Operation 40

Abnormal Operation 40

Emergency Operation 40

Interface Requirements 40

Utilization Equipment Requirements 40

Normal Operation 40

Abnormal or Transfer Operation 40

Starting Operation or Emergency Operation 41

Partial Power Failure 41

AC Phase Power Utilization 41

Transfer 41

Requirements for Alternating Current Power 41

Requirements for Direct Current Power 41

Electromagnetic Compatibility Requirements 53

PLANNING FOR FLIGHT TESTS 54

Source Material 55

Identification of Tests Required 56

PAGE NO

Operating Modes 56

Normal 56

Transfer 56

Starting 56

Abnormal 56

Emergency 56

Ground Tests 58

External Ground Power 58

Internal Ground Power 58

Ground Tests in Preparation for Flight Test 58

Normal 58

Abnormal 58

Emergency 58

Flight Test 58

Normal and Abnormal Mode 58

Emergency Mode 61

Instrumentation 62

Test Information Sheets 62

Integration with Flight Test Program 62

DATA MEASUREMENT, ANALYSIS AND EVALUATION 65

REFERENCES 73

APPENDIX A - EXAMPLE OF TEST INFORMATION SHEET 75

APPENDIX B - EXAMPLE OF TEST PLAN SAFETY REVIEW 85

APPENDIX C - EXAMPLES OF TEST REQUIREMENTS AND PROCEDURES 91

List of Abbreviations, Acronyms, and Symbols 99

LIST OF ILLUSTRATIONS

Figure No.	Title	Page No.
1	Functioning of Cycloconverter	14
2	Functioning of Inverter in Direct Current Link	16
3	Cross-section of AV-8B Generator	17
4	F-20G VSCF System Modules	18
5	Example of Proposed 270 Vdc System	19
6	Examples of Cooling Techniques	21
7	Electrical Multiplex (EMUX) System Control	22
8	Solid State Power Controller Operation	25
9	Comparative Schematics of Power Bus Structures	26
10	Aircraft Multiplex and Processor Standards	27
11	Schematic of F-15 Electrical System	29
12	Alternative Schematic of F-15 Electrical System	31
13	B-1B AC Power System	33
14	Unbalance Limits for 3-Phase Utilization Equipment	42
15	Envelope of AC Voltage Transients	44
16	Envelope of AC Frequency Transients	45
17	Limits for AC Overvoltage or Undervoltage	46
18	Limits for AC Overfrequency or Underfrequency	47
19	Limits for DC Overvoltage or Undervoltage - 28 volts Nominal	49
20	Limits for DC Overvoltage or Undervoltage - 270 volts Nominal	50
21	Distortion Spectrum of AC Voltage	52
22	Distortion (Ripple) Spectrum of DC Voltage	51
23	Example of Response to Changes in Electrical Lead	68

LIST OF TABLES

Table No.	Title	Page No.
1	Interest and Responsibilities of Major Agencies Involved in DT&E Flight Test of Electrical Systems	10
2	B-1B Load Management Modes	34
3	AC Normal Operation Steady State Characteristics	43
4	DC Normal Operation Characteristics	48
5	Flight Conditions for Tests in Normal and Abnormal Operating Modes	60
6	Example of Test Instrumentation	63
7	Operating Modes Tested versus Flight Conditions	64
8	System Evaluation Criteria	67

INTRODUCTION

The purpose of this Handbook is to provide the AFFTC flight test engineer responsible for evaluation of an aircraft electrical system with the background, philosophy and procedures for planning and conduct of tests, data analysis and evaluation. It is advisory in nature and neither supersedes Air Force requirements nor relieves the Flight Test Engineer of the exercise of judgement in its application.

The subjects addressed include the following:

1. The objective of the AFFTC evaluation and its relationship to design requirements and to the needs of of the user.

2. Electrical system elements and basic functions.

3. A review and analysis of requirements.

4. Planning of flight tests.

5. Data analysis and system evaluation.

OBJECTIVES AND ENVIRONMENT OF ELECTRICAL SYSTEM TESTS

The charter of the AFFTC is the development test and evaluation (DT&E) of new and modified weapon systems. In this role the Center is a bridge between the design engineer and the operational user. Center evaluations of aircraft require not only engineering expertise to conduct a technical evaluation, but also a keen and perceptive evaluation of the needs of the operator and of the environment in which the aircraft is to fulfill its mission. As an illustration of operator needs one may consider the tactical pilot who may have to operate in an environment ranging from difficult and distracting to actively hostile. The electrical system should be designed to minimize crew distraction and work load. Similarly, field servicing should be fast, simple and as error proof under stress as is reasonably feasible.

Considerable attention will necessarily be given to testing against specific requirements, but the flight test engineer should seek comment from flight crews with operational experience and continuously encourage ground crews to evaluate the aircraft as an operational system. This Handbook attempts to emphasize this approach,but in the final analysis it cannot be fully defined in print, but must be ensured by the attitude and objectives of the test team.

POSITION OF AFFTC IN THE DEVELOPMENT AND EVALUATION PROCESS

The contractor responds to the specific, program peculiar requirements of his contract and to general system requirements with an "end item specification" for the electrical system of his aircraft. The contractor is required to demonstrate compliance with this specification by flight test of an aircraft representative of the production version. The primary function of the AFFTC is to oversee and cooperate in these tests, perform independent analysis of the data and, if necessary, conduct additional tests.

AGENCIES INVOLVED

Tests of the electrical system at the AFFTC are usually conducted by a Combined Test Force involving a number of Air Force agencies as well as the contractor. Table 1 (page 10) shows the interest and responsibility of each of the major agencies involved. It is important to appreciate the interest and expertise of the agencies involved in order to cooperate effectively. For example,

a. The contractor develops the system and demonstrates to the system Program Office that it meets specifications.

b. The System Program Office reviews the data to check compliance.

c. The AFFTC independently analyzes data, performs additional tests as necessary, provides independent evaluation and reports to the System Program Office.

Table 1

Interest and Responsibilities of Major Agencies
Involved in DT & E Flight Test of Electrical Systems

TYPE TEST Agency	DEVELOPMENT	DEMONSTRATE TO SPECIFICATIONS	TEST AND EVALUATION	RELIABILITY & MAINTAINABILITY	OPERATIONAL EFFECTIVENESS
Contractor	Yes	Yes	Yes	Assist	No
ASD/SPO	Direct	Check Compliance	Monitor	Check	No
AFFTC	Liaison	Monitor & Independent Analysis	Yes	Primary Responsibilities	Yes
AFOTEC	No	No	Yes	Yes	Primary Responsibilities
User Command	No	No	Yes (Thru AFOTEC)	Advance Data Advice	Advance Data Advice
Air Training Command	No	No	No	No	Advance Data
Logistics Command	No	No	No	Advance Data	Advance Data Advice

NOTES: ASD = Aeronautical Systems Division
SPO = System Program Office
AFOTEC = Air Force Operational Test and Evaluation Center

On some in-service aircraft Air Force Logistics Command as Program Manager will be the test requester rather than a System Program Office of Aeronautical Systems Division.

The flight test program is cooperatively developed and is defined in detail in Test Information Sheets (TIS), (an example is included as Appendix A of this handbook). The AFFTC flight test engineer conducts tests or participates in tests conducted to ensure that AFFTC responsibilities are met. As the flight program and development of the test aircraft progresses, the relative roles and responsibilities of the members of the test team change. Initially, emphasis is on developmental testing. Later emphasis shifts to test and evaluation, with increased participation by the AFOTEC and using commands. Even though much of the work may be performed by the contractors team the AFFTC engineer must initiate and conduct tests, as necessary, and oversee analysis and evaluation of results.

MULTI-PURPOSE FLIGHT TESTS

Many electrical system tests will be performed during other tests or during flights which also involve other tests. Hence, the engineer responsible for the test must:

a. See that his tests are properly performed.

b. Encourage the flight and ground crews to report any incidents pertinent to the electrical system.

Since electrical system tests are often performed piggyback on other tests or as alternate missions when the primary mission cannot be performed, the test engineer must see that his tests are properly briefed and that the necessary instrumentation is functional and is used.

Also, the subsystem engineer must interface in some areas of test with other AFFTC organizations such as Human Factors, Reliability and Maintainability or Technical Order Verification and Validation. For this purpose he should identify contacts within these organizations to facilitate good liasion. All-weather tests are usually performed on the total weapon system under the direction of an all-weather test engineer. The electrical test engineer works closely with the all-weather test engineer to develop the test program, plan for the retrieval of his data, conduct the analyses and write the subsystem report.

REPORTING

Problem areas discovered during the test program are immediately reported in Service Reports, (formerly known as Deficiency Reports), as required in References 1 and 2. These are the action documents. They are sent to the System Program Office and reviewed by an SR Review Board. If the Board accepts them a Material Improvement Program (MIP) number is assigned and the SR is sent to the contractor for review and proposed solution. The final report on the DT&E tests of the electrical system will review these as part of the overall evaluation of the aircraft.

FUNCTIONS AND ELEMENTS

The function of the electrical system is to provide reliable, controlled electrical power of acceptable quality to all the using components such as avionics, flight control computers and fuel pumps. Normally the electrical system is considered to end at the delivery point to the using component. However if, for example, electric actuators are used in place of hydraulic actuators for such tasks as operating flaps or inlet ramps then by analogy with the definition of hydraulic systems, these actuators should be considered as part of the electrical system.

MIL-STD-704D (ref 3) defines voltages, frequencies and other parameters on the delivered power. The options are:

1. 115/200 V 3 phase, 400 Hz ac (230/400 V if specifically authorized)

2. 28 Vdc

3. 270 Vdc

The first two are commonly used, but use of (3) is being actively considered (ref 4). The relatively high ac frequency of 400 Hz permits the use of light, high speed ac generators (up to 24,000 rpm, see ref 5).

For many years the basic characteristics of aircraft electrical systems have changed little. The major components are typically:

a. 115/200 V, 3 phase, 400 Hz generators with frequency and voltage controls. The generators are driven at precisely controlled rotational speed by Constant Speed Drives (CSD's) (hydromechanical devices). More recently the CSD is integrated with the generator and the entire unit referred to as an Integrated Drive Generator (IDG). Frequency is controlled by the speed control and voltage by control of the field currents of the generators.

b. transformer/rectifiers (TR's) which convert the ac power to 28 Vdc power backed up by batteries.

c. distribution buses, relays, circuit breakers and current limiters.

d. provisions to limit the effects of failures, including both cross-over provisions between main generators and emergency generators.

In the past years, however, major development has been taking place on alternate approaches and some of the results have already appeared as flight hardware (AV-8B, F-20G, F-18).

The new approaches which are being developed have been made possible primarily by dramatic advances in solid state devices, which can now switch and control high powers, the resulting ability to use computers for generator control and load control, and a substantial reduction in weights and volumes of generators and motors made possible by samarium cobalt magnets.

Implementation of these new approaches is being driven by increasing demands on the capability and reliability of the electrical system (Ref 4) such as anticipated requirements for:

Doubled power

Tripled distribution complexity

Substantially improved reliability and maintainability

GENERATORS AND GENERATOR CONTROL

The approaches in use or being considered include the following (Ref 6):

1. conventional constant speed, constant frequency (CSCF) using a CSD or IDG.

2. variable speed constant frequency (VSCF) using a cycloconverter to extract constant frequency from the varying generator output frequency (F-18).

3. VSCF using a dc link and an inverter (AV-8B, F-20G).

4. generators providing 270 Vdc power to all systems which can use power in this form, conversion to 28 Vdc or to ac being made only where essential (studies only).

5. similar to (4) but with variable frequency ac provided to as many loads as possible.

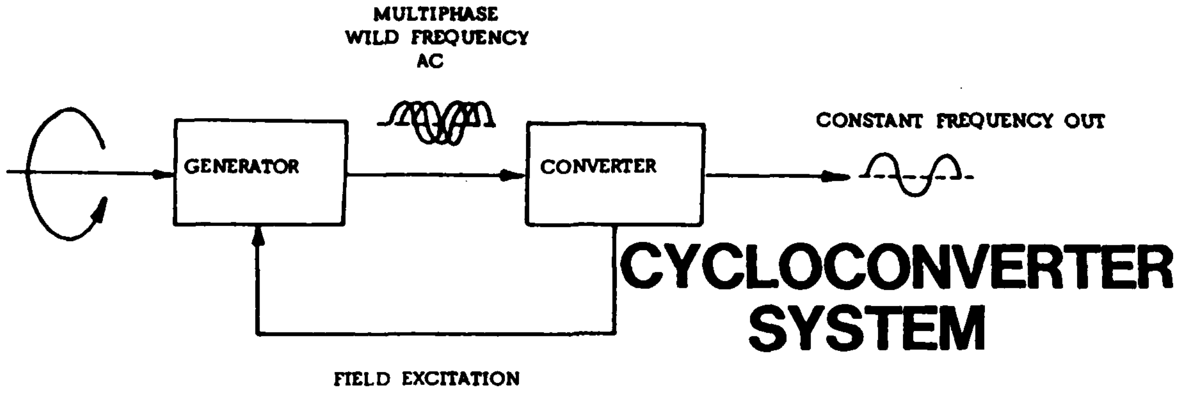
Conventional 400 Hz:

The generators must run at a constant speed, within narrow limits, and are driven by the main engines through the hydro-mechanical constant speed drives which permit engine speed to vary over a range of about two-to-one while maintaining generator speed and output frequency constant. Voltage control is effected by control of the alternator field current. Constant speed drives were developed in 1946 and applied to the B-36. Generators driven by CSD's have since become the normal source for electrical power. Only recently, with major advances in solid state devices, have alternate approaches become competitive.

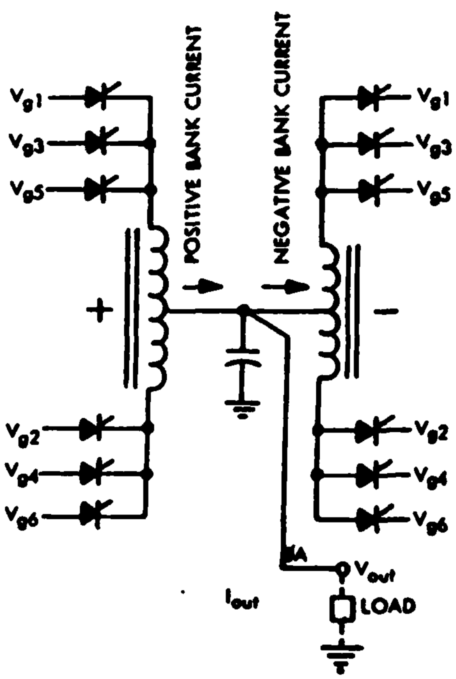
Cycloconverter:

The cycloconverter approach, which is used on the F-18, replaces the constant speed drive and generator for providing 400Hz power. The generator is driven directly by the engine and produces power at frequencies varying with engine speed. For efficiency the output must be at least 2400 Hz and a 6 phase.

The desired 3 phase, 400 Hz power is then extracted electronically by the cycloconverter (Figure 1) by switching between these six phases. Presently the switching is performed by Silicon Controlled Rectifiers (SCRs). Voltage regulation is normally accomplished by control of the field current in the alternators but could be effected by directly controlling the wave form extracted by the cycloconverter from the generator output.



Cycloconverter VSCF



Power stage for cycloconverter system

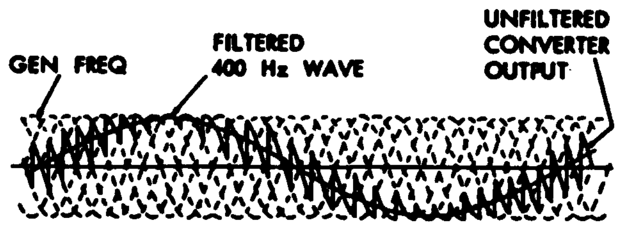


Fig. 4 - Cycloconverter input/output waveform

Figure 1 Functioning of Cycloconverter

Reprinted by permission © 1981 Society of Automotive Engineers, Inc.

Direct Current Link:

Using a direct current link the generator is driven directly, at varying speeds, by the engine, but the output is then rectified and the desired 3 phase 400 Hz wave forms are generated by inverters using a pulse width modulating technique (Figure 2). In the case shown generator voltage is controlled by controlling the widths of the pulses. In the design shown, the inverter produces the three phases with no neutral. This is made into a three line plus neutral system by a neutral forming transformer. Unbalanced loads produce a "neutral" current flow in the transformer windings which flows back to the inverter. This type of system is being used on the F-20G and the AV-8B (Westinghouse) and is under development for the C-130 (Bendix). Figure 3 shows a cross-section of the AV-8B generator and Figure 4 illustrates how the F-20G system is modularized.

270 Vdc:

The cycloconverter and dc link systems replace only the constant speed unit and its controls. The 270 Vdc concept, which is at present in the study/comoponent development phases, proposes using 270 Vdc for all applications which do not have to use power in other forms. This can include not only such tasks as de-icing but also the use of dc motors as actuators. Recent developments have made brushless dc motors close to being competitive with hydraulic actuators. Thus, primary power distribution would be in 270 Vdc form (Figure 5). An interesting feature for commercial application is that 270 Vdc is readily obtained from commercial electric power. The generators rectify the power internally, as with an automobile alternator. This approach is being studied in a joint effort by Lockheed California Company and the US Navy (Ref 4).

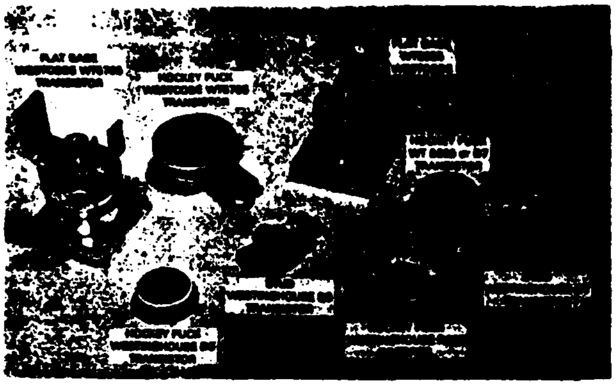
Boeing, in a study of an all electronic airplane concept (Ref 7), proposed a mixed system which provides both 270 Vdc power (200 Kw) and 115/200 V 400 Hz ac power (80 KVA). The generators are permanent magnet (samarium cobalt) which put out variable frequency, variable voltage power. Regulated 270 Vdc power is produced by silicon controlled rectifier bridge networks and the 400 HZ power is by cycloconvertors.

Variable Voltage, Variable Frequency:

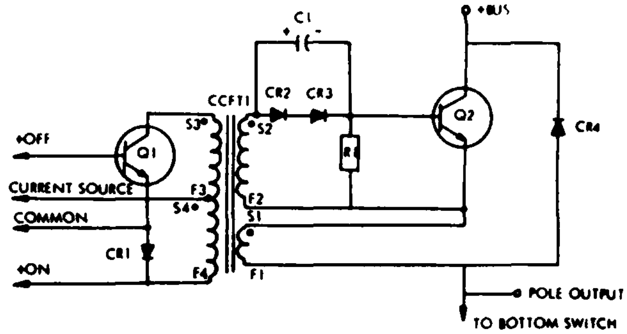
In the variable voltage, variable frequency approach the generator is directly geared to the engine but the output is not immediately rectified. It is used directly where possible, for such functions as de-icing, heating, powering, galley and ac induction motors. A smaller percentage is converted to 270 Vdc or to three phase 200 V, 400 Hz ac. Although there is no production experience with this type of system it was selected by Lockheed California Company, in a study for NASA, as the simplest and most efficient system for an all-electric airplane. The all-electric application replaces all hydraulic actuation functions with electrical actuation (Reference 6). These functions could include starting and using the generators as starter motors. The study suggested that a substantial reduction in weight and fuel consumption might be achieved by this approach.

Permanent Magnet Generators:

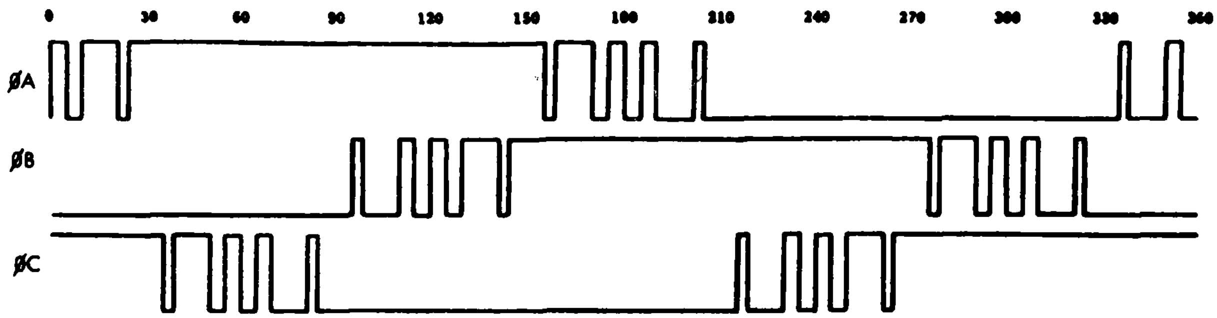
Permanent Magnet Generators, (PMG), (normally with rotating permanent magnets and stationary (windings), are inherently very simple and reliable. For this reason they are frequently used to provide electrical power for the main generator control units (Figure 2). The PMG is part of the main generator assembly, using the same shaft (Figure 3). On the F-16 a PMG is included in



