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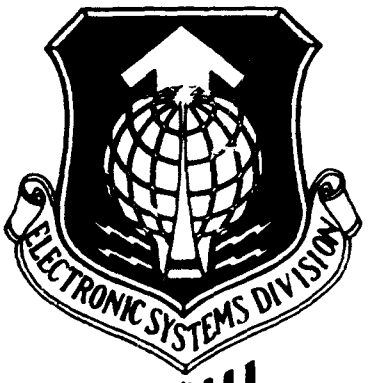

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COMPUTER PROGRAM TESTING

William L. Trainor, Captain, USAF
R. W. Harris, First Lieutenant, USAF

November 1971

TECHNICAL REQUIREMENTS AND STANDARDS OFFICE
HQ ELECTRONIC SYSTEMS DIVISION (AFSC)
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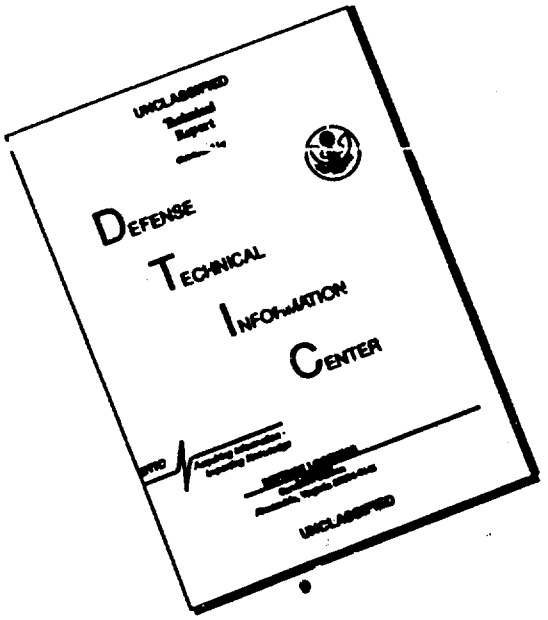

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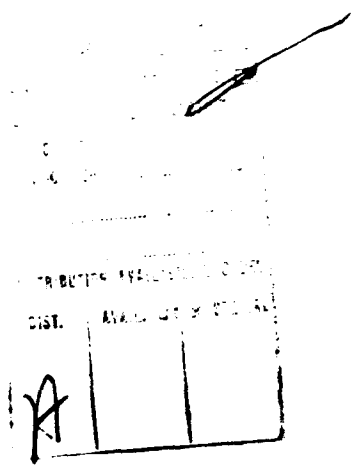

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13 ABSTRACT

This Technical Report addresses the general area of computer program testing. The test program for computer programs is, in many cases, different from that for equipment due to the uniqueness of the computer program configuration item. Thus, testing concepts for computer programs are not always widely understood. This Technical Report attempts to clarify computer program testing requirements and procedures by considering such topics as test requirements documents and test plans/procedures/reports. The concepts of informal versus formal testing are introduced, which lead to the subjects of preliminary and formal qualification testing. Subprogram, functional, and computer program configuration item levels of testing are also explained, and these ideas are in turn related to informal versus formal testing.

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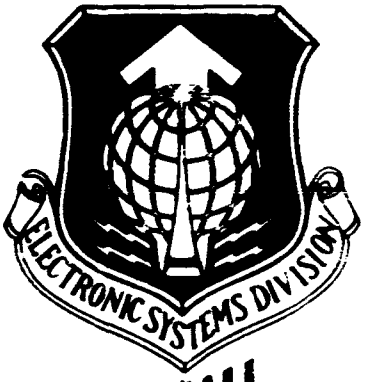

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FOREWORD

This Technical Report was written to be one of a series of such reports that will be incorporated into a Computer Program Management Handbook. As such, this report is directly applicable for use by Electronic Systems Division system program managers in the acquisition of computer program configuration items.

Supplemental guidance concerning computer program testing may be found in AFR 80-14, Test and Evaluation of Systems, Subsystems, and Equipment, and AFSC Design Handbook DH 4-2, Electronic Systems Test and Evaluation.