Power switching devices



Base drive circuit



Pulse width modulated waveform

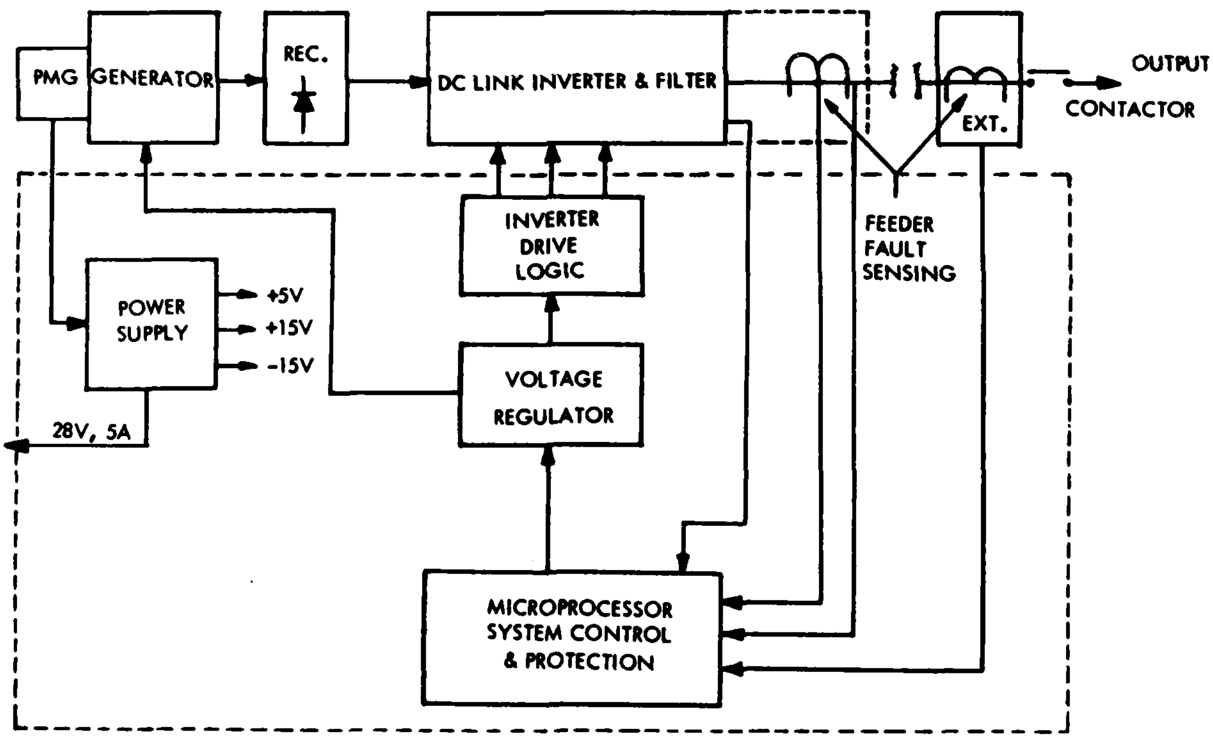


Figure 2 Functioning of Inverter in Direct Current Link

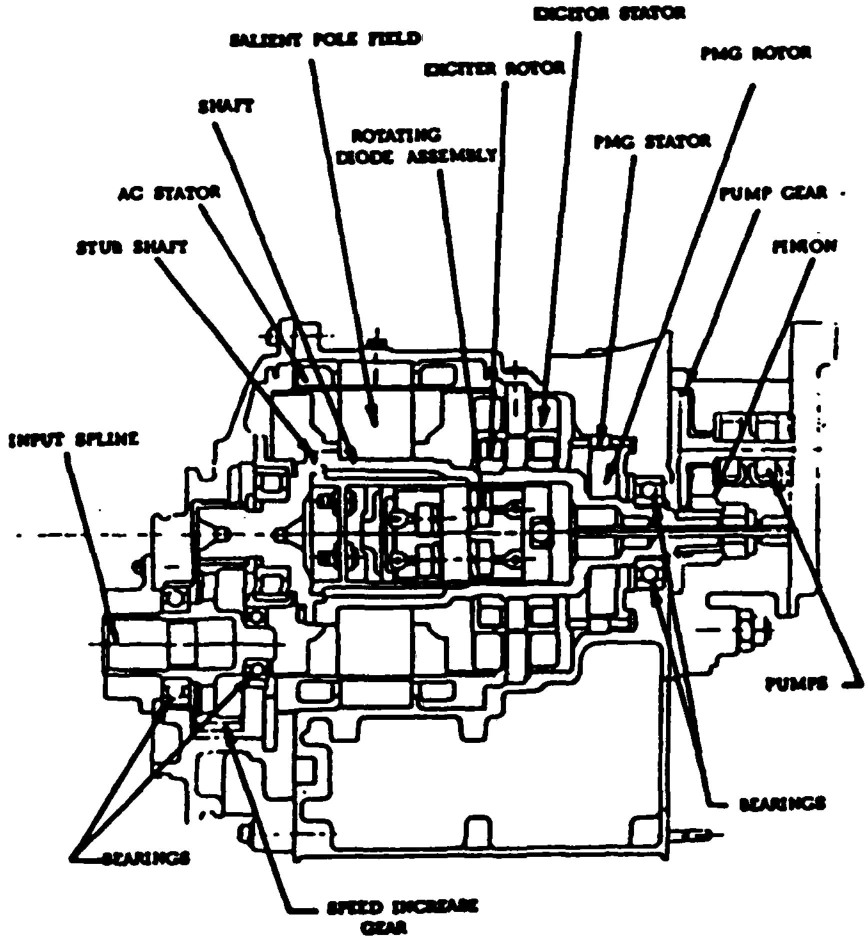


Figure 3 Cross Section of AV-8B Generator

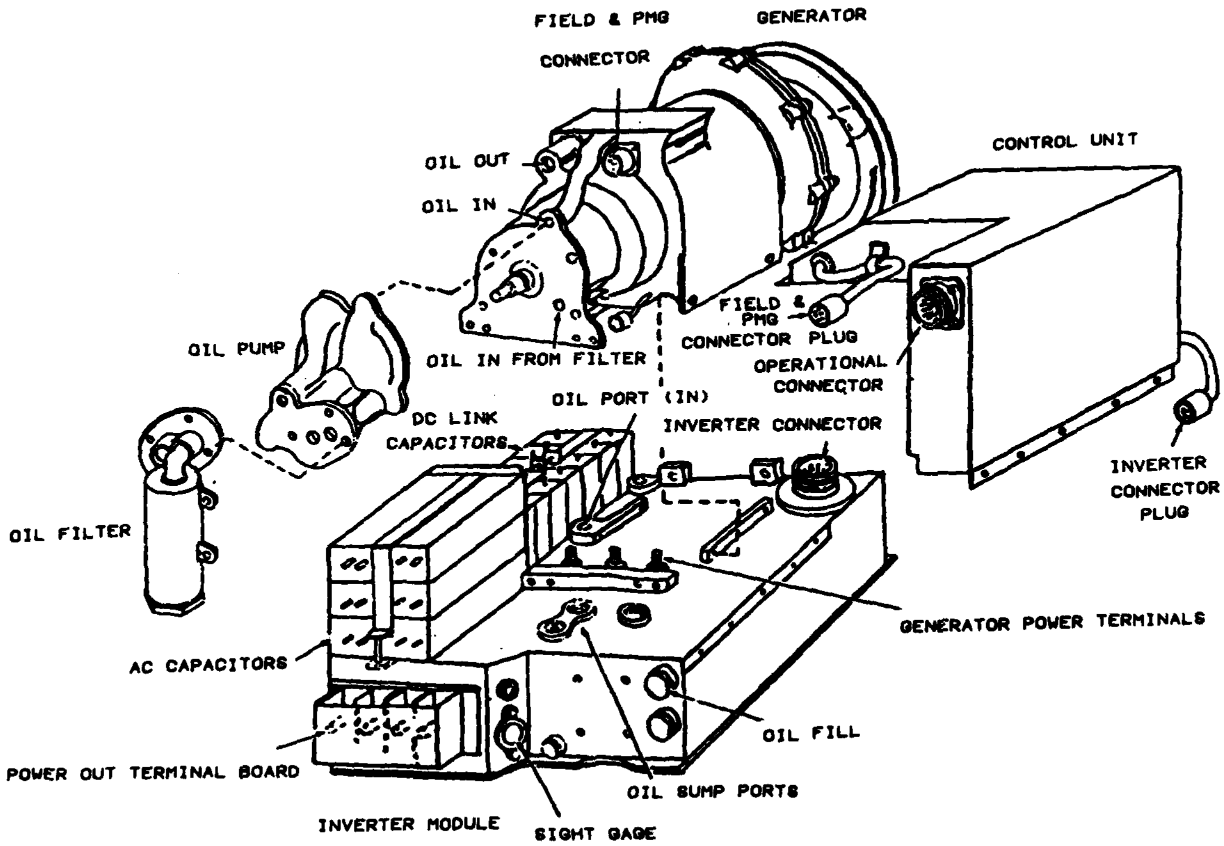
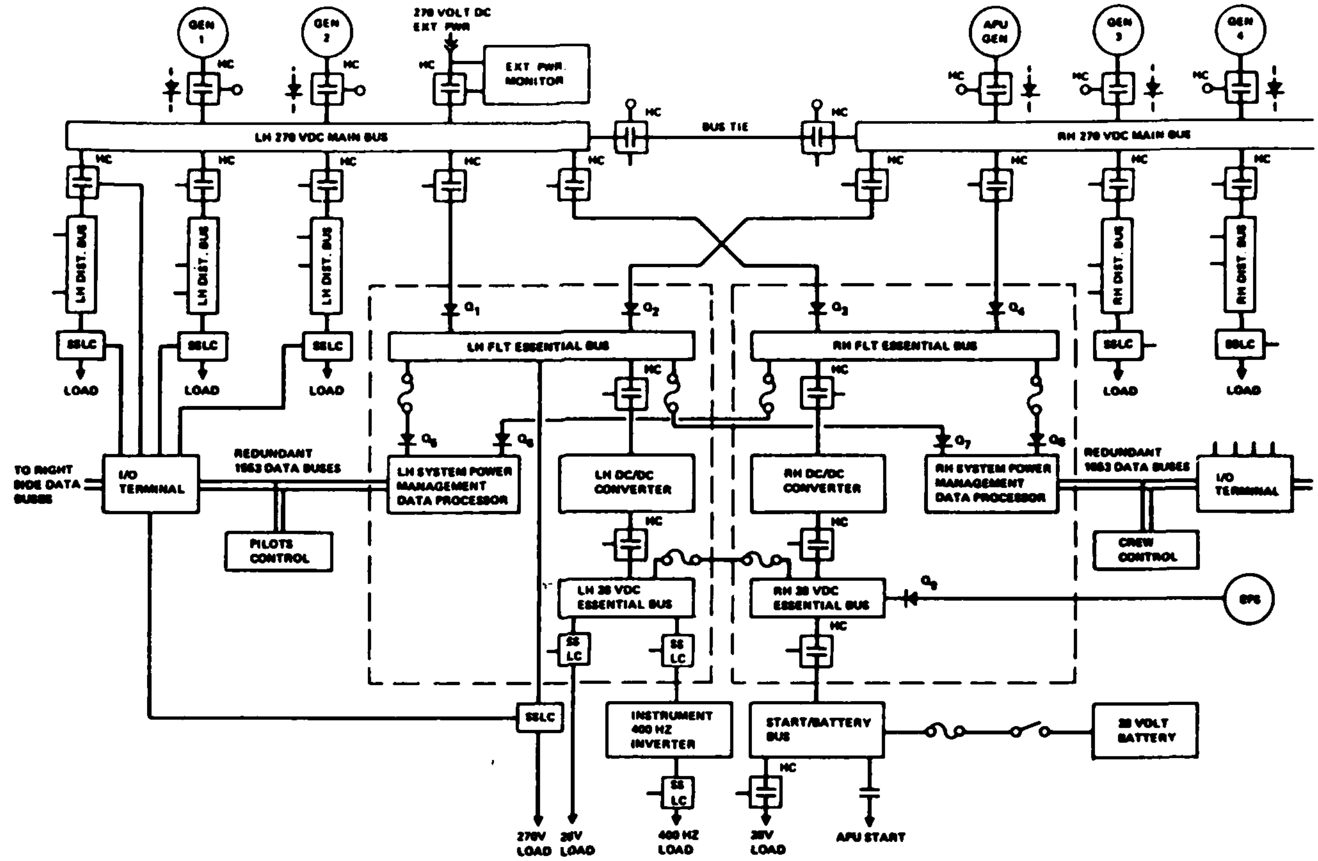


Figure 4 F-20G VSCF System Modules



Symbols

- HC — HYBRID SOLID-STATE POWER CONTROLLER OPERATED BY PRIMARY GENERATOR CONTROL AND PROTECTION-RATINGS OVER 10 AMPERES
- HC — HYBRID SOLID-STATE POWER CONTROLLER OPERATED BY POWER MANAGEMENT DATA PROCESSOR THROUGH I/O TERMINAL-RATINGS OVER 10 AMPERES
- SSLC — SOLID-STATE LOAD CONTROLLER OPERATED BY POWER MANAGEMENT DATA PROCESSOR THROUGH I/O TERMINAL-RATINGS 10 AMPERES AND LESS
- BORON SILVER-LINK FUSE
- OPTIONAL BLOCKING DIODE IN LIEU OF HC
- ELECTROMECHANICAL CONTACTOR OPERATED BY HARD WIRED 28 VOLT DC CIRCUIT

Figure 5 Example of Proposed 270 VDC System

Reprinted by permission © 1981 Society of Automotive Engineers, Inc.

the emergency generator package to provide backup power for the flight control electronics if the emergency generator fails but is still rotating. On the F-15 PMGs provide power for generator control on both primary generators and on the emergency generator.

COOLING

The generators and, when used, cycloconverters and inverters handle very high powers within small volumes. Since they are less than 100% efficient provision must be made to remove the excess heat. Generators are oil cooled either by conduction to oil passed through cooling channels or by spraying cooling oil directly onto, for example, the armature. The oil is in turn cooled by an air-oil or fuel-oil heat exchanger. Conduction-cooled generators, in which the oil does not directly contact electrical or electronic parts may conveniently share cooling with the accessory drive gearbox using its oil and heat exchanger. Figure 6 (ref. 8) shows a diagram of such an arrangement used on the F/A-18. With spray cooled generators it is usually more convenient to use a separate oil system rather than incur the complication of protecting the gearbox oil from possible contamination from the electrical parts. Figure 6 also shows a diagram of a spray oil cooling system for the F-20G. The oil used is usually MIL-L-7808 USAF or MIL-L-23699 (USN) (which are ester base synthetic oils). Items with relatively lower heat dissipation requirements may be cooled directly by convection (air) or by being mounted on a cold plate cooled by oil or air.

POWER DISTRIBUTION AND MANAGEMENT

Purpose and Functions:

These may be summarized as follows:

a. deliver electrical power of the required type, quantity and quality to all using components in normal operation.

b. continue (a) in "abnormal" operation - e.g. failure of one generator (except in a single engined aircraft).

c. provide the required type, quality and quantity of electrical power to flight essential components in "emergency" operation.

d. provide for power for ground checkout, including provisions to supply power from an external source and to check the quality of that power (voltage within limits, all phases present and in proper sequence.)

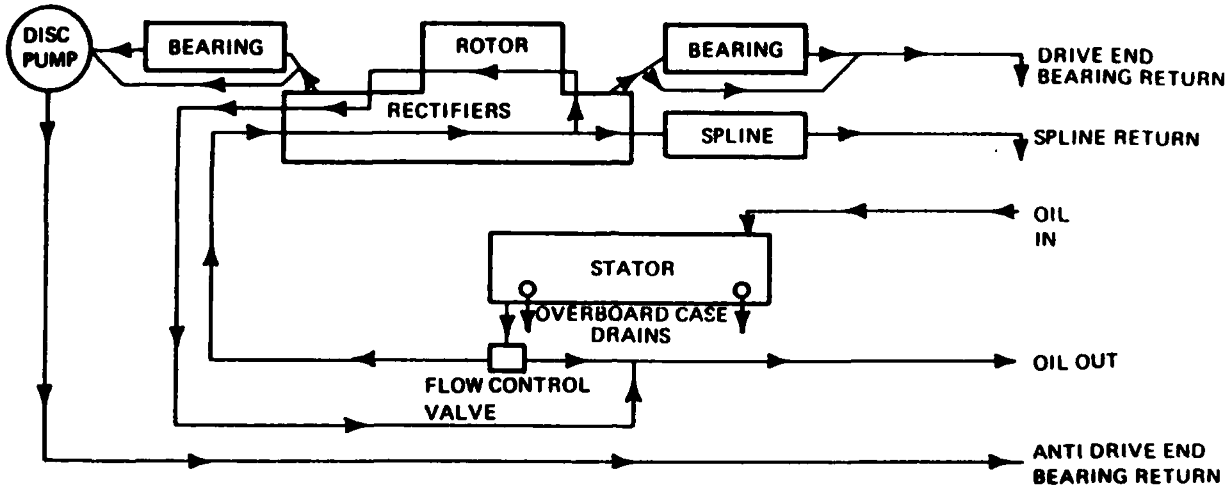
e. control load on remaining generators in case of a generator failure by shedding load as necessary (this prevents cut out of the surviving generator by their own protection devices) and bring using units back on line when power is restored.

f. isolate failed components.

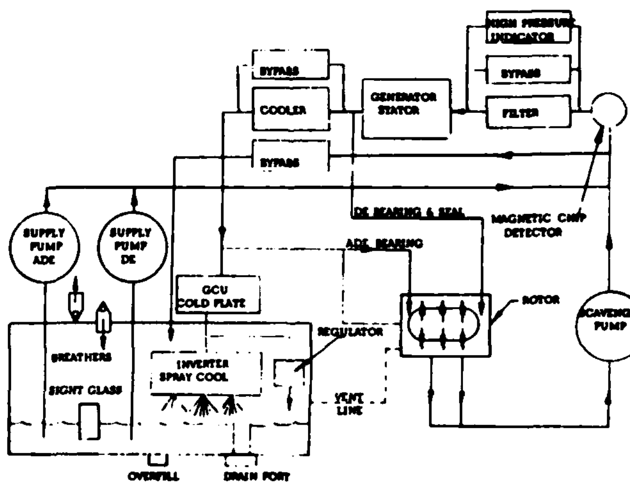
Primary ac power goes first to one or more ac buses from which it will go:

1. directly to using components.

2. to an emergency ac bus which supplies flight essential component using 115/200 V ac power.



System with Shared Gearbox and Cooling Oil



Spray Cooling Oil System Schematic

Figure 6 Examples of Cooling Techniques

Reprinted by permission © 1981 Society of Automotive Engineers, Inc.

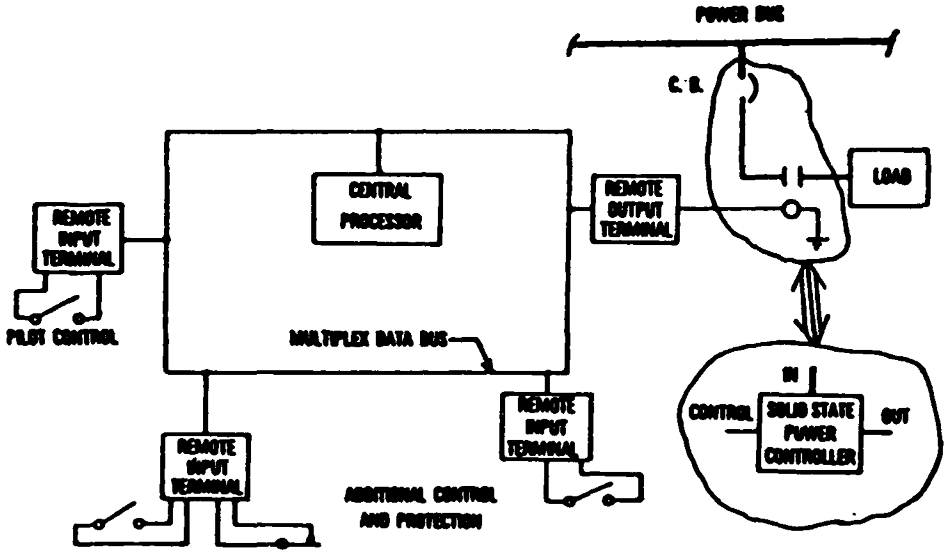


Figure 7 Electrical Multiplex (EMUX) System Control

3. to Transformer Rectifiers (TR's) to supply 28 Vdc power.

4. to dc buses.

5. to an emergency dc bus.

Conventional Approach:

Until fairly recently the approach to performing the above functions has been fairly standardized. Typically the primary 400 Hz, 115/200 Vac power goes first to one or more ac buses from which it goes:

1. directly to using components which use this form of power and are not flight essential.

2. to an emergency ac bus which supplies flight essential components which use 115/200 Vac power.

3. to Transformer Rectifiers (TR's) which supply 28 Vdc power to dc buses. These directly supply components which use this form of power and are not flight essential.

4. to the flight essential dc components via the essential dc bus.

Switching provision is made to supply the flight essential buses from the emergency generator and also to provide external ground power to all using components. The system is controlled by electromechanical devices such as switches, relays and circuit breakers.

New Approaches:

A different concept for aircraft electrical power distribution that eliminates many of the disadvantages of a conventional system has been developed (Ref 10). This advanced electrical system incorporates a central computer for the control of distributed power and a multiplexed digital data bus for routing control information between input switches and load relays. A simplified form of this system is shown in Figure 7. Control functions are input to a central data acquisition system by Remote Input Terminals (RITs). These discrete (on-off) inputs are used as elements in a Boolean logic equation which is being continually solved by the central computer. The equation output (True or False) is routed by the data bus to a Remote Output Terminal (ROT) and used as the control signal for the load relay or solid state power controller. The multiplexed data acquisition system and computer perform essentially the same functions the aircraft wiring, control relays, and switches do in a conventional distribution system. The end result in both cases is the application of power under controlled conditions to a specific load.

The central computer can also provide control functions such as load shedding and phased turn-on of loads that cannot be done easily by a conventional system. Although the computer controlled distribution system can use relays and thermal circuit breakers to control power to the loads, it is generally proposed to be used with solid state power controllers. A solid state power controller (SSPC) provides the functions of the circuit breaker and control relay in one package. It can also provide the status (i.e., ON, OFF, TRIPPED, FAULT) of the power controller to the central processor.

Figure 8 illustrates the power controller functions and typical over-current protection features. The SSPC also provides soft turn-on and turn-off which reduces switching transients on the power bus. The computer controlled electrical distribution system is known by many names of which EMUX (Electrical Multiplexing) is frequently used.

Figure 9 shows comparative schematics of conventional and EMUX power bus structures. In the EMUX approach the loads are not connected directly to a primary bus. Each load is connected to a Load Management Center (LMC) which controls the electrical power to the load and protects the interconnected wiring by using solid state power controllers. Semiconductor switches and the system control computer assure that the LMC internal power bus is connected to only one primary bus at a time. The central processor via the multiplex data bus also determines which loads are connected to the internal LMC power bus. Through the use of a stored program, the central processor can automatically shed loads to prevent overload of the primary generators. This system load shedding capability is especially important under major fault conditions. The computer can prevent complete system shutdown. The system can provide higher reliability power for flight essential loads by incorporating a backup power source such as a battery for load management centers which are designated as flight essential. Flight essential loads can also be powered from two of these LMC's to provide increased reliability.

The development of specialized EMUX hardware and software is expensive. New standards being implemented by the Air Force will help in the reducing develoment costs associated with multiplex systems, standard processors, and their system and support software. Figure 10 shows some of the major standards and specifications that have been developed to standardize aircraft avionics. These standards are very important in any integrated electrical power control system.

The multiplex system standard (MIL-STD-1553B) standardizes the data bus and the interface with processors and remote terminals. Remote terminals, for example, are now being implemented with Large Scale Integration (LSI) microelectronic devices and a few discrete components. This makes it possible to manufacture the remote terminal on a printed circuit module and integrate it into the processor and electrical load management centers. This will significantly reduce the aircraft wiring complexity. Standard digital processors such as the AN/AYK-15A have significantly reduced development and production cost. Vendor competition will assure high quality hardware at reasonable prices. The use of standard avionics processors has not yet been demonstrated for electrical system control. This will be done on an ongoing electrical system development program. The primary concern with using a processor designed for avionics functions is the overhead in processor time and memory requirements. Much faster and more efficient processors can generally be designed to perform Boolean logic.

The use of a standard higher order programming language such as defined in, MIL-STD-1589A results in standard ground support hardware for software development and maintenance. Again the electrical system designer can take advantage of this software development capability. The electrical system will require different computer programs to generate aircraft system software; however, the hardware that is required to perform this effort will be the same hardware that is used for other integrated avionics functions.

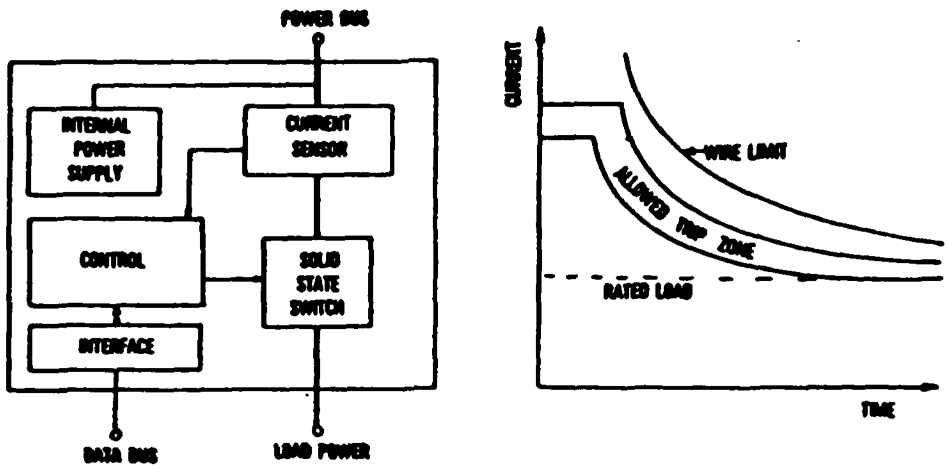
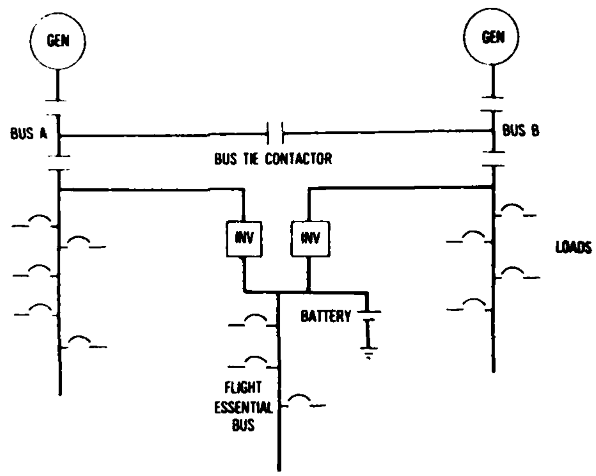
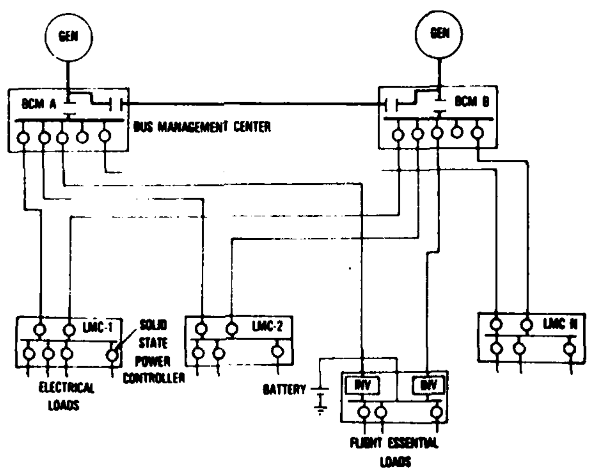


Figure 8 Solid State Power Controller Operation



Conventional Power System Bus Structure



EMUX Power Bus Structure

Figure 8

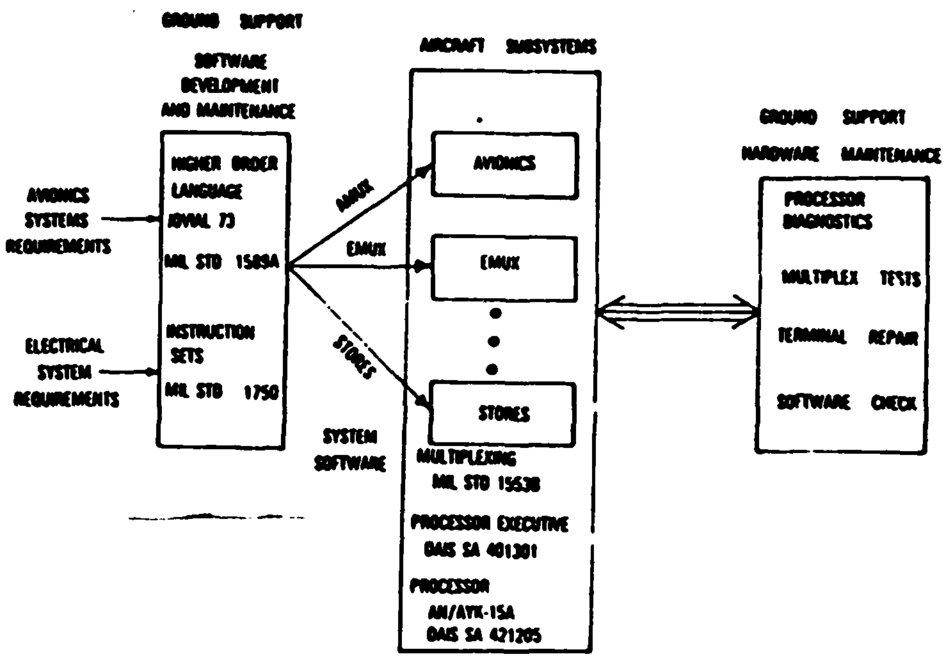


Figure 10 Aircraft Multiplex and Processor Standards

EXAMPLES OF CURRENT SYSTEMS

F-15 Electrical System:

This, being a relatively old design, is a conventional system (Figure 11). There are two primary generators, one driven by each engine by a constant speed drive off of the accessory gearbox. These two generators normally supply separate, left and right ac buses. In case of loss of power from one generator, the other can supply both buses, but phase matching of the generators is not required. The essential ac bus is normally supplied by the left ac bus but it will be supplied by the right ac bus if the left generator fails and by the emergency generator if both main generators fail. Ground power can supply the system through the left and right ac buses after its quality has been verified by the external power monitor.

The right ac bus normally supplies:

- The right 28 Vac bus, through a transformer

- The right 28 Vdc bus, through a transformer rectifier. (This bus supplies the master arm and armament buses (Figure 12).

The left ac bus normally supplies:

- The essential ac bus.

- The left 28 Vdc bus, through a transformer/rectifier.

- The essential dc bus.

Figure 12 presents the F-15 system in a different format and shows which using components are supplied by each bus.

B-1B Electrical System:

The B-1B electrical power supply system is essentially an ac system with dc provided through transformer rectifiers and batteries. The system basically consists of 3 primary ac generator channels, an emergency generator channel, a system integration panel, bus tie contactors, forward and aft main dc and avionics dc power supplies, a power distribution system, and a control panel (on the overhead panel). The primary generator channels power a synchronized parallel bus system. An external power receptacle permits application of power to the complete electrical bus system for ground start and ground operations. The ac power supply system (Figure 13) is fully automatic operation once the generators are on the line. Generator output voltage and frequency regulation, paralleling, system fault protection, and bus fault isolation are among the automatic functions provided.

An EMUX System transmits status information to a System Integration Panel (SIP) and transmits switching orders from the SIP to Power Control Assemblies. There are presently six "Load Management Modes", (Table 2) controlled through the EMUX, with provision for up to sixteen. Essential functions are hard wired.

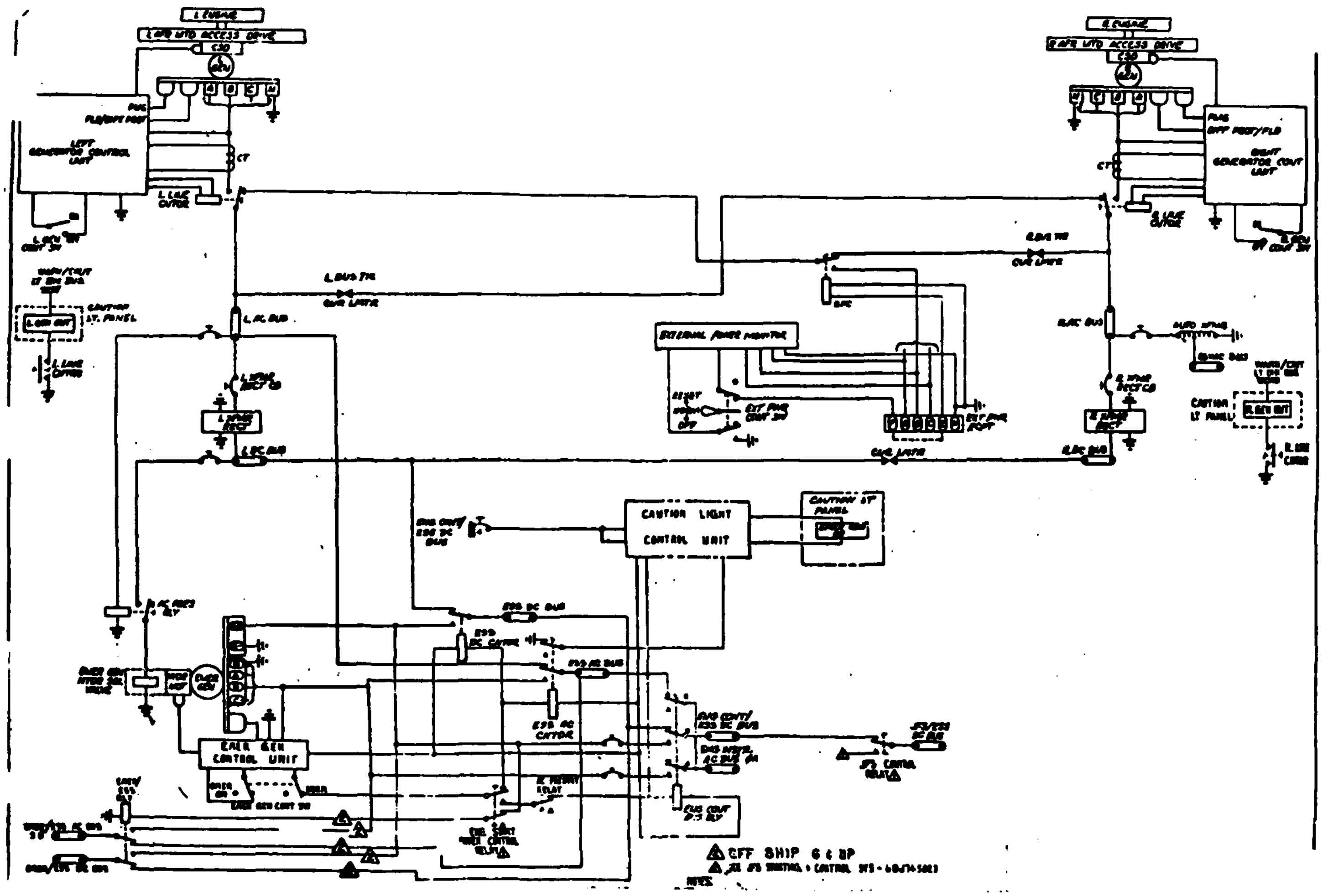


Figure 11 Schematic of F-15 Electrical System

THIS PAGE INTENTIONALLY LEFT BLANK

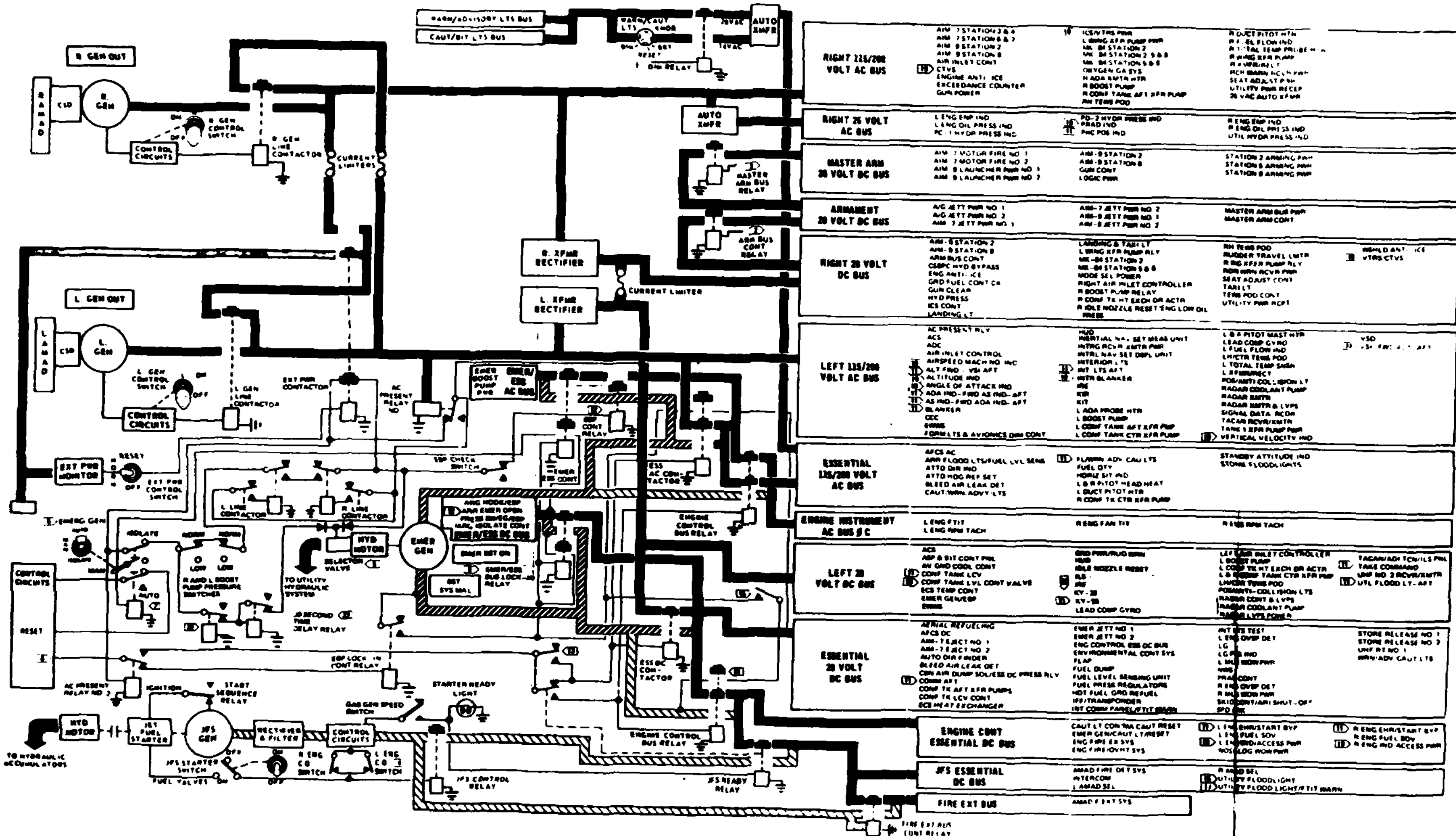


Figure 12 Alternative Schematic of F-16 Electrical System

THIS PAGE INTENTIONALLY LEFT BLANK

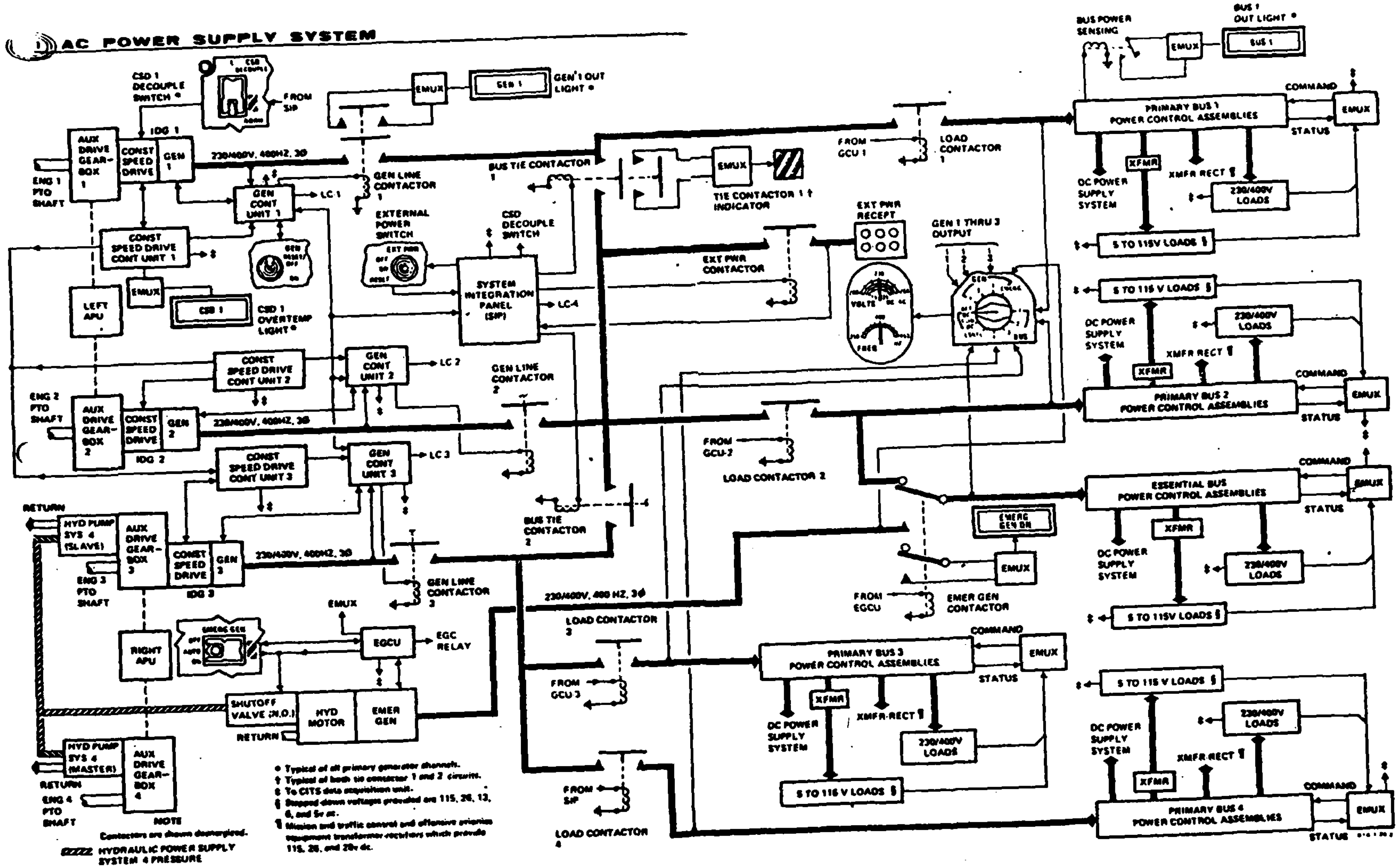


Figure 13 B-1B AC Power System

Table 2

B-1B LOAD MANAGEMENT (LM) MODES

LM Modes Defined:

- LM 1 = Refuel/Defuel Mode (1 APU Operating)
- LM 2 = Alert Mode (2APU's Operating)
- LM 3 = One Generator Mode
- LM 4 = Ground/Flight - All up Mode (Normal Operation)
- LM 5 = CITS Maintenance Mode
- LM 6 = Proximity Switch Mode

CITS = Central Integrated Test System

Primary Generator Channels.

Each of the 3 primary generator channels consists of an ac IDG, a constant-speed-drive control unit (CSDCU), a generator control unit (GCU), control and differential current transformers, a generator line contactor, and a load contactor. The IDGs, individually driven by the auxiliary drive gearbox (ADG) of engines 1, 2, and 3, consist of a 3-phase, oil-cooled self-excited, brushless generator (rated at 105/115 KVA, 240/416 volts, 400 Hz, 3-phase) and an integral constant-speed drive (CSD). The CSD, in conjunction with the CSDCU, maintains a constant generator rpm when gearbox rpm is above minimum speed. In turn, the generator output is maintained at essentially a constant frequency. The CSDCU also provides real load control between generators and go no-go (discrete signals to CITS.

The generator control unit includes a voltage regulator, generator channel control and protective circuits, as well as confidence test circuits which interface with CITS. Each GCU regulates its corresponding generator output at 230/400 volts, which is applied to primary buses 1, 2, 3, 4 and the essential bus. Any out-of-tolerance generator operation or generator failure is sensed by the GCU, and the generator is cut off and removed from the line by opening the applicable generator line contactor. GCU's 1 through 3 also provide control for the corresponding load contactors 1 through 3. An excessive differential fault current or any phase difference will cause the load contactor to trip. The system integration panel provides control for load contactor 4. The SIP, in conjunction with the GCU's, provides parallel system fault protection and bus fault isolation. The primary generator channels make use of a frequency reference unit in the SIP for synchronized frequency operation. The SIP monitors external power when connected to the aircraft. If external power is connected for APU start, the frequency of the first primary generator to come on line is slaved to the external power source rather than the SIP.

Normal operation of the system is with all 3 generators on the line and paralleled. However, if a malfunction should cause both bus tie contactors (BTC) to open (controlled by the SIP), primary generator channel 1 would power primary (BTC) channel 2 would power primary 2 and essential bus, and channel 3 would power buses 3 and 4. If only BTC 1 opens, generator 1 power bus 1 and generators 2 and 3 operate in parallel to power all other buses. If only BTC 2 opens, generators 1 and 2 operate in parallel to power buses 1, 2, and the essential bus and generator 3 powers buses 2, 3, and 4.

Loss of 2 generators will cause power-down of some electrical loads through EMUX load management (mode 3) to the capacity of 1 generator. The emergency generator provides a backup source of power for the essential bus.

Emergency Generator Channel.

The emergency generator channel consists of a 15 KVA ac generator, a hydraulic CSD assembly, an emergency generator control unit, and a line contactor.

The function of the emergency generator is to provide an emergency power source for the aircraft in the event of failure of the primary generator channels. The emergency generator is controlled by the AUTO emergency generator switch, having OFF, AUTO and ON positions. In AUTO (normal) or OFF, no generator field excitation is provided, and a normally open solenoid valve on the hydraulic drive assembly is energized (closed). With the valve closed, the emergency generator idle rotation rate is 225 rpm. This idle speed mode, which is provided to prolong bearing life and facilitate rapid warmup, is considered to be the normal nonoperating condition for the emergency generator during aircraft flight operations. The emergency generator hydraulic drive assembly motor is driven by hydraulic power system 4.

With the EMERG GEN switch at AUTO, if there is a loss of primary generator power, the emergency generator control unit senses this condition and deenergizes (opens) the hydraulic drive solenoid valve. The generator is driven at its rated operating speed of 8,000 rpm and the field is energized. Then the emergency generator contactor energizes, transferring electrical power from the emergency generator to the essential bus. If power is lost on primary bus 2, the emergency generator is automatically turned on. When the power on primary bus 2 returns to normal and it is desired to turn off the emergency generator, the emergency generator switch must be placed momentarily to OFF, then to AUTO.

The ON position of the emergency generator switch provides a manual means of turning the emergency generator on and connecting it to the essential bus in place of the primary generator system. This switch position is used if the automatic switching function fails and also to test operation of the emergency generator.

The emergency generator control unit (EGCU) provides all emergency generator voltage sensing, voltage regulation, and control and indicating functions. Electrical power from the emergency generator permanent magnet generator is used by the power source for the emergency generator exciter and the emergency generator contactor.

AC Power Distribution.

Electrical power (230/400-Vlt, 400 Hz, 3-phase) is routed from the primary generators to the 5 power distribution buses through the generator line contactors, bus tie contactors, and load contactors. Power from the 5 ac buses 1, 2, 3, 4, and essential) is fed through power control asemblies prior to being applied to the utilitization loads. The power control assemblies on-off switching functions controlled by EMUX. Relays controlled by relay drivers are used for the switching functions. Safety-of-flight and specific critical circuit breakers are in the crew compartment, accessible to the (OSO), Offensive Systems Operator and (DSO), Defensive Systems Operator in their seated position.

These circuit breakers power the relays in various power control assemblies. Some other circuit breakers are in power control assemblies which are located in the crew/central avionics compartment and are also accessible to the crew for in flight emergency use. The power distribution system includes stepdown transformers which provide various ac voltages ranging from 115 to 5 volts.

Generator and Bus Control Operation.

Fully automatic protective and corrective controls maintain optimum system operation under all conditions. Manual backup controls are provided where required. The system permits continued operation with one primary generator in operation; however, some electrical loads are powered down by EMUX (load management mode 3). In the unlikely event of loss of all primary generators, the emergency system provides sufficient power to insure safe return to base.

On the ground with engines and APU's off and no external power, all primary system generator line contactors are open and all load buses are deengerized. The load and bus tie contactors are closed unless a failure occurs. Upon initiation of a start cycle from the aft battery, the APU turbine is spun up by the hydraulic accumulator. APU fire detection and extinguishing are also powered by the aft battery. Immediately after APU start is achieved, the two gearboxes associated with the APU are engaged and brought up to speed. The first generator to come up to minimum speed is automatically connected (if previously selected) to all ac buses through the corresponding generator line contactor. When the second generator reaches synchronous speed and all conditions for paralleling are satisfactory, the corresponding line contactor closes and both generators operate in parallel. Until the first engine is started and delivers power to its gearbox, only electrical loads required for alert and starting are connected to the ac buses. All other loads are automatically disconnected by the electrical load management function of EMUX. As the third generator reaches synchronous speed and conditions for paralleling are satisfactory, the corresponding generator line contractor closes, providing parallel operation by all three generators.