Since this report was written, Capt. Trainor has been reassigned to the Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio.

This technical report has been reviewed and is approved.

Carmine Pinto

CARMINE PINTO, Chief
Tech Rqmts & Stds Office

ABSTRACT

This Technical Report addresses the general area of computer program testing. The test program for computer program is, in many cases, different from that for equipment due to the uniqueness of the computer program configuration item. Thus, testing concepts for computer programs are not always widely understood. This Technical Report attempts to clarify computer program testing requirements and procedures by considering such topics as test requirements documents and test plans/procedures/reports. The concepts of informal versus formal testing are introduced, which lead to the subjects of preliminary and formal qualification testing. Subprogram, functional, and computer program configuration item levels of testing are also explained, and these ideas are in turn related to informal versus formal testing.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ABBREVIATIONS AND SYMBOLS

AI&C	Adaptation, Installation and Checkout
AFLC	Air Force Logistics Command
AFR	Air Force Regulation
AFSC	Air Force Systems Command
CI	Configuration Item
CP	Computer Program
CPC	Computer Program Component
CPCI	Computer Program Configuration Item
DID	Data Item Description
DT&E	Development Test and Evaluation
ECP	Engineering Change Proposal
EQUIP.	Equipment
FCA	Functional Configuration Audit
FQT	Formal Qualification Test
I&C	Installation and Checkout
OT&E	Operational Test and Evaluation
PCA	Physical Configuration Audit
PMD	Program Management Directive
PMP	Program Management Plan
PQT	Preliminary Qualification Test
SPO	System Program Office

SECTION I

INTRODUCTION

1. General. Testing performed as an integral part of the acquisition process is governed by AFR 80-14 and is addressed in this document as Development Test and Evaluation (DT&E), and Operational Test and Evaluation (OT&E). The purpose of the total test effort is to verify the performance requirements and compliance with specifications of configuration items, subsystems, and the total, integrated system.

2. Development Test and Evaluation. The DT&E effort is divided into the two areas of CI/Subsystem Test and System Test. The functions of each of the two areas of DT&E are given below.

a. CI/Subsystem Test. The CI/Subsystem testing effort consists of the development testing and evaluation of the individual configuration items (CIs), subsystems and, in certain cases, the complete system. The Air Force actively participates in, evaluates, and controls the CI/Subsystem testing; however, the tests are conducted predominantly by the contractor who is under Air Force Systems Command (AFSC) direction and control.

(1) The overall objective of the CI/Subsystem effort is the qualification of all CIs and subsystems or segments, thereby preparing each element of the system for the subsequent System test program. The total objective is fulfilled by the following subordinate accomplishments:

(a) Engineering test and evaluation necessary to the development of an acceptable design.

(b) Preliminary Qualification Testing (PQT) to confirm the functional integrity of mission critical functions.

(c) Formal Qualification Testing (FQT) of each CI, or group, to both environment and functional performance requirements.

(d) Reliability test and analysis which confirms reliability goals and defines potential problems.

(e) Integration of hardware, computer programs, and personnel subsystems.

(f) Qualification of system segments or subsystems as specified in performance requirements.

(2) Government control of the CI/Subsystem test program is established primarily through provisions of the contract and requirements of the specifications. Although government personnel will

normally not conduct any CI/Subsystem testing, it is intended that the SPO will designate government representatives, on site, to perform as monitors to determine the test progress, adherence to test procedures, validity of collected data, and performance of the equipment and computer programs. Normally, all Computer Program Configuration Item (CPCI) testing will be conducted as an integral part of the CI/Subsystem effort.

b. System Test. The System testing effort consists of testing and evaluation spanning the integration of subsystems into a complete system, and development tests of the completed system in as near an operational configuration and environment as practicable. System testing is an Air Force effort with contractor participation, under AFSC direction and control, and with active operating and supporting command participation. Actual test operation and maintenance should be performed by military personnel who have received formal system training.