DC Power Supply System.

The dc power supply system consists of forward and aft dc power systems and avionics dc power supplies. The forward and aft dc power systems provide 28-volt dc for safety-of-flight circuits. As such, each power supply provides power for APU and engine fire detection and extinguishing circuits. The aft power supply also provides power for APU and engine start circuits. The forward and aft dc power suply systems are essentially the same except for the ac buses, which provide the input power to the transfomer-rectifiers and battery charges. Each system basically consists of a transformer-rectifier, a battery, a battery charger, a battery current-voltage sensor, a transformer-rectifier voltage sensor, control relays, switches, a battery bus, a transformer-rectifier bus, and a main dc bus. Input power for the forward and aft transformer-rectifiers is provided by the essential bus and primary bus 3, respectively. Primary bus 3 also powers the forward battery charger, and primary bus 1 powers the aft battery charger. With the battery switch at AUTO/ON, each battery (forward and aft) powers its corresponding main dc bus when there is a loss of input power to the transformer-rectifier failure during operation. The battery also powers the bus during an alert start (the battery switch at ALERT/ARM, and the alert start button, on the nose gear strut door, momentarily depressed) or when the battery switch is placed at AUTO/ON with the essential or bus 3 (as applicable) deenergized. In AUTO/ON, the battery drops off the bus when the applicable ac bus (essential or bus 3) is energized. In ALERT/ARM, after momentarily depressing the alert start button, the battery remains connected to the main bus until the switch is positioned to AUTO/ON or OFF.

External Power.

When the aircraft is on the ground, electrical power can be provided through the external power receptacle, accessible through a hinged door at the bottom of the left nacelle. The external power source delivers 3-phase, 4-wire wye-connected 230/400-volt, 400 Hz, electrical power.

The external power source delivers sufficient power for ground operation and battery charging and can be used for APU start initiaion. External power will automatically be disconnected from the aircraft buses when any of the aircraft primary generators are operating within system voltage and frequency design limits.

If external power is connected to the aircraft at the time of APU start, the first generator to become operative will momentarily parallel with the external unit before the external power contactor (EPC) opens. Thus, uninterrupted power transfer is accomplished.

With no external power applied and with all engines shut down, all generator line contactors will be open (bus tie and load contactors closed) and all load buses will be deenergized. Upon application of satisfactory external power monitor, and actuation of the EXT PWR switch to RESET and then ON, the EPC closes and all buses will be energized. To protect the aircraft against unsuitable external power, the external power monitor section of the system integration panel controls the application of external power through operation of the external power contactor, which closes when phase rotation is in proper sequence, when voltage and frequency limits have been met, and when the EXT PWR switch is momentarily positioned to RESET. The external power monitor section of the SIP will disconnect the aircraft buses (the EPC opens) when the ground power unit generated voltage or frequency is out of limits or the phase rotation is out of sequence.

Circuit Breakers.

The ac and dc electrical power distribution circuits are protected by thermal circuit breakers mounted in power control assemblies, which are in the crew compartment, central avionics compartment, main landing gear wheel wells and aft avionics compartment. The status of each circuit breaker is monitored by EMUX.

SYSTEM REQUIREMENTS

INTRODUCTION

The electrical requirements of concern to the AFFTC are functional requirements and are not affected by the very substantial changes in system design reviewed in the preceding section. These requirements fall into two groups:

a. requirements for adequacy and quality of electric power provided to using components

b. electromagnetic compatibility requirements

ELECTRIC POWER CHARACTERISTICS

The requirements for aircraft electrical power characteristics are summarized in MIL-STD-704D (Ref 3). This standard defines the performance requirements for the power system and the interface requirements on the utilization equipment. Essentially, the utilization equipment should:

a. perform satisfactorily when supplied with power which meets the standards.

b. interface satisfactorily with the electrical system.

Alternating current power must be either a single-phase line-to-neutral (only for loads not exceeding 0.5 KVA) or a three-phase, wye-connected, neutral or ground return system having a nominal voltage of 115/200 volts and a nominal frequency of 400 Hz. The only alternate standard is a nominal 230/400 (as on the B-1B) volts when specifically authorized by the procurement agency. Direct current power must be 28 volts (nominal) or, with authorization by the procurement agency, 270 volts (nominal).

Modes of Operation:

The following definitions of operating modes are quoted directly from MIL-STD-704D:

Normal Operation. Normal operation is that condition wherein the electrical system is operating as intended in the absence of any fault or malfunction which degrades performance below established requirements. It includes all system functions required by all phases of aircraft operation except during the electrical starting of the propulsion engines when this is required. Normal operating conditions include switching of utilization equipment, engine speed changes, synchronizing and paralleling of power sources, and operation from external ground power. Although transfer operation as defined herein is a normal characteristic of most electrical systems, it is treated as a separate operating condition in this standard because of the power interruption which it usually produces.

Transfer Operation. The transfer operation is that condition of the electric system which takes place when a transfer occurs between power sources, including transfers from or to external power sources.

Starting Operation. The electrical starting operation is that condition of the aircraft electrical system, which occurs during the electrically powered starting of the propulsion engines of certain aircraft. This condition results in power requirements that exceed the limits for normal operation, due to the starting load.

Abnormal Operation. Abnormal operation is that condition of the electrical system wherein a malfunction or failure in the system has taken place and the protective devices of that system are operating to remove the malfunction or failure from the remainder of the system before the limits for abnormal operation are exceeded.

Emergency Operation. The emergency operation is that condition of the electrical system whereby a limited electrical power source, independent of the main generation equipment, is used to power a selected, reduced complement of flight essential distribution and utilization equipment.

Interface Requirements:

The aircraft electrical power system must provide electric power with characteristics as specified at the utilization equipment terminals during all operations of the power system, including operations from externally-supplied power sources but excluding periods of electrical starting of the propulsion engines. The external power source shall exhibit the electrical power characteristics as specified at the power input connections of the utilization equipment during all operations with the steady state voltage drop between the aircraft external power receptacle and the aircraft utilization equipment terminals as follows:

(1) ac feeder voltage drop of 0 to 5 volts.

(2) dc feeder voltage drop of 0 to 2 volts.

Utilization Equipment Requirements:

The following requirements are quoted directly from MIL-STD-704D:

Normal Operation. When supplied electric power characteristics as stated herein for normal operation, each utilization equipment shall provide the full performance required by its specification.

Abnormal or Transfer Operation. When supplied electrical power with characteristics as stated herein for abnormal or transfer operation, each utilization equipment:

a. shall be permitted a mandatory degradation or loss of function unless otherwise required by its specification, and

b. shall not produce a damaging or unsafe condition, and

c. shall automatically recover full specified performance when the electrical power characteristics are restored to the normal operation limits herein.

Starting Operation or Emergency Operation. When the detail specification for the utilization equipment requires operation during starting operation or emergency operations, then the utilization equipment shall provide the full performance required by its detail specification when supplied electrical power characteristics as stated herein for starting operation or emergency operation.

Partial Power Failure. The failure of one or more phases of ac power or the loss of power to any input terminals of equipment which require ac and dc power shall not result in an unsafe condition.

AC Phase Power Utilization. Loads greater than 0.5 KVA utilizing ac power shall be configured to utilize 3-phase steady state balanced power within the limits of Figure 14 Single phase power shall be used only on a line-to-neutral basis.

Transfer:

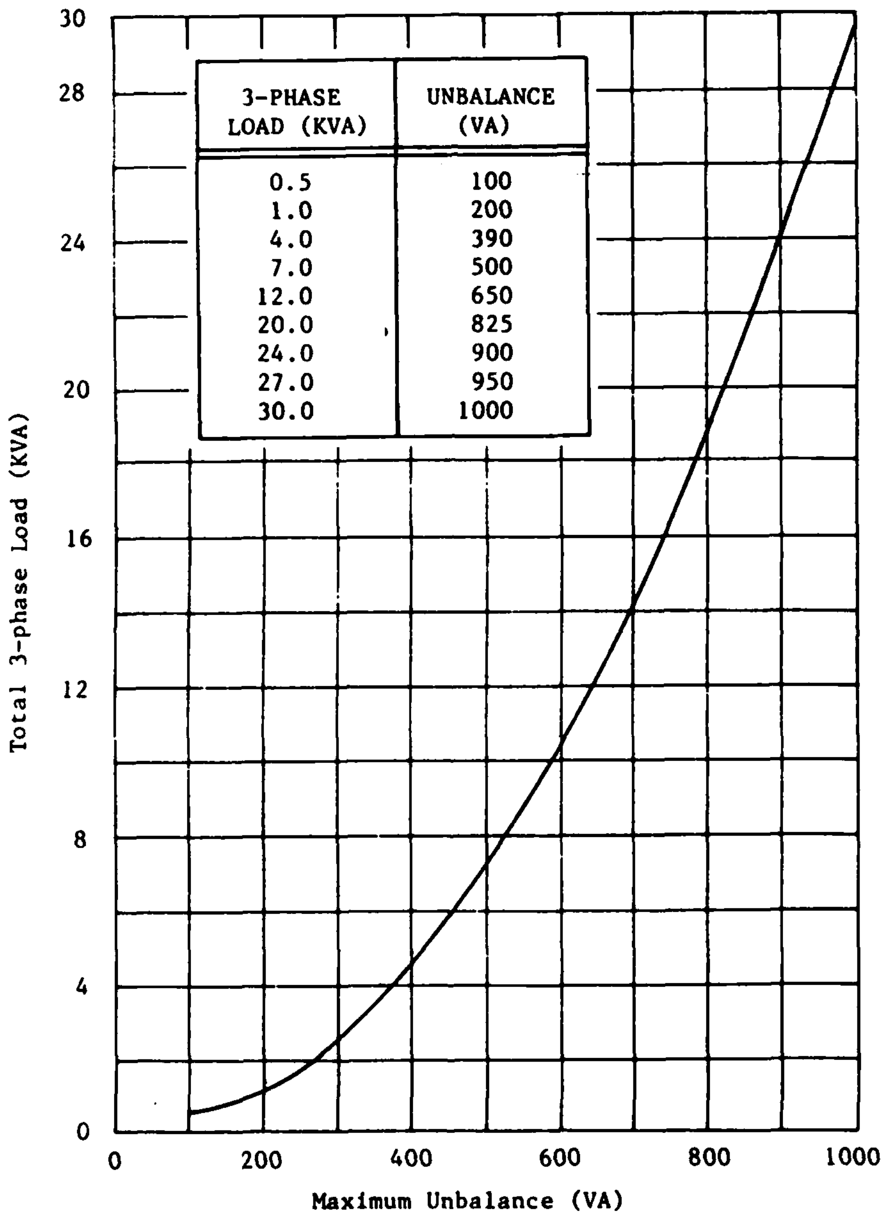
Under conditions of bus or power source transfers, voltage shall be between zero volts and normal electric system operating characteristic for no longer than 50 milliseconds.

Requirement for Alternating Current Power:

Requirements for normal operation are summarized in Table 3, as reprinted from Table 1 of MIL-STD-704D. Transient limits on voltage and frequency are shown in Figures 15 and 16. Limits on under-and over-voltage and under-and-over frequency are shown in Figure 17 and 18 for abnormal operation - is when a malfunction or failure has taken place and the protective devices of the electrical system are operating to remove the malfunction or failure from the remainder of the system before the limits for abnormal operation are exceeded.

Requirements for Direct Current Power:

Requirements for normal operation are summarized in Table 4, reprinted from Table II of MIL-STD-704D. In abnormal operation (i.e. after a failure) the dc over voltage or under voltage shall be within the limits shown in Figure 19 (28 volts nominal) or Figure 20 (270 volts nominal). If dc power is used for starting the dc voltage in the electrical starting operation shall be within 12.0 to 29.0 volts.



3-PHASE LOAD (KVA)	UNBALANCE (VA)
0.5	100
1.0	200
4.0	390
7.0	500
12.0	650
20.0	825
24.0	900
27.0	950
30.0	1000

Figure 14 Unbalance Limits for 3-Phase Utilization Equipment

Table 3

AC Normal Operation Steady State Characteristics

Characteristics	Limits
Voltage	108.0 to 118.0 volts
Voltage unbalance	3 volts maximum
Voltage phase difference	116° to 124°
Waveform distortion factor	0.05 maximum
Waveform distortion spectrum	Figure 21
Crest factor	1.31 to 1.51
DC component	+0.10 to -0.10 volts
Frequency	393 to 407 Hertz
Frequency deviation	Figure 16
Frequency drift rate	15 Hertz per minute maximum