( ) The objective of System testing is the formal qualification of the system specification requirements. Specific objectives of the System test effort are:

(a) Demonstrate that the system can perform the mission as specified in Section 3 of the System Specification.

(b) Verify results of CI/Subsystem testing with Air Force crews in a live operational environment.

(c) Qualify and/or demonstrate the performance of CIs which require full system operation for qualification.

(d) Verify the adequacy and compatibility of the maintenance and supply support concepts as developed.

(e) Determine the safety characteristics of the system, and procedures necessary to operate and maintain the system.

(f) Provide sufficiently trained personnel for the operating commands to assume operational evaluation tasks during the OT&E phase.

(g) Verify required technical handbooks and manuals.

3. Operational Test and Evaluation. The OT&E testing effort normally follows System testing and completes the testing phase of the Program Management Plan (PMP). OT&E tests will be conducted by the appropriate operating command with technical support by Air Force Systems Command and Air Force Logistics Command.

SECTION II

TEST DOCUMENTATION

1. Introduction. There are several types of test documentation which, collectively, form the basis for an effective test program. Broadly, these can be classed as:

a. Test Requirements, which are Section 4 of each System (Type A) or CI (Type B or C) Specification.

b. Test Plans, which are usually the product of a validation phase and should reflect the overall planning for test and evaluation of the system or a subsystem.

c. Test Procedures, which are the detailed procedural information for conducting each test delineated in the test plans (ref. "b" above).

d. Test Reports, which summarize the results and analysis of each test conducted.

2. Test Requirements Documents. Section 4, "Quality Assurance," of each System (Type A) or CI (Type B or C) Specification contains specified contractual requirements for testing of the respective system or CI. This specification section should depict a requirement to test each performance and design requirement contained in Section 3 of the specification. Generally, Section 4 of a Type A specification will specify requirements for System Test, and Section 4 of a Type B or C specification will specify requirements for CI/Subsystem Test.

a. Section 4, System Specification. Section 4, "Quality Assurance," contains the requirements for the system test program. These requirements must be relatable to performance/design requirements stated in Section 3. Therefore, Section 4 will normally be limited to system level test requirements, but will also include requirements for CI/Subsystem engineering tests, qualifications, and reliability tests which can be accomplished only at the system test location(s). The principal content of Section 4, however, is the specification of System test requirements.

b. Section 4, CPCI Part I Specification. Test requirements are developed initially by the contractor for incorporation into Section 4 (Quality Assurance) of the Part I specification. This section should identify test methods (to the level of detail necessary to clearly establish the scope and accuracy of the methods) to be employed in qualifying the CPCI against all performance and design requirements specified in Section 3 of that CI specification. In addition, it should identify requirements for government-furnished equipment and facilities to support the contractor's computer program test and evaluation, as well

as designate those performance characteristics to be demonstrated and/or verified during preliminary qualification tests and demonstrations, formal qualification testing, and System testing.

(1) Requirements of Section 4 should be specified to the level of detail which:

(a) Designates verification requirements and methods for each performance/design requirement identified in Section 3. The method of verification to be specified may include inspection, review of analytical data, demonstration tests, and review of test data.

(b) Clearly establishes the scope and accuracy of the test method.

(2) Types of CI/Subsystem tests which may be specified in Section 4 of a CPCI Specification are:

(a) Computer Programming Test and Evaluation which are tests conducted primarily to support the design and development process. They are listed in the specification only when they meet one of the following criteria:

1. They are intended to be the only source of data to qualify specific requirements in Section 3.

2. They must be accomplished as part of an integrated test program involving other systems/equipment/programs.

3. They require the use of government-furnished test facilities or equipment.

(b) Preliminary Qualification Tests, which are formal tests oriented primarily towards verifying portions of the CPCI prior to formal qualification tests of the integrated CPCI.

(c) Formal Qualification Tests, which are formal tests oriented primarily towards testing of the integrated CPCI, using operationally configured equipment.

(3) The System test requirements to be identified in Section 4 concern those performance/design requirements which cannot be verified until System testing. Emphasis should be placed on minimizing these types of requirements and, if possible, eliminating them altogether. This will ensure that the CPCI that is CI/Subsystem tested has in fact attained a high degree of confidence. Also, this will allow the System test program to proceed with its prime objective, testing of system level requirements.

(4) An important point to remember is the differentiation between Section 4 and other testing documents. Section 4, by virtue of

being part of the Part I CPCI Specification, is a contractual document, and the contractor is required to conduct only those tests that are called out in that section. Any changes or deviations from these requirements (once baselined) must be approved by the System Program Office (SPO) through Engineering Change Proposal (ECP) actions. Thus, careful attention must be given to ensuring that the testing has been scoped properly, and the test requirements are complete and acceptable.

3. Test Plans/Procedures/Reports. Figure 1 shows a typical test documentation "tree" for a large system. The tree is constructed from the list of approved test plan/procedure/report data item descriptions (DIDs) contained in AFSCM/AFLCM 310-1, Vol II.

a. System Test Plan. The System Test Plan, DID T-101-1, is the "top document" for the test program which structures and unifies all subsequent test plans. Its purpose is to provide an overall outline of the total system test program to include planning factors, objectives, and scope of all phases of the test program. The system contractor prepares the System Test Plan (DID T-101-1), normally for delivery in the Conceptual or early Validation Phase. This plan will contain basic test planning information for all phases of the test program and cover the life cycle of the system through the end of the Full Scale Development Phase. The scope and level of detail of the information is sufficiently broad and comprehensive to provide basic test inputs to the Program Management Plan (PMP) and sufficiently detailed to provide the basis for preparing all subsequent test plans--particularly CI/Subsystem (DID T-102-1 and DID T-103-1) and System (DID T-106-2) plans.

(1) The System Test Plan (DID T-101-1) is based upon the test concepts and requirements contained in the Program Management Plan (PMP), the System Specification, and related system engineering documentation. It covers all aspects of the system, including hardware, facilities, computer programs, personnel, and procedural data with respect to such consideration as the following:

(a) Organizational responsibilities for testing.

(b) Basic system test concepts and objectives for CI/Subsystem, System, Implementation, and Acceptance tests.

(c) Overall system test operations, including test control requirements and test support requirements.

(d) Test evaluation requirements.

(e) Test reporting requirements

(f) Overall test schedules.