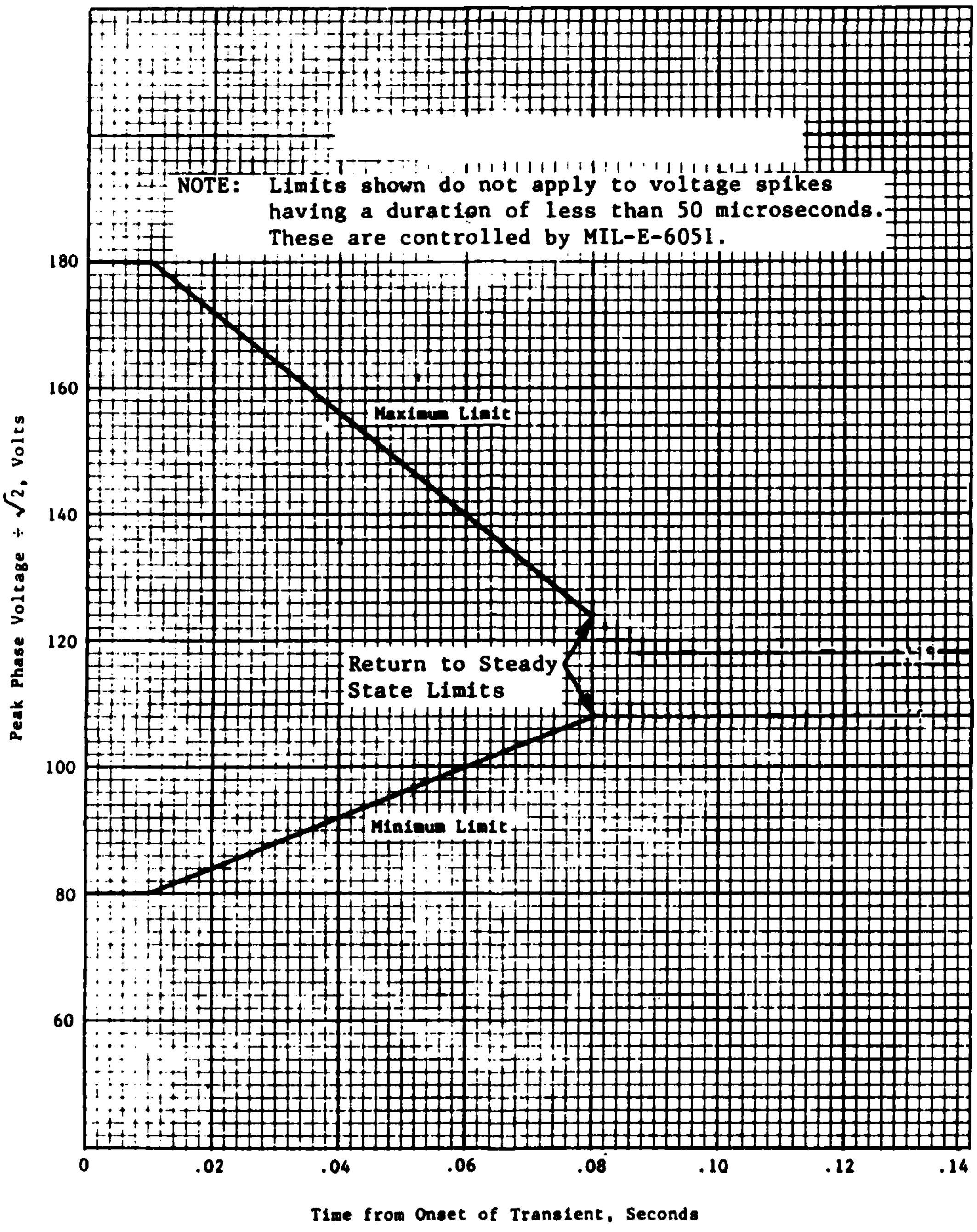


Figure 15 Envelope of AC Voltage Transients

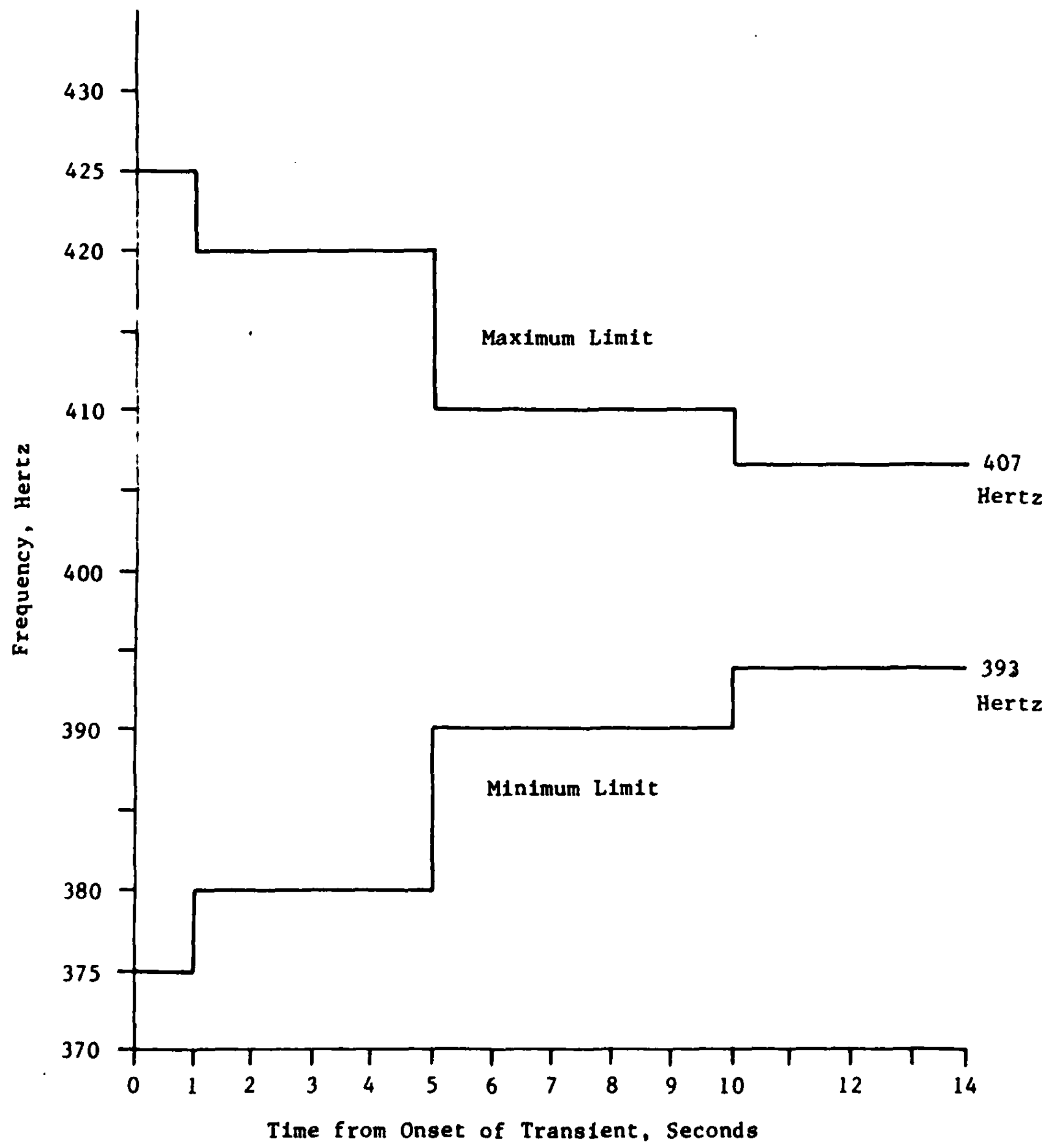


Figure 16 Envelope of AC Frequency Transients

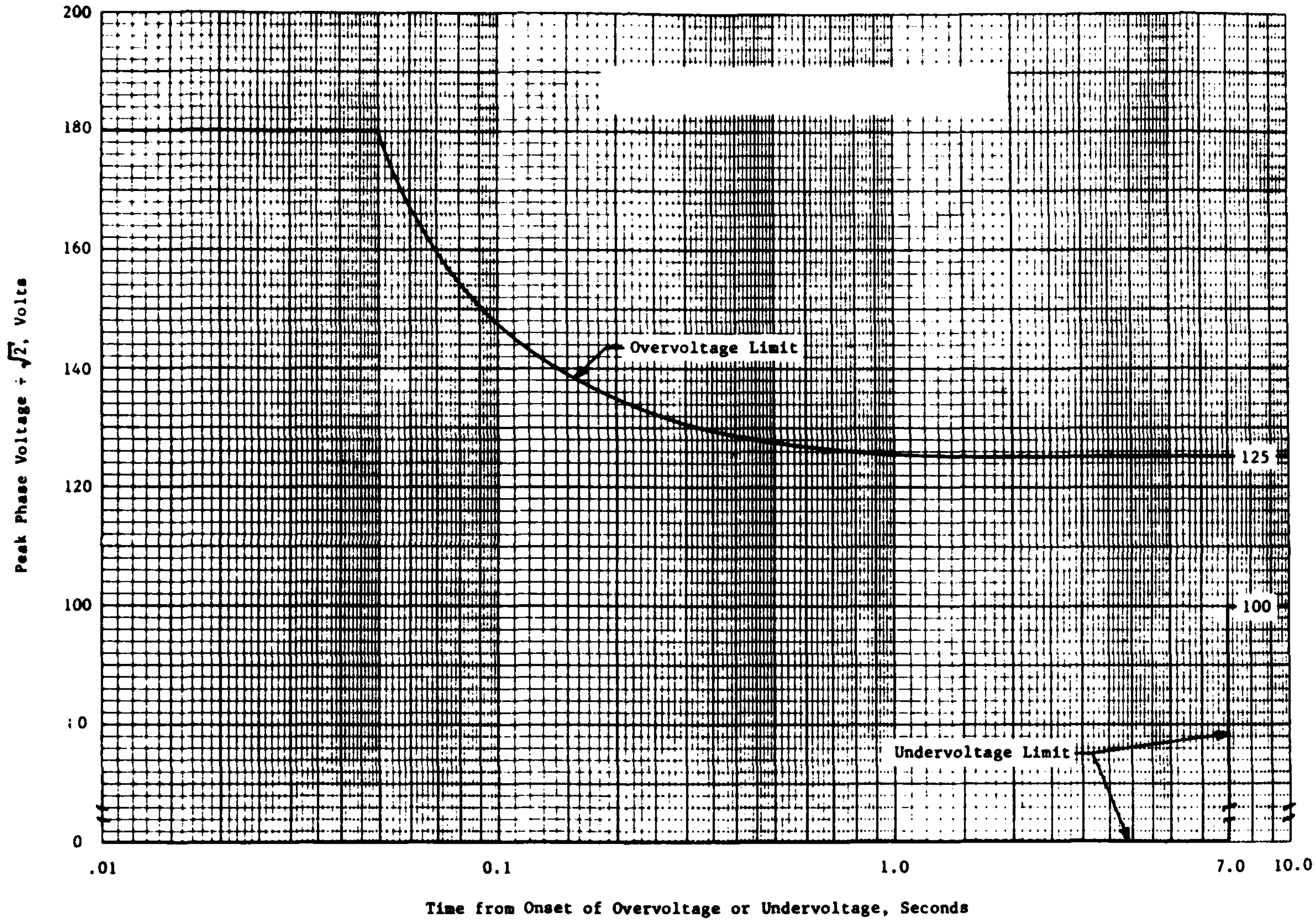


Figure 17 Limits for AC Overvoltage or Undervoltage

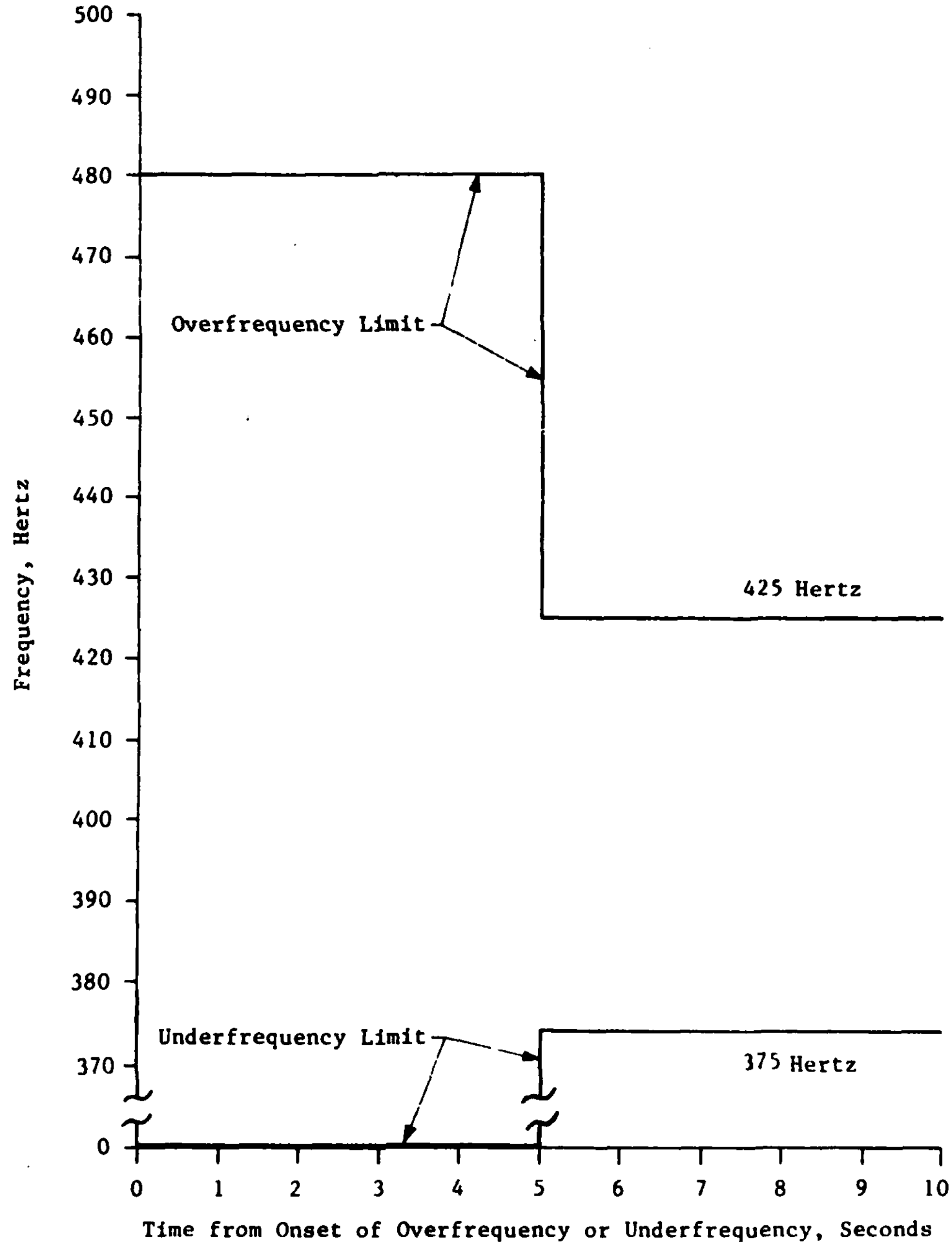


Figure 18 Limits for AC Overfrequency or Underfrequency

Table 4

DC Normal Operation Characteristics

Characteristics	Limits	
	28 volts (nominal) DC system	270 volts (nominal) DC system
Steady state voltage	22.0 to 29.0 volts	250 to 280 volts
Distortion factor	0.035 maximum	0.008 maximum
Distortion spectrum	Figure 21	Figure 22
Ripple amplitude	1.5 volts maximum	6.0 volts maximum
Voltage transient	Figure 19	Figure 20

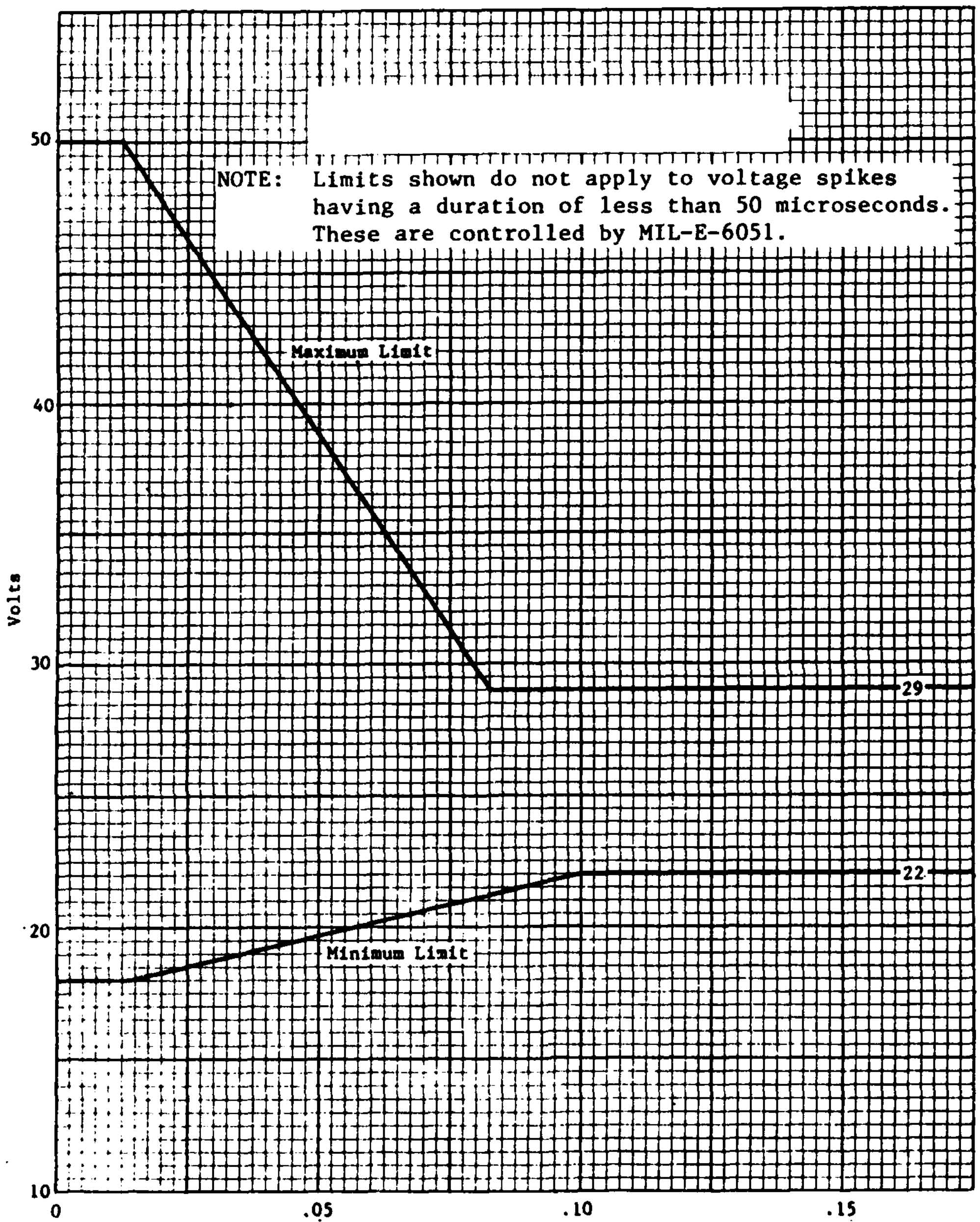


Figure 18 Limits for DC Overvoltage or Undervoltage - 28 Volts Nominal

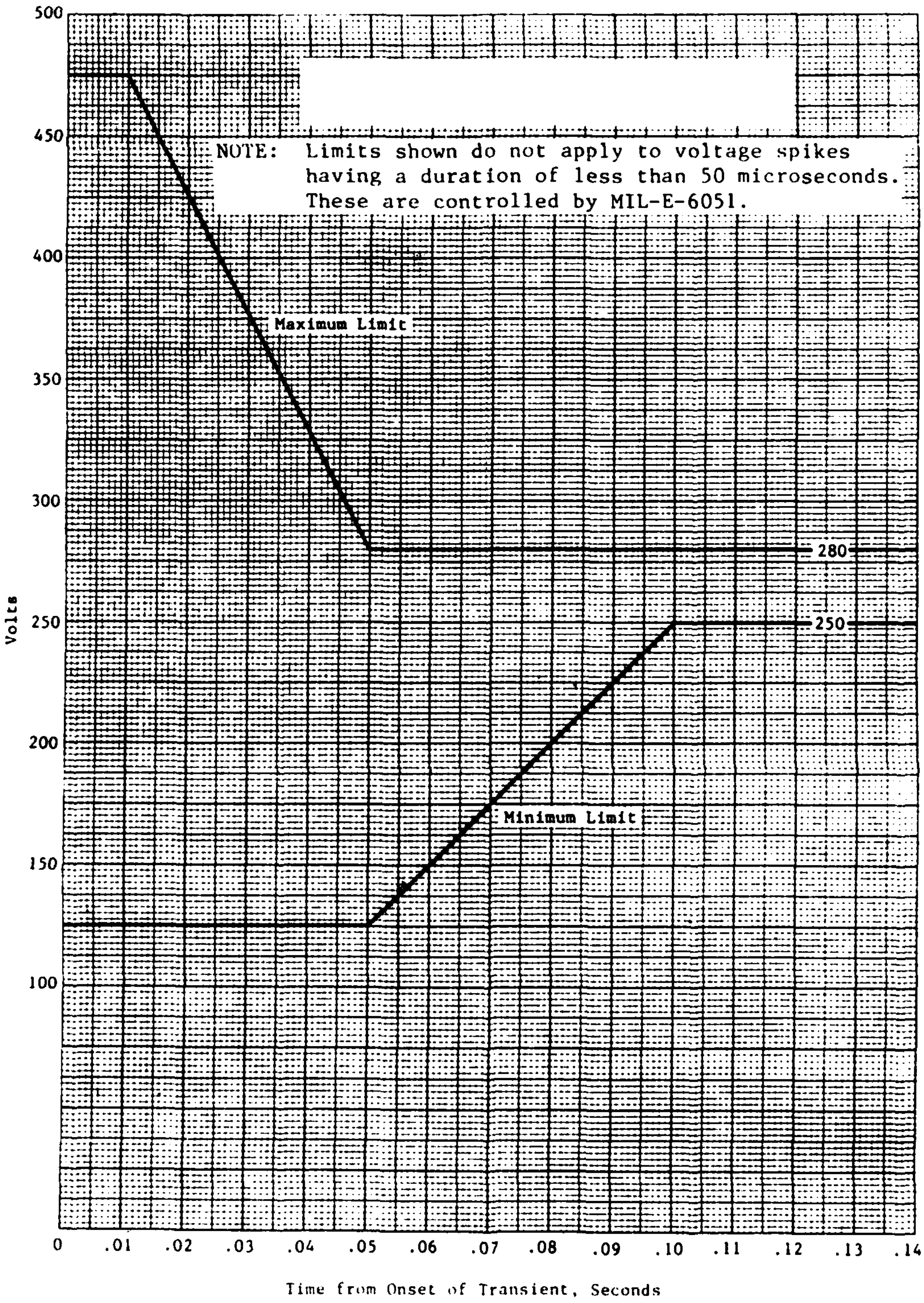


Figure 20 Limits for DC Overvoltage and Undervoltage 270 Volts Nominal

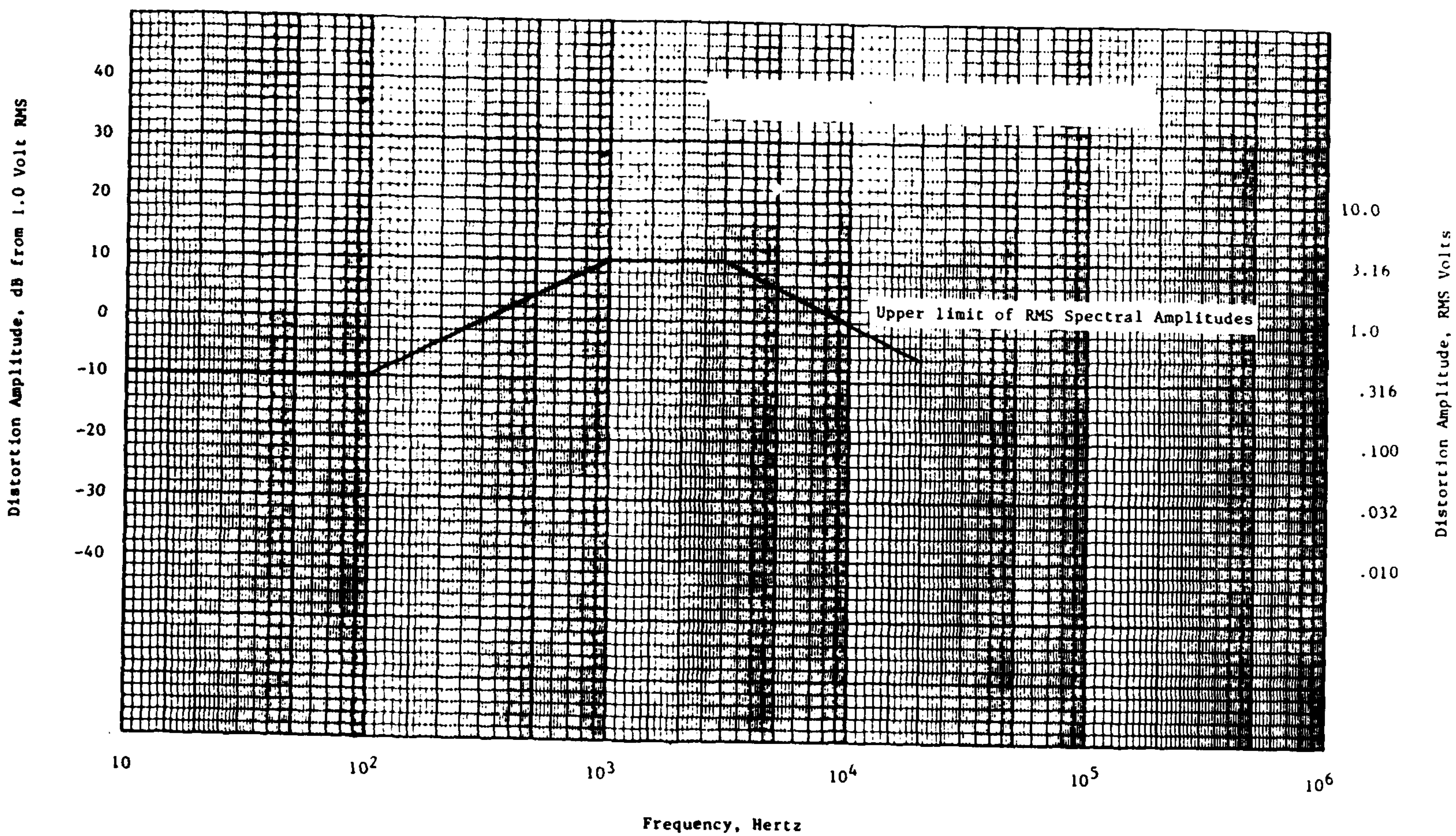


Figure 21 Distortion Spectrum of AC Voltage
(See Table 2)

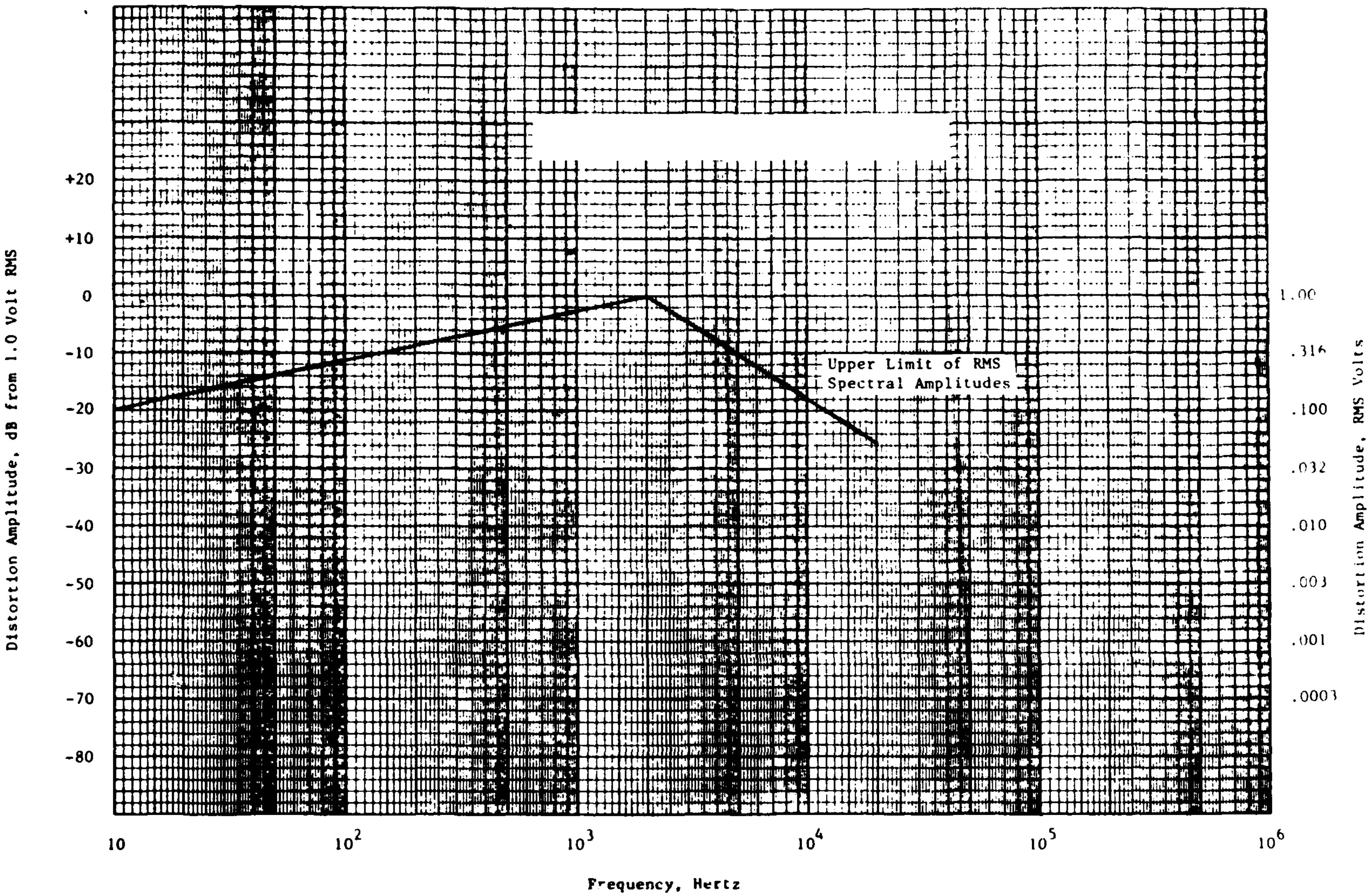


Figure 22 Distortion (Ripple) Spectrum of DC Voltage
(See Table 4)

ELECTROMAGNETIC COMPATIBILITY REQUIREMENTS

An aircraft includes many potential sources of electromagnetic radiation and also many devices which are sensitive to such radiation. Electromagnetic interference (EMI) can produce noisy radio, spurious signals into computers or inadvertent firing of missiles or release of bombs.

Control of EMI is primarily accomplished in the design and development phases by:

1. Control of emissions

2. Control of sensitivity to emissions

3. Mockup tests to verify electromagnetic capability.

MIL-E-6051D (Ref 11) requires the prime or integrating contractor to establish an electromagnetic compatibility program and an electromagnetic compatibility board whose members have enough authority within their respective organizations to implement the program effectively.

This approach should detect and correct any problems before the aircraft reaches AFFTC. Tests made at AFFTC will normally be limited to:

a. watching for EMI during normal test programs and

b. checking for transients which could inadvertently cause a fire or release signal at a weapons station when equipment is switched on and off

c. possibly, check during a dry pass over the range.

d. lightning strike tests in some cases. These have been conducted in the Weight and Balance Hangar but they require special equipment available from AFWAL.

PLANNING FOR FLIGHT TESTS

This section addresses planning of the content of the electrical system flight test program. The administrative procedures required to execute these plans are common to all AFFTC flight tests and will change from time to time. The engineer should familiarize himself with AFFTC Regulation 80-12 (Test Plan) and AFFTC Regulation (80-13) (Test Plan Technical Review) and other regulations such as AFFTC Regulation 80-1. Safety procedures are similarly applicable to all flight testing and the engineer should familiarize himself with references 12 and 13. Examples of Test Project Safety Reviews are given in Appendix B.

Electrical system tests will usually be conducted along with other tests through Combined Test Force (CTF) operations and will be part of a coordinated, combined overall program. This program will be designed to meet the needs of all interested parties - primarily the contractor, System Program Office (SPO) and AFFTC. It will be jointly developed and will be defined in detail in a series of Test Information Sheets (TIS). An example of an electrical subsystem TIS is included as Appendix A of this handbook.

Initial emphasis is on development. Later, test emphasis will shift from development to operational evaluation, with increased participation by AFOTEC and the using command. At all times the AFFTC flight test engineer must, however, ensure that the test program and the data acquired are adequate to meet AFFTC requirements and must independently analyze the data and evaluate the system. The engineer should also establish good communications with flight and ground crews and ensure alertness to all system incidents relevant to evaluation.

The flight test engineer must become throughly familiar with the system both as described in flight and maintenance manuals and as it exists in hardware form. These versions may differ significantly in the development phase of a new aircraft (and sometimes in later phases).

Careful record keeping is important. The engineer should make and adhere to specific plans to maintain detailed, accessible and complete test records for later use in preparation of Technical Reports and for the benefit of his successor if he should leave the program.

It is good practice to draft relevant sections of the report in the test planning stages. Writing the sections on Test Item Description and Test Methods and Conditions not only speeds the reporting process but also helps ensure that important information is not overlooked or lost.

Much of the electrical system testing in normal operating mode does not require dedicated flight-time. It will be done on a ride-along basis, since functional adequacy of all systems must be evaluated throughout the mission and operational envelope of the aircraft. Hence, normal operation can be evaluated along with other testing on representative operational missions. However, dedicated tests are required for some aspects of operation in abnormal and emergency modes. Another aspect requiring cooperation is that some aspects of system evaluation involve the expertise of Reliability and

Human Factors engineers. They will have primary responsibility in their areas of concern, but the electrical system test engineer should be aware of their activities and make sure no interfaces are overlooked.

This section is concerned with identification of the tests required. Integration of these tests into the particular test program is extremely program peculiar and will not be discussed. A fairly complete set of examples of tests has been relegated to Appendix C since it it necessarily repetitive and would obscure the logic of identifying the kinds of tests required.

SOURCE MATERIAL

The test planner should become familiar with the following source material:

(1) The contractor End Item Specification and equivalent documents

(2) The contractor Design Analysis Report

(3) The contractor Failure Modes and Effects Analysis (may be part of (2)).