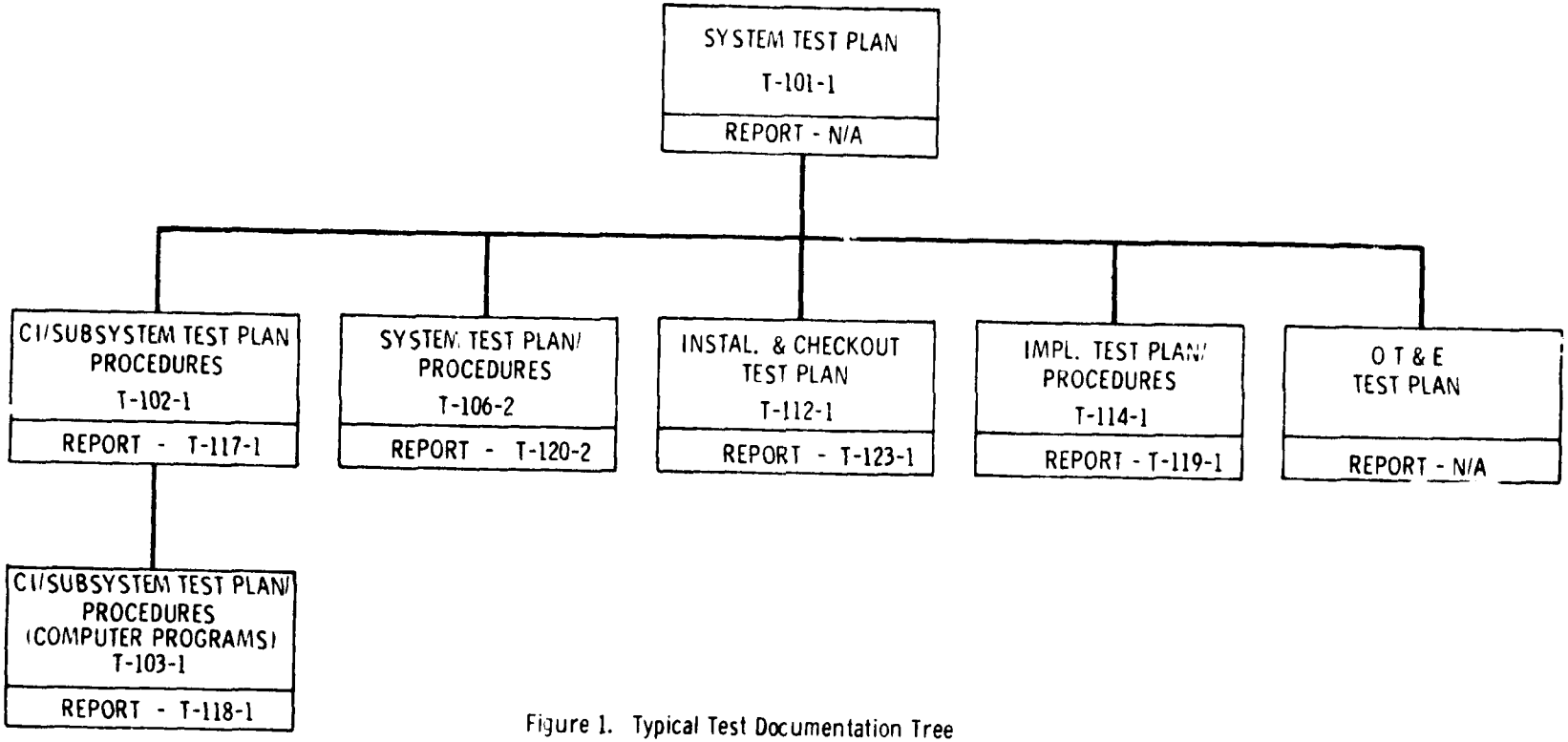

Figure 1. Typical Test Documentation Tree

(2) A primary function of the System Test Plan (DID T-101-1) is to guide the contractor's planning, analysis, and system engineering activities related to the test areas. During the Validation Phase the contractors expand basic planning and guidance information contained in the System Test Plan (DID T-101-1) and, in effect, replace it with the following documents:

(a) CI/Subsystem Test Plan (DID T-102-1 and T-103-1).

(b) Inputs to the System Test Plan (DID T-106-2).

(c) Inputs to the Implementation Test Plan (multisite systems; DID T-114-1).

(3) Special problems to be considered concerning computer programs may include provisions for computing equipment required for contractor development and testing of computer programs. The CI-Subsystem test cycle for computer program CIs will normally begin early during the Full Scale Development Phase; it may have to be initiated using a prototype computer and peripheral equipment, or in some cases by simulation on existing computers. As development of the CPCI progresses, testing will encompass progressively expanded groups of routines, and will require additional items of computing equipment for realistic testing of functions. Preliminary qualification tests/demonstration will normally occur at the contractor's plant, or other locations of available equipment. Formal qualification of the computer program CI may require scheduled time at the System test site for testing those computer program functions that depend upon the operationally configured system/equipment and for which simulation is not adequate. For a multisite system which requires adaptation of the operational computer program CI at each site location, the expected sequence of events at each follow-on site will be installation and checkout of equipment at the site facility, installation testing, adaptation, installation and checkout of computer programs, and implementation testing (See Figure 2).

b. CI/Subsystem Test Plan/Procedures/Reports (Equipment). The CI/Subsystem Test Plan/Procedures data item, DID T-102-1, is the overall planning document for the CI/Subsystem test program. It is subordinate (in the test planning tree) only to the System Test Plan (DID T-101-1). This document should provide complete planning information on each CI/Subsystem test specified in each of the CI specifications on contract--i.e., System Specification, CI Specification, Critical Component Specification, Military Specification, and other contractual documents that include CI/Subsystem test methods and success criteria. Note that test planning and procedures information for CI/Subsystem testing of computer programs should not be included in this document. In the case where the system involves computer programs, an additional test data item is used to detail the planning and procedural information for testing of the computer programs. This document is CI/Subsystem Test Plan/Procedures (Computer Program), DID T-103-1, which should be referenced in DID T-102-1.