(4) Project Directives and specific requests by the System Program Office.

(5) Flight Manual.

(6) Maintenance Manual

(7) The contractor Electrical Systems Verification Test.

Item (1) together with MIL-STD-704 (discussed in the proceeding section) define the requirements to which the aircraft is designed and against which it will be tested, subject to the overriding requirements of operational suitability and functional adequacy. Item (5) is very important for showing how the system is to be operated.

Item (2) is very useful. It shows how the system is intended to work, what conditions the designer expects to be stressing, what degraded modes of operation are provided for and how they are brought into operation.

OBJECTIVES AND REQUIREMENTS

The objective of DT&E tests of the electrical system is to evaluate its "functional adequacy, operational suitability, and compliance with specifications". Adequacy and suitability in the operational context (mission plus environment) in which the aircraft will be used are key criteria. The AFFTC, represented in this task by the subsystems test engineer, has a primary responsibility to the user to ensure that these criteria are met.

The function of the system is to supply adequate electrical power in the form and of the quality required for ground checkout and under all conditions of flight called for by the mission. It must continue to supply flight-essential services in case of complete failure of the primary system.

The electrical system will typically consist of:

a. one or more primary generators (usually one per engine) each with its own control system to control voltage and frequency and to protect it from overload.

b. a distribution and load control system to distribute the power, convert it to other forms as necessary by transformers or transformer-rectifiers isolate failed components, cross-feed power in case of generator failure, and bring using components back on line when power is restored.

c. provision for power for ground checkout and servicing.

d. an emergency generator and distribution system to supply flight essential services in case of complete failure of primary power.

IDENTIFICATION OF TESTS REQUIRED

The tests required must be detailed in a Test Information Sheet (TIS). These details will be peculiar to the aircraft type under test, so we will presently review a general approach to determining what tests are required. These tests are the means of evaluating the system throughout the condition required by the mission and must cover all operating modes of the electrical system for representative flight conditions.

Operating Modes:

Definitions of operating modes from MIL-STD-704D were quoted in the preceding section. They may be conveniently grouped as follows:

a. Normal, transfer and (if relevant) electrical starting, (all modes with no failure)

b. Abnormal operation

c. Emergency operation

Normal, transfer and starting operations are all concerned with operation in the absence of any failure. Operation of the system will be checked for:

1. Effectiveness of protection against under/over voltage or phase error in ground power.

2. Adequacy of external power provisions and, if relevant, electrical power provided Auxiliary Power Unit (APU) driven generator.

3. Acceptable transients during transfer to normal on board power (from engine driven generators) and acceptable paralleling time (if relevant).

4. Acceptable power quality and quantity during steady state operation.

5. Acceptable transients during when major loads (e.g. avionics) are turned on and off.

6. No EMI (electromagnetic interference).

7. Generator synchronization (if relevant).

If the airplane has electric actuators then functioning should be checked under conditions of high control activity flight as in rough air (or control movements to simulate control in rough air), terrain following (with terrain following radar (TFR) and other relevant avionics such as Electric Warfare Systems (EWS) functioning) and landing.

Abnormal operations involve one or more failures in the primary system but not complete primary system failure. The failure modes of concern will depend on, for example, the number of primary generators, since the failure of one generator on a single engined aircraft will lead directly to emergency mode operation. The test planner should therefore review the End Item Specification for the electrical system and contractor analyses, including the Failure Modes and Effects Analysis, to find the failure modes which should be tested. In general, AFFTC flight test is concerned only with failure of major components such as generators, bus cross tie switches or transformer-rectifiers and with the effective isolation of failed components.

Each failure mode should be simulated and the system checked for:

1. Satisfactory isolation of the failure

2. Adequacy of remaining power

3. Load control (to prevent overloading of remaining system)

4. Transients

5. EMI

6. Restoration when failure is corrected.

Emergency operation involves the supply of a selected reduced complement of distribution and utilization equipment by an alternate source, independent of the main generation equipment. The following should be checked:

a. satisfactory activation of the emergency supply

b. satisfactory quantity and quality of power

c. acceptable transients

d. restoration of normal supply when primary generators are brought back on line.

If the emergency generator is hydraulically powered, tests should include conditions of high flight control activity and reduced hydraulic power output, as in a simulated landing or idle power descent with flight control activity simulating flight in turbulence. This type of condition should also be checked if the airplane has electrically powered flight control actuators.

GROUND TESTS

Ground tests fall into two groups:

a. Tests to evaluate the system during normal servicing, starting and pre-flight using the procedures prescribed in Technical Orders.

b. Precautionary tests of such functions as response to failure and activitation of the emergency mode, made prior to flight evaluation.

Throughout all tests any Electromagnetic Interference (EMI) problems will be noted and the source identified by selectively switching off eqiupment.

External Ground Power:

Power carts as specified in TO's will be used. Functioning of the power monitor will be verified by:

1. Hooking the cart up to the aircraft through a load bank and varying the voltage to determine the trip limits of the monitor.

2. Hooking the cart up with phases out of sequence/missing to ensure that the monitor refuses contact.

Functioning of the system will be verified during normal maintenance and ground starts, including the following:

3. Satisfactory operation of JFS/APU ignition as relevant.

4. Satisfactory assumption of load by primary generators after engine start.

Internal Ground Power:

If the aircraft has an internal source of ground power such as from an Auxiliary Power Unit (APU) satisfactory operation of this system will be checked during normal ground servicing, engine start and pre-flight.

Ground Tests in Preparation for Flight Tests:

These lists are to provide verificaton on the ground of system operation in normal and abnormal modes.

Normal Mode.

With all primary generators operating tests will be made to evaluate:

- the ability to support full using equipment load
- transients when using equipment is switched on and off
- (possibly) simulated lightning strikes.

Abnormal Mode.

All the failure modes identified as abnormal modes will be simulated to evaluate:

- load capability of system in mode
- isolation of failed components
- load control to protect operation of remaining generators.
- resumption of normal operation when fault is removed.
- operation of using equipment during transients.

Note that if the operation of a using component is disrupted by a transient which is within specification limits this is a shortcoming of the using equipment.

Emergency Mode.

With engines running at ground idle and electric loads on disconnect all primary generators and:

- evaluate actuation of emergency electrical system
- evaluate functioning of load control
- evaluate adequacy and quality of power to essential service
- If the emergency generator is hydraulically driven or if the flight controls are electrically activated, activate flight controls to simulate activity in landing or in rough air and verify continued adequacy of power.
- re-connect primary generators
- evaluate restoration of supply to non-essential using components
- evaluate that they come on line
- evaluate reactivation of using components.

FLIGHT TEST

Normal and Abnormal Modes:

Tests in normal and abnormal operating modes will be performed in the following flight conditions summarized in Table 5.

Table 5

Flight Conditions for Tests in Normal and Abnormal Operation Modes

Flight Conditions	Normal Mode	Abnormal Mode
Normal Mission Profiles	X	-
Cruise Altitude		
Cruise Speed	X	All identified abnormal modes
High Speed	X	-
Loiter	X	-
High Speed, low altitude (hot day if available)	X	-
Medium Altitude, medium and high speed	Maximum and minimum 'g', full maneuvering envelope	-
Terrain following, target tracking, weapon delivery	X	Generator failure on multiengined aircraft

In the normal operating mode electrical loads (primarily avionics loads) will be switched on and off in turn. The tests will evaluate:

- adequacy of power to handle all load combinations

- distribution of load between generators

- quality (voltage, frequency, transients)

- operation of using components during transients

- temperatures of oil in constant speed drives and of generator cooling oil within limits.

Each abnormal mode identified will be simulated, with full normal electrical load, to evaluate:

- load capability of the system in the mode

- isolation of failed components.

- load control to protect operation of remaining generators

- resumption of normal operation when fault is removed

- operation of using equipment during transients.

In the case of fighter aircraft with two primary generators, each generator in turn will be turned off during radar tracking to check whether track is maintained when loads are transferred.

Emergency Mode:

These tests will evaluate the following:

- Automatic actuation of the emergency system

- Functioning of load control

- Adequacy of quality of power to essential service

- If the emergency generator is hydraulically driven or if the flight controls are electrically activated, capability of the system to provide emergency power when flight controls are actively used

- Restoration of supply to non-essential using components when primary generators are reactivated

- Reactivation of non-essential using components.

Tests will be initiated at an altitude from which a simulated descent and landing will be made. If the aircraft has more than one primary generator, one will first be turned off and then back on to verify satisfactory reactivation. When this has been verified all primary generators will be turned off and activation of the emergency system verified. With engines at idle power a simulated approach and landing will then be performed at a safe altitude, using the flight controls actively, normal power will then be restored.

INSTRUMENTATION

Time histories are required of the following:

- voltages and currents of all phases of all generators
- voltages and currents for all buses.

An example of test instrumentation is shown in Table 6. High frequency response and high data rates are needed to record transient ac voltages during transfers. For this a frequency response of not less than 100 Hz and a data rate of not less than 100 samples per second should be provided.

TEST INFORMATION SHEETS

The tests required must be documented in standard format in a Test Information Sheet and approved. An example, for the F-15, is included as Appendix A. The format and approval procedure are common to all AFFTC flight tests and will not be further discussed here.

INTEGRATION WITH TEST PROGRAM:

Evaluation of the electrical system requires a fairly limited amount of special purpose testing. Functioning of the system in normal mode can be largely evaluated on a ride-along basis during other tests. Table 7 gives an example of a summary of tests versus flight conditions Preparation of such a summary for the particular test aircraft will help with integration of the electrical system tests into the total program. (See also Table 5.)

Table 6

Example of Electrical System Test Instrumentation

AC System

Current, all phases of all generators

Voltages, all phases main and emergency ac buses

DC System

Voltages, main and emergency buses

Currents, main and emergency buses

Transients, main buses

JFS System and Auxiliary Power Unit

Voltage and currents

Transients

Bay Temperature

Generators and Constant Speed Drives

Constant Speed Drive Charge Pressures

Accumulator Precharge Pressures

Primary Generator Permanent Magnet Generator Frequencies

Primary Generator Stator Voltages

Primary Generator Stator Frequencies

Constant Speed Drive Oil Temperatures

Normal Accelerations

Table 7

Operating Modes Tested versus Flight Condition

Flight Condition	Operating Modes Tested				
	Normal	Start	Transfer	Abnormal	Emergency
Maintenance	X				
Engine Start	X	*			
Ground Idle	X		X	X	X
Pre-flight	X				
Climb & Idle Power Descent	X				
Representative Cruise	X			X	X
Normal Mission Profiles	X				
Simulated Landing					X
Limit Normal Acceleration	X				
Combat Maneuvers	X			Failure of 1 generator	

* Different Requirements if Engine Start is Electrical

An example of electrical systems test instrumentation was given in Table 5. It should include at least the following:

Airspeed, altitude, load factor in maneuvers

Generator currents - all phases

AC bus voltages - all phases

Transformer Rectifier input currents

DC bus voltages

JFS generator voltage and current - if relevant

JFS bay temperatures

APU compartment temperatures

Constant Speed Unit Oil Temperatures

Generator Cooling Oil Temperature

Since electrical systems tests by AFFTC are primarily to determine whether the system is acceptable and operationally suitable, extreme precision is not normally required. It is, however, important that the frequency response and data rates be adequate to handle transients correctly. Current calibrations should be available. The engineer should review these to ensure that they cover the appropriate ranges, do not show excessive hysteresis and are in general acceptable.

The overall objective of the tests is to evaluate the electrical system as a subsystem of an operational aircraft and to determine if any serious problems or deficiencies exist. This evaluation will draw on qualitative comments of air and ground crews and on experience gained in tests flown for other objectives and/or other aircraft as well as on data from tests specifically made to evaluate the electrical system.

The final report on the evaluation will give a brief description of the system and draw attention to leading particulars and to the basic logic of its operation. It is good practice to draft the sections of the report on Test Item Description and Test Methods and Conditions during test planning. This helps ensure that important information is not overlooked and possibly lost. For each test the aircraft model, designation and serial number will be given.

Problem areas discovered during the test program will have been reported in Service Reports, (formerly known as Deficiency Reports), as required in References 1 and 2. These are the action documents. They are sent to the System Program Office and reviewed by an SR Review Board. If the Board accepts them a Material Improvement Program (MIP) number is assigned and the SR is sent to the contractor for review and proposed solution. The final report on the DT&E tests of the electrical system will review these and the corrective actions taken as part of the overall evaluation of the aircraft.

It will usually be convenient to discuss each operating mode in turn, as follows:

1. Servicing and Maintenance

2. Start and Pre-flight

3. Normal

4. Abnormal

5. Emergencies

For each mode the tests and data sources will be detailed (including observation made during normal flight operations). The criteria will be briefly summarized and a statement made as to whether they are met. These criteria will always include the overriding criterion of operational suitability. If the system fails to meet a specification requirement it may still be considered operationally acceptable. Further, it may meet specification requirements and be considered unsuitable for operational use.

When criteria are not met enough detail must be given to effectively define the shortfall. Tabular summaries will be given of the tests conducted with appropriate comment. When appropriate, as in dynamic conditions in general, time history plots will be presented with attention drawn to the important parameters. Still photographs are an important highly effective means of illustrating some types of problems. The engineer should ensure that appropriate photographic documentation is obtained. Evaluation criteria are summarized in Table 8. Figure 23 shows an example of time histories of system response to changes in electrical load.

Table 8

System Evaluation Criteria

Operating Mode	Flight Condition	Evaluation Criteria
Servicing & Maintenance	Ground	Maintainability and operational suitability trip limits of external power protection system Functioning and adequacy of onboard power (APU)
Start and pre-flight	Ground	JFS/APU operation Correct assumption of load by primary generator Phasing time (if relevant) Voltages and frequencies within limits Transients
Normal	Normal Mission Profiles	Adequacy of power, load distribution CSU and cooling oil temperatures Voltages and frequencies within limits
	Cruise Altitude, Various Speeds	Acceptable transients when switching loads
	Limits of Maneuver Envelope	CSU pressure within limits, generators stay on line
	High Speed, low Altitude, High Air Temperature	Oil temperatures within limits
Abnormal	Cruise	Correct response to failure Satisfactory load control Voltages, frequencies and transients Correct restoration of normal operation when failure corrected
	Terrain following, Tracking, Weapon delivery	Satisfactory operation after generators failure (multiengined aircraft).
Emergency	Cruise (preliminary tests on ground) Idle Power descent	Satisfactory activation of emergency mode Voltages, frequencies and transients If hydraulic adequate power when flight controls used satiafactory resumption of normal mode.

Flight No: 226

Date: 15 Aug 74
Aircraft: 71-0285

TEST CONDITIONS: 40,000 feet PA and 500 KTAS

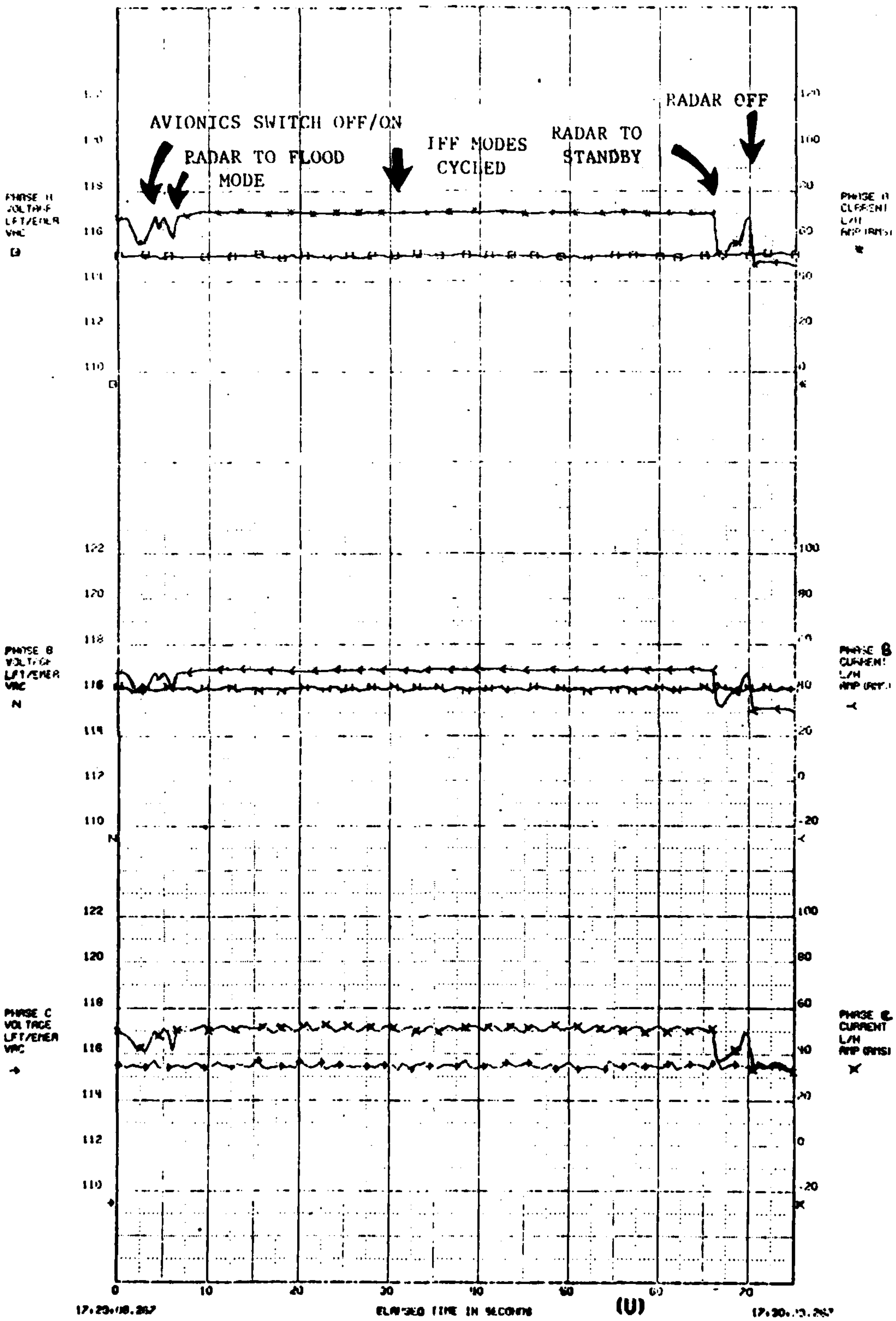


Figure 23 Example of Response to Changes in Electrical Load

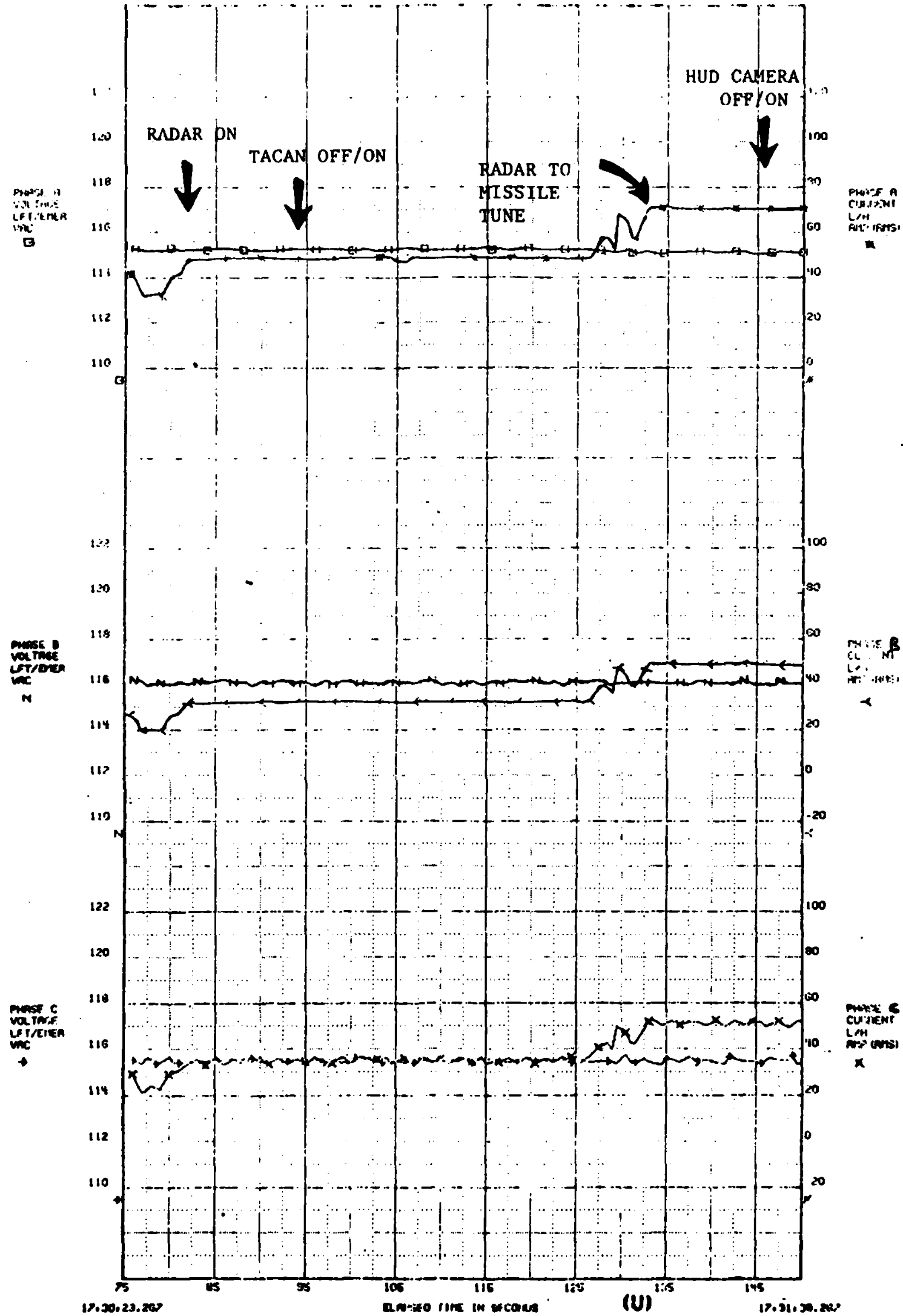


Figure 23 (continued)

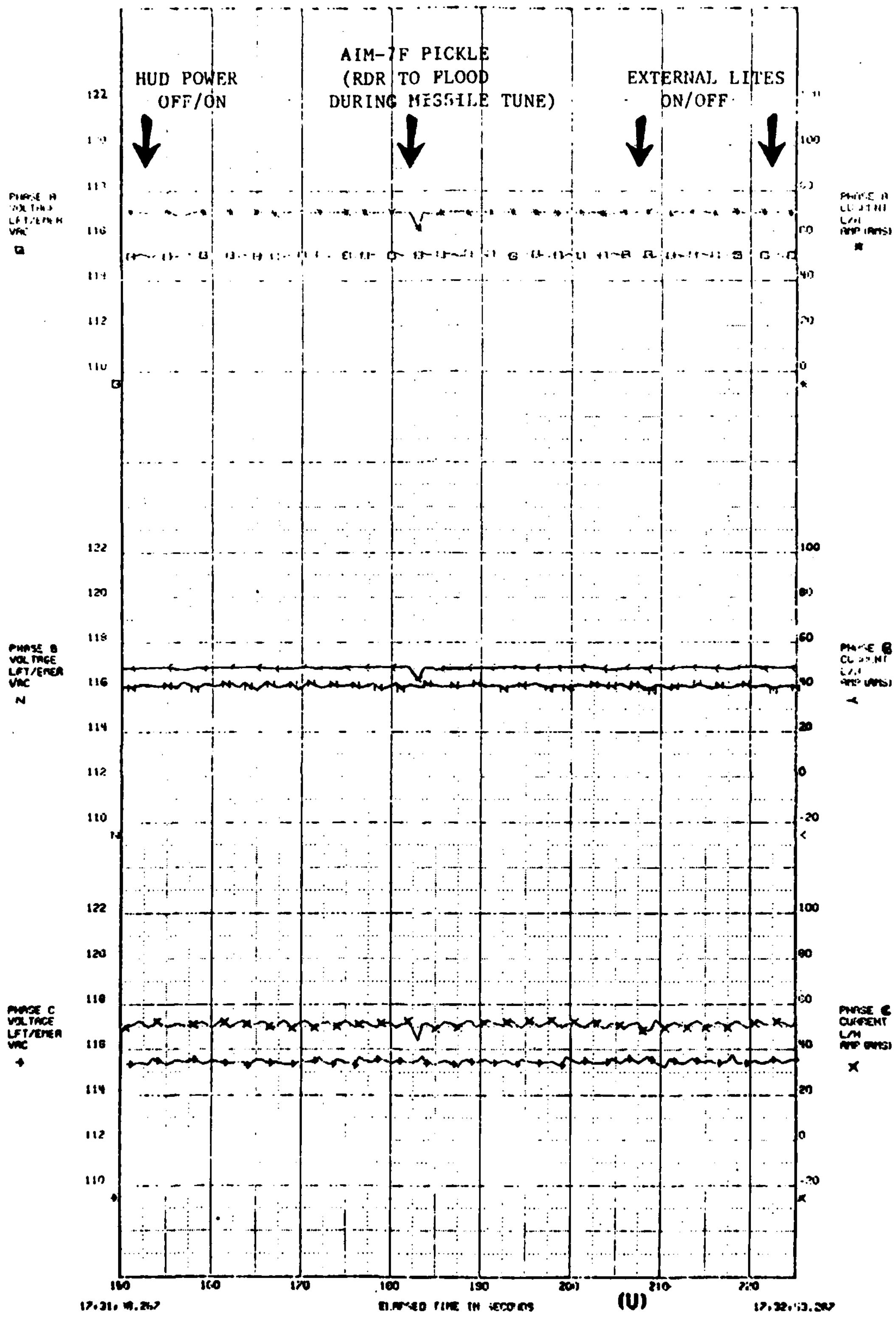


Figure 23 (continued)

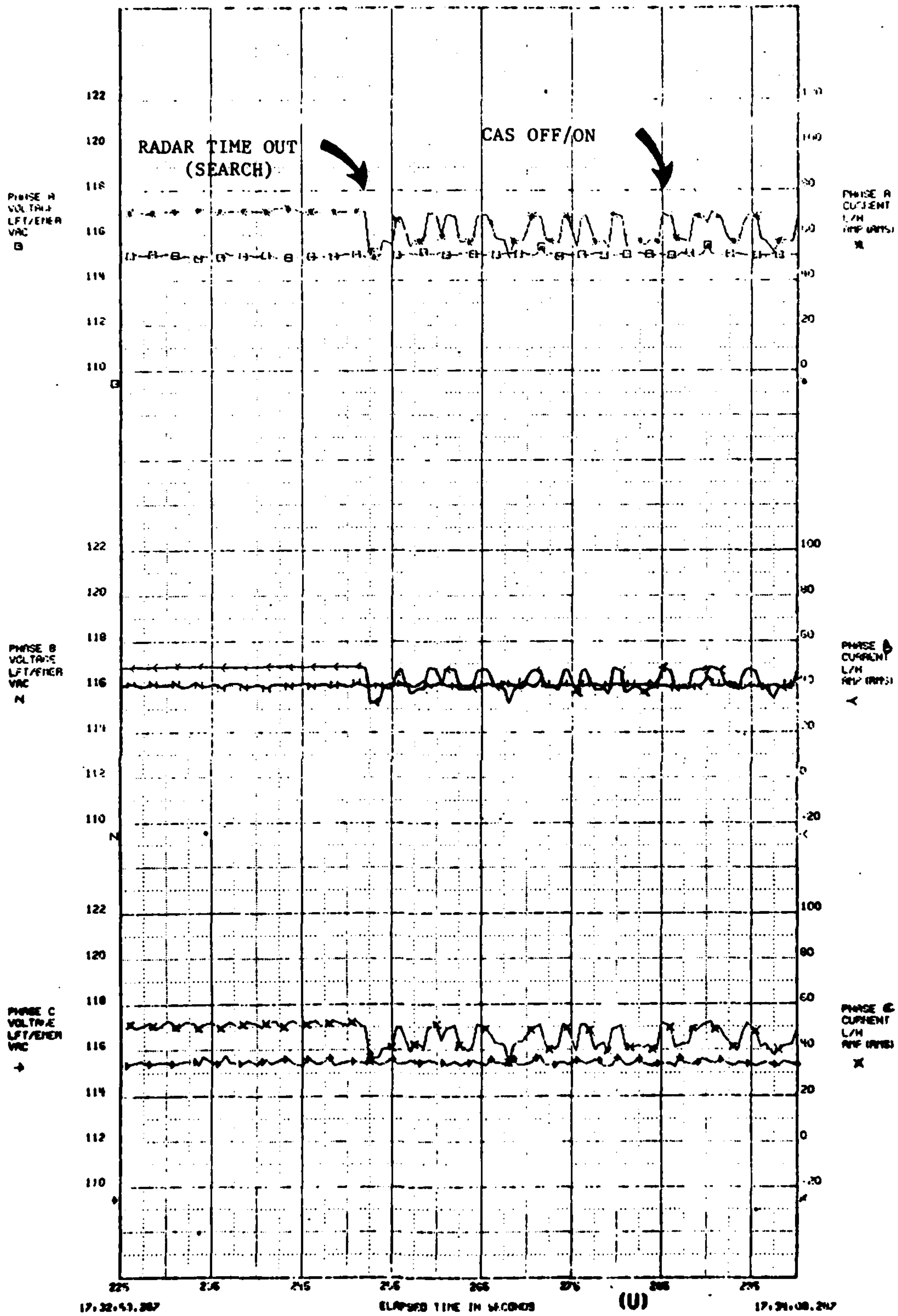


Figure 23 (continued)

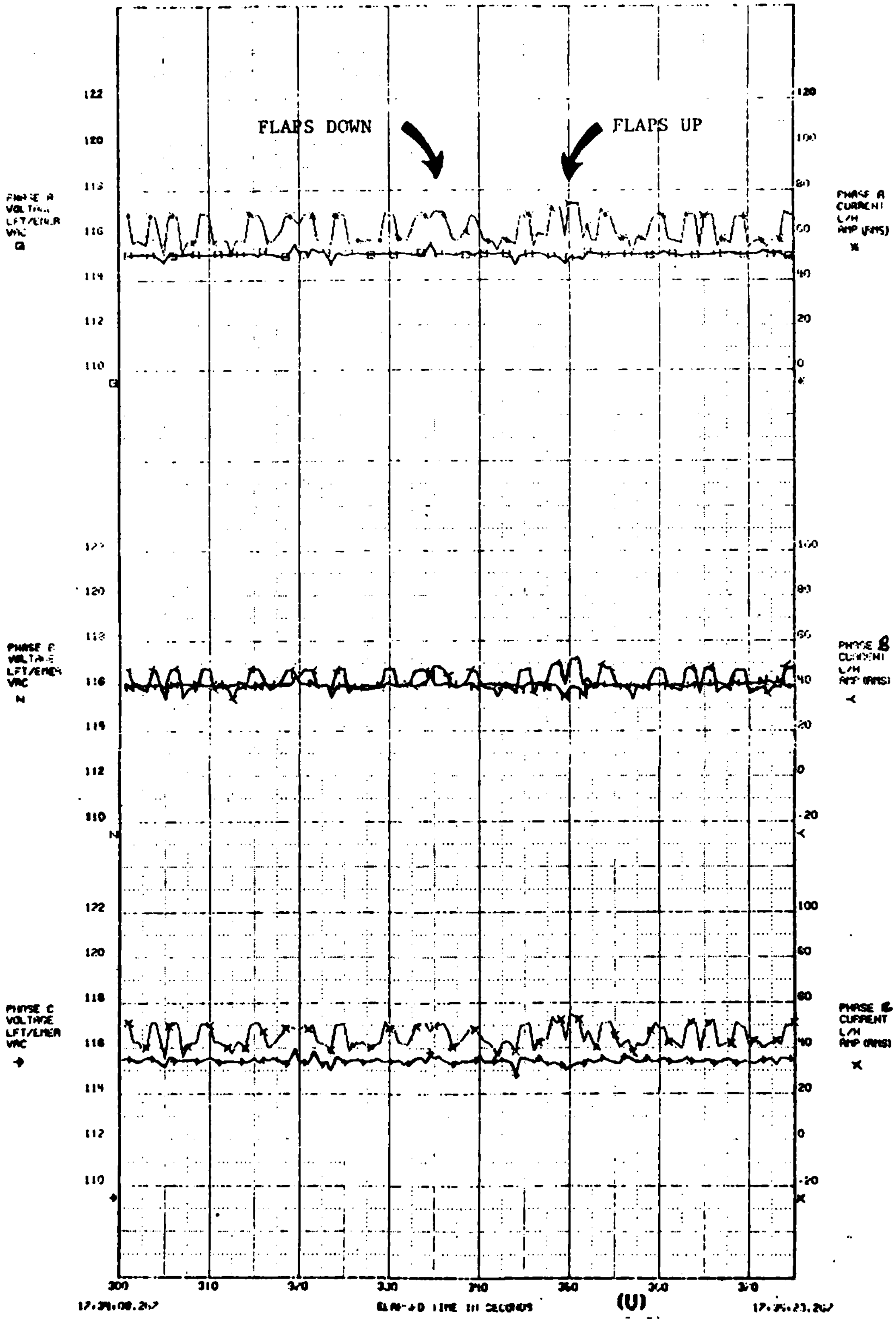


Figure 23 (concluded)

REFERENCES

1. USAF Material Deficiency Reporting and Investigation System, T.O. 00-35D-54.

2. Research and Development Test Program Deficiency Reporters, AFFTC Regulation 80-2.

3. Aircraft Electric Power Characteristics, MIL-STD-704D.

4. J.D. Segrest and W.W. Cloud, Evaluation and Development of High Voltage (270 Volt) D.C. Aircraft Electric Systems in the United States, SAE 811087.

5. R.J. Kenneth, Advanced Generating System Technology, SAE 811084.

6. M.J. Cronin, All-Electric vs Conventional Aircraft: The Production/Operational Aspects, Journal of Aircraft Vol 20 No 6.

7. Eldon T. Reiquam, Power System Design for an All Electric Aircraft, IECEC 809081.

8. R.C. VanNoeck and W.A. Carmuni, Cost of Ownership Advantages with a Shared Oil System, SAE 811082.

9. David D. Pollard and Gary E. Krajci, Packaging the VSCF System for an Aircraft Environment, SAE 811088.

10. Duane G. Fox, Integrated Control Techniques for Advanced Aircraft Electrical Power Systems, IECEC 809080.

11. Electromagnetic Compatibility Requirements, Systems, MIL-E-6051D.

12. Flight Safety Planning Guide for Flight Testing, AFSC Pamphlet 127-2.

13. Safety Planning for AFFTC Flight Tests, AFFTC Regulation 127-3.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A

EXAMPLE OF ELECTRICAL SUBSYSTEM TEST INFORMATION SHEET

AFFTC TEST INFORMATION SHEET (TIS) (F-15 TEST PROGRAM)	DATE 17 December 1973	PAGE 1 OF 8 PAGES
TITLE OF TEST: Electrical Subsystem and Lighting Evaluation	VEHICLE TYPE: F-15	TIS NUMBER: 42
	EFFECTIVITY: F-6	REVISION: A

TEST TIME	TEST PERIOD	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
[X] PRIMARY	Dec 73 - Feb 74	AFFTC/DOVJ	None
[ ] CONCURRENT	LOCATION OF TEST: Edwards AFB	TIS TYPE: [ ] PLAN [X] PROCEDURAL	SECURITY CLASSIFICATION: UNCLASSIFIED

1.0 REFERENCES:

1.1 PID CP76301A328A087A, F-15 Electrical Subsystem, December 1969, revised May 1973.

1.2 T.O. 1F-15A-1, 1 April 1972, revised 1 July 1973.

1.3 PID CP76301A328A020A (S), F-15 Air Superiority Vehicle, December 1971, revised June 1973.

1.4 MIL-STD-704, "Characteristics and Utilization of Aircraft Electrical Power," 7 February 1968.

1.5 DR 17-16, "Poor location of external power receptacle," 11 October 1972.

1.6 DR 133-123, "Control of the emergency generator was not reliable," 26 Apr 1973.

1.7 MIL-F-25381, "General Requirements for Flight Testing of Electrical System of Piloted Aircraft," 12 April 1956.

1.8 AFPE Report #6, September 1973.

1.9 PID CP76301A328A085A, F-15 Secondary Power, December 1969, revised January 1973.

1.10 AFFTC TIS IAFDT&E-3, 3 October 1973.

1.11 F-15 AFDT&E Plan, AFFTC, Edwards AFB, CA, July 1972.

1.12 PID 094-005764 (S), F-15 Countermeasures Set, February 1972, revised August 1973.

2.0 DESCRIPTION

ACTION	OFFICE OR POSITION/PHONE	SIGNATURE	DATE
PREPARE	Capt Willmann/73885	Robert L. Willmann	19 DEC 1973
REVIEW	AFFTC/DOVJE/DOEES	Joseph F. Strafaace	7 Jan 1974
REVIEW	AFFTC/DOVJ/TACD-J		4 Jan 1974
REVIEW	AFFTC/DOV		22 Jan 74
APPROVE	AFFTC/DO		23 Jan 74

AFFTC FORM JAN 72 0-128

The electrical subsystem consists of two main AC generators mounted on the AMAD, two transformer-rectifiers located in compartments 10 R & L, a hydraulically-driven emergency AC/DC generator, a jet fuel starter (JFS) permanent magnet generator, a power distribution (bus) system and an external ground power circuit. The two main generators are rated at three phase, 115/200 VAC, 400 Hz and capable of delivering 40K/50K volt-amperes. Each generator powers separate buses or split bus for non-synchronized operation. The emergency generator is rated at three phase, 115/200 VAC, 400 Hz, and capable of delivering 5K volt-amperes and a DC rating of 28 VDC with a 50-ampere capability. It is operated off of the utility hydraulic system when its control senses no AC present on the main buses.

The DC power is supplied by the two 150-ampere transformer-rectifiers (T/R) connected in parallel through a 60-ampere current limiter which permits transfer of current in event of one T/R failure or prevents a short on one bus from affecting the other.

The external ground power receptable is located on the bottom of the forward fuselage near the nose gear wheelwell just in front of the left engine inlet. An external power monitor samples the applied power and checks for proper phase sequence, missing phase, voltage magnitude and frequency.

2.2 The lighting system on the F-15 is divided into two groups, i.e., exterior and interior. The exterior lights consist of the position lights (wing and tail), anti-collision lights (wing and tail), electroluminescent formation lights (wingtips and fuselage), aerial refueling white lights (A/R receptacle compartment and left fuselage) and landing and taxi lights. Of particular note are the formation lights. These lights are similar to those found on the later models of the F-4 aircraft. The F-15 is provided with six green electroluminescent formation lights. Two are on the wingtips behind the position lights, two are on the side of the fuselage just forward of the cockpit, and two are on the fuselage just aft of the wing trailing edge.

The interior light group consists of integral lighting and lightplates for the flight instruments, engine instruments, auxiliary instruments and ACS (armament control panel); lightplate lighting for the left and right console panels; floodlight/thunderstorm lighting; a standby compass light; and a utility floodlight.

3.0 OVERALL TEST OBJECTIVE:

3.1 The operational suitability of the electrical subsystem and the lighting subsystems* will be evaluated. Tests will be conducted primarily at the AFFTC with some of the objectives repeated under extreme environmental conditions. Specific objectives will be expanded at a later date to include these conditions.

4.0 SPECIFIC TEST OBJECTIVES:

4.1 OBJECTIVE: To evaluate the ground power circuit for suitable location of power receptacle, for compatibility with standard Air Force AGE, and for proper operation and trip limits of the external power monitor.

AFFTC FORM JAN 72 0-128

* Lighting evaluations are now performed by Human Factors personnel.

4.1.1 Requirement References: Reference 1.1, 1.5 and 1.11.

4.1.2 Test Conditions: Normal ground starts throughout the AFDT&E program. The voltage and frequency of the applied power will be varied to determine the trip out limits of the power monitor. For each step of the procedure the pilot will monitor cockpit systems and the ground crew will monitor all external flight control systems. The aircraft during ground engine run will be prepared by installing the FOD prevention screens on both intake ducts.

4.1.3 Test Procedures: The AM32-60A power cart will be hooked up to the aircraft ground power receptacle through the LB-1 load bank. The voltage and frequency of the applied power will be varied and the trip out limits of the power monitor will be determined. Repeat for each different model of electrical power cart (if available). Switch on all normally ground operated electrical systems. Start R/H engines. Switch from ground power to aircraft power. Remove ground power cord. Start L/H engine. In the event of any electromagnetic interference (EMI) problems selectively turn off and on electrical equipment to isolate source. Disconnect L/H T/R unit, with all precautions taken to avoid shocks or shorts in the system. Reconnect L/H T/R unit and disconnect R/H T/R unit. Reconnect both T/R units in normal configuration. Turn off L/H main generator. Turn L/H main generator on and turn R/H main generator off. Verify the emergency generator switch is in NORM position turn off L/H main generator (both generators will now be off). Pilot will verify that the emergency generator has come on the line. All caution lights will be called out by pilot. Pilot will exercise flight controls to verify that use of hydraulic system does not interfere with the ability of the emergency generator to power essential electrical systems. After data is acquired return to normal configuration for take-off.

4.1.4 Support Requirements: Ground/JTF crew, -60A Electrical AGE unit, and LB-1 Load Bank.

4.1.5 Data: Comments by maintenance, JTF engineers and flight crew on operational suitability of external power circuit, receptacle and associated AGE. Trip out limits (frequencies and voltages) for the external power monitor. Parameters in Tables 1 and 2, reports of any indications of effects of power transients and/or EMI as observed by ground/JTF crew.

4.2 OBJECTIVE: Evaluate the ability of the JFS electrical system to provide the necessary power for JFS ignition and essential bus operation.

4.2.2 Test Conditions: All JFS starts on the ground and those inflight utilizing the JFS, if applicable.

4.2.3 Test Procedures: All JFS starts will be monitored and any malfunctions associated with the ignition system will be recorded.

4.2.4 Support Requirements: F-15 no. 6.

4.2.5 Data: Aircraft maintenance records reporting any abnormal operation, and selected parameters from Table 3.

AFFTC TEST INFORMATION SHEET (TIS) – CONTINUATION
(TEST PROGRAM)

TIS NO.	REVISION
42	A
PAGE 4 OF 8 PAGES	
DATE 17 December 1973	

3 OBJECTIVE: Demonstrate the operation of the electrical subsystem throughout the flight envelope.

4.3.1 Requirement References: Reference 1.1, 1.3, 1.7, 1.10 and 1.11.

4.3.2 Test Conditions: The following representative points throughout the design flight envelope will be flown:

Airspeed (KIAS)	Pressure Altitude (FEET)	Maneuver
200, 250, 350, 400 450, 550, 600, 650 700, Vmax	15,000	Stabilized level flight
200, 250, 300, 350, 400, 450, 500, 525, 550, Vmax	50,000	Stabilized level flight
375, 525	25,000	Wind Up Turn to aircraft limit
375, 525	25,000	Negative g's to aircraft limit
300	40,000 - 10,000	Climb and Idle power descent

4.3.3 Test Procedures: During each test point in para. 4.3.2, the satisfactory operation of the electrical subsystem will be verified. For stabilized maneuvers, avionics subsystems will be turned off and on systematically to verify that transient and steady state voltages and currents meet the requirements of MIL-STD-704, Category B. The negative g's pushover to the structural aircraft limit will be performed to verify that the integrated drive generators (IDG) remain on the line. The test points in para. 4.3.2, whenever possible, will be flown concurrently with other tests.

4.3.4 Support Requirements: Use of F-15 #6.

4.3.5 Data: Pilot comments, onboard instrumentation, and time history plots of selected parameters from Tables 1 and 2.

4.4 OBJECTIVE: The capability of one main AC generator to supply all the necessary electrical power will be evaluated, and the ability of the subsystem to prevent significant electrical transients during generator switching will be determined.

4.4.1 Requirement References: Reference 1.1, 1.7, 1.8 and 1.10.

4.4.2 Test Conditions: At flight conditions that the pilot deems convenient between 20K - 35K feet PA and 250 - 400 KIAS.

AFFTC FORM JAN 77 0-128

4.4.3 Test Procedures: Approximately halfway through a captive AIM-7 radar mission when the pilot is stabilized at the conditions in para. 4.5.2, he will switch off the L/H generator. The pilot will report over TM all illuminated caution lights. All possible BIT lights will be cleared before continuing. The remainder of the radar mission will be performed utilizing only the R/H generator. If problems develop, the pilot will reset the L/H generator. Prior to landing, if the L/H generator has not already been reset, the pilot will reset it.

4.4.4 Support Requirements: Safety chase aircraft, F-15 #6, captive AIM-7, TM, and target aircraft and tracking radars as required.

4.4.5 Data: Pilot comments, onboard instrumentation, time history plot of those measurands listed in Tables 1 and 2.

4.5 OBJECTIVE: Evaluate the performance of the emergency generator system in flight while performing an approach to a simulated landing at altitude.

4.5.1 Requirement References: Reference 1.1, 1.6, and 1.7.

4.5.2 Test Conditions: The test will begin at 20,000 feet MSL at 300 KIAS within sight of the base runways.

4.5.3 Test Procedures: The pilot will verify the emergency generator switch is in NORM position. Then at 20K feet and 300 KIAS, the pilot will switch off one main generator and operate for several minutes on one main generator to verify the proper switching of the electrical load. Reset the generator to verify that it will reset. Then switch it off again. The pilot will then switch off the other main generator and verify that the emergency generator has come on the line. All caution lights will be noted by pilot. The pilot will begin a shallow descent to 10,000 feet MSL to simulate a landing. During the descent the flight controls will be exercised by making gentle 30 degree bank-to-bank turns. The speed brake will be utilized and at approximately 12,000 feet and 200 KIAS the gear and flaps will be lowered. Using 10,000 feet as a base altitude a simulated landing will be performed by decreasing the airspeed from 200 KIAS to about 145 KIAS. At about 10,500 feet a go-around will be performed. A 360 degree (closed pattern) approach to a simulated landing will then be performed. Once the simulated flare has been completed, the main generators will be reset and a normal landing will be made. The chase aircraft will observe and note any unusual flight control surface movement throughout this test.

4.5.4 Support Requirement: Safety chase aircraft.

4.5.5 Data: Pilot (test and chase aircraft) comments, onboard instrumentation, time history plots of selected parameters from Tables 1 and 2.

4.6 OBJECTIVE: Evaluate the operational effectiveness of the interior and exterior lighting, including taxi, beacon, formation and landing lights during night flights.

4.6.1 Requirement Reference: Reference 1.10 and 1.11.

4.6.2 Test Conditions: At least two night missions will be flown to satisfy

TIS NO.	REVISION
42	A
PAGE 6 OF 8 PAGES	
DATE 17 December 1973	

other objectives. Different pilots will participate in each mission to broaden the qualitative comments required. The mission will be scheduled for a night takeoff and landing.

4.6.3 Test Procedures: The aircraft will be flown at night to evaluate the night lighting during all phases of flight including taxi, takeoff, climb, formation maneuvering, level flight, letdown and landing. Following the flight the pilot will taxi the aircraft to a location where little or no external lighting is visible in the cockpit. With canopy down the pilot will switch off both main generators and evaluate cockpit lighting available with the emergency generator.