This data item is normally obtained in the Validation Phase as a complete plan and individual test information sheets are then updated in the Full Scale Development phase prior to each test. Test reports are obtained under DID T-118-1.

c. CI/Subsystem Test Plans/Procedures/Report (Computer Programs). The computer program CI/Subsystem Test Plan/Procedures, DID T-103-1, is a subordinate and supplementary document to the overall CI/Subsystem Test Plan/Procedure, DID T-102-1. When the system involves computer programs and equipments, DID T-103-1 should be placed on contract along with DID T-102-1; DID T-102-1 will apply to the CI/Subsystem testing of all equipments and reference DID T-103-1 which will cover the CI/Subsystem testing for the computer programs.

(1) The CI/Subsystem Test Plan for computer programs is a contractor-prepared document which establishes criteria, general methods, responsibilities, and overall planning for CI/Subsystem testing of a CPCI. Normally, the test planning information is obtained in the Validation Phase as a complete plan applicable to all computer programs of the system. Generally, only one plan (and one volume) will be prepared for a single system or contract--this allows for the presentation of an integrated test plan which will apply to all computer programs for a particular system. Exception to this guidance can be obtained for the individual system. Sections of the plan which apply to computer programs for subsystems for which inadequate information exists at time of writing of the plan, can be updated at a later date. When this is the case, the section should be included nonetheless with the remark, "to be completed later."

(a) The plan should contain detailed information concerning the implementation of preliminary and formal qualification tests, along such lines as the following:

1. Locations at which the tests will be conducted, and schedules relative to milestones in the overall acquisition schedule.

2. General methods for preparation of input data--i.e., simulation and/or generation vehicles to be used.

3. General procedures for test conduct, and responsibilities for test direction, operation, and observation.

4. General procedures for analysis of test results.

5. Requirements for other computer programs, equipment, and facilities.

6. Personnel requirements, including numbers, responsibilities, and particular knowledge and skills required.

(b) The plan may also set forth the requirements and procedures for controlling and documenting the CI/Subsystem test program, including procedures for preparing, reviewing and revising documentation of specific test procedures; requirements and procedures for preparing and reviewing reports of individual qualification tests; summaries of the CI/Subsystem test program or phases thereof; and other reports related to the CI/Subsystem test activity.

(2) The CI/Subsystem Test Procedures are produced by the contractor during the Full Scale Development Phase.

(a) For each individual CI/Subsystem Qualification Test (PQT or FQT) for a CPCI, the contractor will prepare a CI/Subsystem Test Procedure in accordance with Section 2 of DID T-103-1. These procedures are prepared incrementally during the Full Scale Development Phase and submitted prior to the test date of the PQT or FQT to which they apply. Information included in a test procedure includes the following:

1. Location and schedule of the test, briefings, debriefings, and any associated data reduction/analysis.

2. References to applicable test plan, specifications, manuals and handbooks.

3. Detailed objectives of the test.

4. Requirements and responsibilities for console operators, test directors, technical consultants, data analysts, or other essential test personnel.

5. Requirements for other computer programs (other than the CPCI being tested) or equipment.

6. Test operating procedures to specify how to initiate the computer program operation, maintain the computer program operation, and terminate and/or restart the computer program operation.

7. A detailed test description for each test (or portion of a test) to be performed. This description should include detailed information on test inputs, outputs, events, expected results, reactions to be verified, and methods of verification.

8. Requirements and procedures for recording, reduction and analysis of test data.

(3) The CI/Subsystem Test Reports for computer program tests are obtained under DID T-118-1. These are contractor prepared documents, compiled incrementally during the Full Scale Development Phase.