4.6.4 Support Requirements: In addition to that required for the primary objective, a chase aircraft, one C-band tracking radar, and a 16mm movie camera suitable for night aerial photography are required.

4.6.5 Data: Pilots comments and movie film.

4.7 OBJECTIVE: The interfacing of the electrical subsystems with the other major subsystems, i.e., flight controls, avionics, armament (weapons release), ECS, etc. will be investigated.

4.7.1 Requirements Reference: Reference 1.1.

4.7.2 Test Conditions: Same as para. 4.3.2.

4.7.3 Test Procedures: All flights will be monitored for interface/integration problems. Particular emphasis will be placed on single generator failures during radar, weapons release, and tracking missions.

4.7.3.1 Prior to the first weapons delivery flight, a ground test will be conducted to determine any voltage transients which could inadvertently cause a release or fire signal at the weapons stations. This will be accomplished with no weapons, using the PSM-6 Multimeter. With aircraft engines running and both main generators on, the R/H generator will be switched off, and any transients noted.

4.7.3.2 During a radar mission, after a successful lockon has been attained, a main generator will be switched off. Any reduction in the avionics performance will be noted.

4.7.3.3 Prior to the last test point on an air-to-ground weapons delivery a planned "dry" pass will be made. All necessary armament switches will be ON for the particular system being delivered. The aircraft will be over the range within weapons release parameters and cleared by the safety chase pilot and range officer. Prior to the end of the "dry" run the pilot will switch off the R/H generator. Any inadvertent release or firing caused by electrical transients will be noted. Then all armament switches will be safetied before the generator is reset. On another air-to-ground mission the same procedure will be followed only the L/H generator will be switched off on this pass.

4.7.4 Support Requirements: Portable oscilloscope and technician, or PSM-6 multimeter and F-6 equipped with pylons.

AFFTC FORM JAN 72 0-128

4.7.5 Data: Pilot's and safety chase pilot's comments, report of any significant transients noted at weapons stations.

4.8 OBJECTIVE: Evaluate the ability of the electrical subsystem, both dual and single generator operations, to power the Tactical Electronic Warfare System (TEWS).

4.8.1 Requirement Reference: 1.12

4.8.2 Test Conditions: Flight parameters will be on a ridealong basis and as specified during the TEWS missions. The avionics will be operated as follows:

Condition	TEWS Mode	Other Avionics
Ground	Standby	OFF
Ground	Standby	ON
Stabilized flight	Standby	Minimum req'd ON
Stabilized flight	Transmit	Minimum req'd ON
Stabilized flight	Transmit	Maximum req'd ON
Maneuvering flight	Transmit	Maximum req'd ON

4.8.3 Test Procedures: An instrumentation record will be taken at each of the conditions stated in para 4.8.2 with both generators operating. After the results of dual generator operation have been analyzed and it is determined that single generator operation would not overload the system, the conditions will be repeated with only one main generator operating.

4.8.4 Support Requirements: F-15 #10.

4.8.5 Data: Pilot comments, time history plots of selected parameters from Tables 1 and 2.

AFFTC TEST INFORMATION SHEET (TIS) – CONTINUATION
(TEST PROGRAM)

TIS NO.	REVISION
42	A

PAGE 8 OF 8 PAGES

DATE 17 December 1973

TABLE 1

Seq No.		Measurand Name
SE18	N.B. FM	PHASE A VOLT. LEFT/EMER
SE19	N.B. FM	PHASE B VOLT, LEFT/EMER
SE20	N.B. FM	PHASE C VOLT, LEFT/EMER
SE21	N.B. FM	PHASE A VOLT R/H BUS
SE22	N.B. FM	PHASE B VOLT R/H BUS
SE23	N.B. FM	PHASE C VOLT R/H BUS
SE24	N.B. FM	PHASE A CURR L/H GEN
SE25	N.B. FM	PHASE B CURR L/H GEN
SE26	N.B. FM	PHASE C CURR L/H GEN
SE27	N.B. FM	PHASE A CURR R/H GEN
SE28	N.B. FM	PHASE B CURR R/H GEN
SE29	N.B. FM	PHASE C CURR R/H GEN

TABLE 2

Transformer-Rectifiers

SE13	LT/EMER BUS VOLTAGE 28VDC
SE14	CURRENT 28VDC L/H BUS
SE17	TRANSIENTS 28VDC L/H BUS
SE41	28VDC INPUT VOLTAGE
SE45	CURRENT 28VDC R/H BUS
SE46	TRANSIENTS 28VDC R/H BUS
SE05	CURRENT 28VDC EMERGENCY BUS

TABLE 3

JFS Electrical System

SE50	VOLTAGE 28VDC JFS GEN
SE51	CURRENT 28VDC JFS GEN
SE52	TRANSIENTS 28 VDC JFS GEN
SB18	JFS BAY TEMPERATURE

AFFTC FORM JAN 72 0-128

DEPARTMENT OF THE AIR FORCE

HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)

WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: ASD/YFT

14 Mar 74

SUBJECT: Review of TIS AFFTC #42(A) Electrical Subsystem and Lighting Evaluation

TO: AFFTC/DOVJ
Edwards AFB, Ca.

Subject TIS has been reviewed and the following comments offered:

a. Paragraph 4.5: McAir data should be used to cover as many of the requirements as possible.

b. Table I should be expanded to include that instrumentation necessary to measure the emergency generator output AC/DC voltage, current and frequency and right and left main generator frequency.

FOR THE COMMANDER

DAMERON R. SPRUILL, COLONEL, USAF
Director, Test and Deployment
Deputy for F-15/JEPO

APPENDIX B

EXAMPLE OF SAFETY REVIEW

SAFETY REVIEWS

GENERAL

Two safety reviews covered the testing actually accomplished during evaluation of the electrical system, hydraulic system, and MIL-H-83282 hydraulic fluid. The results of these reviews are contained in AFFTC Form 28 control numbers 76-54 and 78-19. The TISs specifically covered are listed in references 12 and 17 and 20 of this report. A close-out memorandum for the record was prepared for control number 78-19 and for the secondary power section of control number 76-54. Other testing under control number 76-54 was still in progress at the date of this report and portions of that Form 28 remained active.

Only the basic test plan reviews including OHAs and memorandums for the record pertinent to the testing reflected in this report are included in this appendix.

TEST PLAN SAFETY REVIEW

PROJECT TITLE & JON	PERFORMING AGENCY		
F-16 Air Combat Fighter 2185A0	AFFTC/DOVF & General Dynamics		
REQUESTED BY (Typed Name and Grade)	**PHONE NUMBER**	**SIGNATURE OF REQUESTING OFFICIAL**	**DATE**
James G. Rider, LTC	72130		22 Nov 76

I SAFETY REVIEW BOARD ACTION/COORDINATION

TEST PLAN REVIEWED	DATE 22 NOV 76	TEST PLAN REVIEWED. OPERATING HAZARD ANALYSIS APPROVED.
TEST PLAN REVIEWED. NO OPERATING HAZARD ANALYSIS REQUIRED.		OPERATING HAZARD ANALYSIS APPROVED. REQUIRES FINAL COORDINATION PRIOR TO START OF TEST
TEST PLAN REVIEWED. FURTHER HAZARD ANALYSIS REQUIRED		REMARKS (See Section IV)

TYPED NAME AND GRADE	SIGNATURE	TYPED NAME AND GRADE	SIGNATURE
AFFTC SYSTEM SAFETY OFFICER		**UNIT SAFETY OFFICER/JTF FLYING SAFETY OFFICER**	
G. C. CARDEA, MAJ USAF SES		R.C. GRAZIER, COL USAF DOV	
PILOT'S SUPERVISOR / OPERATIONS OFFICER		**ENGINEERS SUPERVISOR**	
R. C. ETTINGER, LTC USAF DOVF		G. AM. ETZEL, LT COL USAF DOEFS	

II BRIEF DESCRIPTION AND JUSTIFICATION OF TEST (Use additional sheet of plain bond paper if needed)

STARTING DATE	COMPLETION DATE	HAZARD CATEGORY	CONTROL NUMBER
15 Dec 76	31 Dec 78	See Below	76-54

A Safety Review Board was conducted on 22 and 23 Nov 76 to consider the Operating Hazard Analysis for the following F-16 Full Scale Development test plans. The overall hazard category for each test plan assigned by the Safety Review Board is shown below.

16PP202 - Flying Qualities - Hazardous

16PP205 - Performance - Low Risk

16PP206 - Propulsion - Hazardous

16PP208 - Secondary Power - Low Risk

16PP209 - Equipment Subsystems - Hazardous

ENGINEERING SUPERVISOR	
P. M. JEGLUM, LT COL USAF DOEEP	

III FINAL COORDINATION & APPROVAL

COORDINATING OFFICIAL: TYPED NAME, GRADE AND TITLE	SIGNATURE	DATE	CONCUR: YES	NO	W/AS TO COMMENTS IN SEC IV
JAMES G. RIDER, LTC, USAF Director, F-16 JTF		3 Dec 76	X		X
MARCUS H. COODY, Maj, USAF Cmdr, Det 2, AFCMO		9 Dec 76	✓		✓
L. D. McCLAIN, COL, USAF Asst Dep Cmdr for Operations		11 Dec 76			
J. A. GUTHRIE, COL, USAF AFFTC DEP COMMANDER FOR OPNS		14 Dec 76	✓		✓
C. F. WATTS, LTC, USAF AFFTC DIRECTOR OF SAFETY		8 Dec 76	✓		✓
J. S. BURKLUND, COL, USAF AFFTC VICE COMMANDER		14 Dec 76	✓		✓

TEST [ ] APPROVED [ ] DISAPPROVED [✓] APPROVED SUBJECT TO REMARKS ON REVERSE SIDE

TYPED NAME AND GRADE OF AFFTC COMMANDER	SIGNATURE OF AFFTC COMMANDER	DATE
T. P. STAFFORD, MGEN, USAF Commander		15 Dec 76

AFFTC FORM MAR 76 28 PREVIOUS EDITIONS WILL BE USED PAGE 1 OF 2 PAGES

OPERATING HAZARD ANALYSIS

TEST SERIES
Electrical System Evaluations

HAZARD/UNDESIRED EVENT	CAUSE	EFFECT	HAZARD CATEGORY	CORRECTIVE ACTION/MINIMIZING PROCEDURES	REMARKS
Inability to re-energize the primary generator	Intentional shutdown of the primary generator to evaluate the emergency generator	Reduced electrical power generation	II	1. The EPU has been thoroughly tested during component item qualifications and "on aircraft" ground tests. 2. The EPU bleed air mode will be capable of sustained safe flight and landing for 5 hours in the event of loss of either the power takeoff shaft, the accessory drive gearbox, the primary generator, or the hydraulic pumps; also the monopropellant fuel mode will have the capacity to supply 10 minutes of hydraulic and electrical power for a safe return to base in the event of an aircraft engine loss. 3. The EPU has multiple start capability and start may be manual as well as automatic. 4. Qualified contractor and Air Force engineers will be available at the radio. An F-16 pilot will be either in a chase aircraft or available as a ground monitor. 5. All emergency electrical/EPU tests will be conducted within gliding distance of Rogers Dry Lake. 6. Safety chase will be utilized during Emergency Generator/EPU evaluations. 7. Edwards approach control flight advisory services will be used. 8. Radar vectoring for positioning within the Edwards complex will be used as available. 9. T/M monitoring of critical parameters will be used.	

AFFTC FORM JAN 78 23 PREVIOUS EDITIONS ARE OBSOLETE

MEMO FOR RECORD 28 Sep 81

SUBJECT: Partial Closeout of AFFTC Form 28 Control No. 76-54

1. This memo for record closes out the subject form 28 for the F-16 Secondary Power (16PP208) evaluation. The objectives were to evaluate the functional adequacy and operational suitability of the FSD electrical and hydraulic systems on both the F-16A and F-16B aircraft.

2. The hazard identified in the OHA addressing emergency electrical power generation remained realistic during FSD. The minimizing procedures were effective in preventing a mishap.

3. Attach this MFR to the subject form 28.

David W Milam

DAVID W. MILAM, Lt Col, USAF
Director, F-16 Combined Test Force

Copy to: SES, Stop 101

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C

EXAMPLES OF TEST OBJECTIVES AND PROCEDURES

INTRODUCTION

In the section of this Handbook on Test Planning we outlined the philosophy and background of electrical system tests at the AFFTC and described how to identify what tests were required on any specific aircraft type. In order to preserve a reasonable degree of readability, detailed descriptions of each test were deferred for presentation in this Appendix.

The test descriptions given here should be treated as examples and as points of departure. When the test planner has identified the tests required for his aircraft he should review the tests described here for applicability and completeness and then write up his own set of descriptions.

GROUND TESTS

These will include both evaluation of normal maintenance, start and preflight procedures and precautionary tests made on the ground of, for example, abnormal and emergency operating modes prior to flight tests in these modes.

<u>Normal Servicing and Maintenance</u>:

<u>Test Objectives</u>. These are:

1. To evaluate the functional adequacy and operational suitability of the hydraulics in normal servicing and maintenance.

2. To identify deficiencies and problem areas.

3. Specific objectives requested by the System Program Office.

<u>Test Conditions and Procedures</u>. Maintenance and servicing as called for in TOs will be evaluated during test operations. These evaluations will involve Human Factors and Reliability and Maintainability personnel, but the subsystems test engineer should follow maintenance and servicing closely and ensure that any problem areas are reported and documented.

<u>Data and Support Requirements</u>. Test data will consist of crew comments on maintenance and servicing, supported by photographic and other appropriate documentation of any problem areas. Both favorable and unfavorable comments should be recorded. Support requirements are ground support equipment as called for by Technical Orders.

<u>Engine Start</u>:

<u>Test Objectives</u>. These are:

1. To evaluate the functional adequacy and operational suitability of the electrical system during the engine start sequence.

2. To identify deficiencies and problem areas.

3. Specific objectives requested by the System Program Office.

Test Conditions and Procedures. Test Procedures will be the normal procedures called for by Technical Orders. Test conditions will be those encountered during normal maintenance for the flight test program, but the experience gained should be evaluated with the expected operational background of the type in mind.

Data and Support Requirements. Test data will consist of:

a. crew comments, support by photographic and other documentation of any problem areas.

b. time histories of primary generator voltages and bus voltages:

Support requirements will be normal ground support equipment as called for by Technical Orders and magnetic tape or other recording of system parameters.

Pre-Flight:

These tests are to evaluate normal pre-flight procedures as called for in T.O.s.

Test Objectives. These are:

1. to evaluate the functional adequacy and operational suitability of the pre-flight check procedures.

2. to identify deficiencies and problem areas.

3. specific objectives requested by the System Program Office.

Test Conditions and Procedures. Normal pre-flight checks performed during evaluation flight tests will be reviewed for functional adequacy and for operational suitability in the expected operational environment of the aircraft.

Data and Support Requirements.- Data will consist of crew comments, supported by photographic and other documentation of problem areas as appropriate. Support will consist of ground support equipment as specified in Technical Orders.

Use of External Ground Power:

Test Objectives. These are:

1. to evaluate the functional adequacy and operational suitability of the electrical system using external ground power and system compatibility with the ground power source.

2. to evaluate functioning of the protection system.

3. to identify any deficiencies and problem areas.

4. specific objectives requested by the System Program Office.

Test Conditions and Procedures. Power carts as specified in Technical Orders will be connected to the aircraft ground power receptacle through a load band and voltage and frequency will be varied and the on and off trip limits of the protection system determined. Power will also be connected with phases crossed and with phases omitted and system protection from these errors verified.

Data and Support Requirements. Support requirements are power carts as specified in Technical Orders and a load bank to vary voltage.

Data requirements are:

1. Comments by maintenance crew on the operational suitability of the external power circuit.

2. On and off voltage and frequency trip limits.

3. Effectiveness in refusing wrongly phased power.

Ground Tests of Functioning in Normal Mode:

These tests are made to verify functioning of the system on the ground in normal operating mode, prior to flight tests of that mode.

Test Objectives. These are:

1. to verify operational suitability and functional adequacy of the electrical system in normal operating mode.

2. to evaluate the supply of adequate and suitable power to all using components.

3. to evaluate switching transients.

4. to evaluate Electromagnetic Compatibility.

5. specific objectives requested by the System Program Office.

Test Conditions and Procedures. With engines at idle power and all primary generators on line, all using components operable on the ground will be switched on in combinations called for by the mission. Each load will be switched on and off in turn to verify that switching transients and electromagnetic interference are acceptable. If electromagnetic interference is found, loads will be switched on and off in turn to identify the source. Transients at weapon stations should be measured with a multimeter.

Data and Support Requirements. Data required are:

1. Comments by ground and flight crews on operational suitability

2. Time histories of voltages and currents of all phases of primary generators

3. Bus voltages, transients and currents for dc buses

4. Description of any EMI problems and identification of sources.

Ground Tests of Functioninq in Abnormal Modes:

These tests are made to verify satisfactory system functioning in all abnormal modes prior to flight test of the system in those modes.

Test Objectives. These are:

1. To evaluate functioning and load control upon initiation of each abnormal mode

2. To evaluate resumption of normal mode operation when problem is removed

3. To evaluate of transfer and switching transients

4. Specific objectives requested by the System Program Office.

Test Conditions and Procedures. With all engines at idle power and all primary generators on line and representative electrical loads each abnormal mode will be simulated in turn and the response to failure observed including report of all caution lights. The simulated failure will then be corrected and resumption of normal mode operation verified.

Data and Support Requirements.

1. Definitions of each abnormal mode.

2. Crew comments.

3. Time histories of voltages and currents of all phases of primary generators.

4. Bus voltages, transients and currents for dc buses.

5. Description of load shedding or other response to abnormal mode.

6. Report of warning lights.

7. Description and time histories of response to removal of problem

Ground Tests of Functioning in Emergency Mode:

These are tests to verify the satisfactory functioning of the electrical system in emergency mode before flying this way. If satisfactory the emergency prodecures will be followed during flight tests, subject to safety review.

Test Objectives. These are:

1. to evaluate operational suitability and functional suitability of the electrical system in emergency mode, including activation, support of flight essential functions and satisfactory resumption of normal mode operation.

2. Specific objectives requested by the System Program Office.

Test Conditions and Procedures. With engines at idle power, all primary generators on line, and representative electrical load and the emergency system in AUTO the primary generators will be disconnected and automatic activation of the emergency mode verified. If the emergency generator is hydraulically driven, flight controls will be activated to check for any effect on emergency power. Operation of all caution lights will be reported. The primary generators will then be brought back on line and satisfactory resumption of normal mode operation verified.

Data and Support Requirements. These are:

1. Crew comments

2. Time histories of parameters such as those in Table 6.

FLIGHT TESTS

Flight Tests in Normal Operating Mode:

These tests will be performed at a number of flight conditions representative of the mission profiles. They will include maximum and minimum permissible normal load factors.

Test Objectives. These will be:

1. To evaluate the operational suitability and functional adequacy of the electrical system in normal operating mode throughout the mission profile.

2. Specific objectives requested by the System Program Office.

Test Conditions and Procedures. Normal mode operation will be evaluated throughout representative mission profiles including, as appropriate, terrain following, tracking and weapon delivery. At a number of stabilized level flight conditions representative of the mission flight profile, with all primary generators on line, avionics subsystems and other major loads will be turned on and off systematically to verify that transient and steady state currents and voltages meet the requirements of MIL-STD-704. Windups and pushovers to limit load factors will be performed to verify that the generators remain on line.

Data and Support Requirements. These are:

1. Records of flight conditions and electrical loads

2. Time histories of the parameters in Table 6.

3. Crew comments.

Flight Tests in Abnormal Operating Modes:

Operation in each abnormal mode will be evaluated in flight after satisfactory ground test results have been obtained.

Test Objectives. These are:

1. To evaluate functioning and load control upon initiation of each abnormal mode.

2. To evaluate resumption of normal mode operation when the problem is corrected.

3. To evaluate transfer and switching transients.

4. Specific objectives requested by the System Program Office.

Test Conditions and Procedures.

1. At each of a series of cruise conditions representative of the mission envelope, with all primary generators on line and representative electrical loads each abnormal mode will be simulated in turn and the response of the system, including transients, load control and operation of warning lights will be verified. The simulated failure will then be corrected and resumption of normal mode operation verified.

2. In the case of multiengined aircraft generator failure during tracking terrain following and weapon delivery (as appropriate will be simulated and the effects evaluated.

Data and Support Requirements. Data required are:

1. Definitions of flight conditions.

2. Crew comments, record of warning lights etc.

3. Time histories of parameters in Table 6.

4. Description of load shedding or other response to abnormal mode.

5. Description of response to correction of simulated failure.

Flight Tests of Functioning in Emergency Mode:

After satisfactory operation has been verified in ground tests, and subject to safety review, flight tests will be performed of the operation of the electrical system in emergency operating mode.

Test Objectives. These are:

1. To evaluate functioning of the electrical system in emergency operating mode including activation, support of flight essential functions and satisfactory resumption of normal mode operations.

2. Specific objectives requested by the System Program Office.

Test Conditions and Procedures. At a representative cruise condition at a safe altitude, with the emergency system in AUTO, all primary generators will be switched off and satisfactory activation and operation in the emergency mode verified. Operation of warning lights will be reported If the emergency generator is hydraulically driven a simulated approach and landing will be performed. Normal mode operation will then be restored.

Data and Support Requirements. These are:

1. Crew comments.

2. A record of all warning lights, etc.

3. Time histories of parameters such as those in Table 6.

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AC	Alternating Current
ACS	Armament Control Panel
ADG	Auxiliary Drive Gearbox
AFFTC	Air Force Flight Test Center
AFOTEC	Air Force Operational Test and Evaluation Center
AFPE	Air Force Preliminary Evaluation
AFSC	Air Force Systems Command
AFWAL	Air Force Wright Aeronautical Laboratory
AMAD	Airframe Mounted Accessory Drive
APU	Auxiliary Power Unit
ASD	Aeronautical Systems Division
BTC	Bus Tie Contactors
CITS	Central Integrated Test System
CSCF	Constant Speed, Constant Frequency
CSD	Constant Speed Drives
CSDCU	Constant Speed Drive Control Unit
CTF	Combined Test Force
DC	Direct Current
DSO	Defensive Systems Operator
DT&E	Development Test and Evaluation
EGCU	Emergency Generator Control Unit
EMI	Electromagnetic Interference
EMUX	Electrical Multiplex System Control
EPC	External Power Contactor
EPU	Emergency Power Unit
EWS	Electric Warfare Systems
FOD	Foreign Object Damage
FSD	Full Scale Development

ABBREVIATIONS, ACRONYMS, AND SYMBOLS CONTINUED

GCU	Generator Control Unit
IDG	Integrated Drive Generator
JFS	Jet Fuel Starter
K	Thousand
Kias	Knots Indicated Airspeed (corrected for instrument error)
KVA	Kilovolt (ampere)
KW	Kilowatt
L/H	Left Hand
LM	Load Management
LMC	Load Management Center
LSI	Large Scale Integration
MFR	Memo For Record
MIP	Material Improvement Program
MSL	Mean Sea Level
OSO	Offensive Systems Operator
PID	Permanent Magnet Generators
R/H	Right Hand
RIT	Remote Input Terminal
ROT	Remote output Terminal
RPM	Revolutions Per Minute
SCR's	Silicon Controlled Rectifiers
SIP	System Integration Panel
SPO	System Program Office
SSPC	Solid State Power Controller
SR	Service Report
TEWS	Tactical Electronic Warfare System
TFR	Terrain Following Radar
TIS	Test Information Sheet

ABBREVIATIONS, ACRONYMS, AND SYMBOLS CONCLUDED

TM	Technical Manual
T.O.	Technical Order
TRs	Transformer/Rectifier
USAF	United States Air Force
USN	United States Navy
V	Volt
Vdc	Volts Direct Current
VSCF	Variable Speed Constant Frequency

THIS PAGE INTENTIONALLY LEFT BLANK