Generally, one test report (in accordance with DID T-118-1) is prepared for each PQT or FQT conducted.

d. System Test Plan/Procedure/Report. DID T-106-2 is the basic document which provides the overall integrated outline of the System Test Program. It includes all planning factors, scope, detailed test objectives, identification of test areas, responsibilities of participating agencies, and associated information necessary to implement the minimum acceptable performance requirements of the Program Management Directive (PMD) and/or the System Specification. Normally, the contractor will prepare the System Test Plan and Procedures (DID T-106-2) with the intent being to establish a test and evaluation program to ensure that the system/equipment/computer programs meet the minimum acceptable performance requirements of the PMD and System/CI Specifications in as realistic and complete an operational environment as practicable. Test Reports are obtained under DID T-120-2.

e. Installation Testing. Installation Testing, normally conducted after completion of each installation, includes Preshakedown Tests, which are performed as a combination alignment check and test to assure that the installation is properly completed; Shakedown Tests, which are performed to assure that all detected marginal parts and material have been eliminated and that the installation is ready for operational tests; and Operational Tests, which are performed to demonstrate that the equipment is properly installed and is capable of performing its operational mission up to a specified interface with other portions of the subsystem/system.

(1) The Installation and Checkout Plan (I&C), DID T-112-1, is initially prepared by the contractor during the Validation Phase and later expanded to reflect the system engineering and detail design activity of the Full Scale Development Phase. Procedures are prepared to implement the plan, based upon assembly levels of components and consideration of all interfaces. In general, individual items are installed, physically and functionally checked out, then mated to other subsystems. This graduated process is applied successively until the complete system is ready for system tests.

(2) I&C plans are reviewed and approved by the SPO and the procedures selectively reviewed and approved.

(3) Adaptation, installation, and checkout (AI&C) of the computer program will normally occur after installation and checkout of equipment and facilities. Normally, the work will be accomplished by the contractor in accordance with the approved plans and procedures obtained under DID T-112-1. At the System Test Site, AI&C of the computer program may be followed by Formal Qualification Testing prior to initiation of the System Test. Based upon the experience gained at the System Test Site, the I&C plan may be modified and updated for use at each follow-on site. AI&C of computer programs at follow-on sites will

include the same basic activities as for AI&C at the System test site and will occur in the same general sequence, i.e., following I&C of the equipment/facilities, but prior to the start of Implementation Tests (see Figure 2). For computer programs, appendices may be used to cover unique adaptation features for each site.

(a) The computer program contractor must identify requirements for AI&C of the computer program at the System test site, and for multisite systems, must also include requirements for AI&C at subsequent site installations. Documentation should include a detailed description of all aspects of the adaptation, installation and checkout activities. Detailed schedules should be provided and all support requirements clearly identified, including required computer time, requirements for other system equipments such as communication, display consoles, etc., and requirements for trained personnel. Detailed information should also be provided concerning the training of personnel for the field locations, scheduled movement of field personnel, local transportation, office space and facilities, and living quarters at remotely located sites. Procedures should be prepared indicating in detail the exact manner in which the plan will be implemented.

NOTE: "Adaptation" refers to the process of inserting into the computer program the coded data which are appropriate to the geography or other characteristics of the given site. "Installation" refers to insertion of the coded instruction/data into the computing equipment; in contrast with equipment installation, computer program installation typically involves relatively insignificant effort or time. The major task of AI&C is the checkout activity, which may in some cases involve assembly of new elements, compiling, and extensive debugging, as well as personnel training and preliminary rehearsals of FQT procedures.

f. Implementation Testing. Implementation Testing is a concept which has been defined to meet the specific requirements of multisite (i.e., ground installation, airborne vehicles, space platforms, or tactical emplacements) electronic systems. The concept is based on experience which has shown that additional testing beyond Installation Testing may be required at successive operating sites to insure that these sites, individually and collectively, function as parts of a system in accordance with the requirements of the system performance specification. These tests encompass real-time functional testing performed at the system level with the purpose of exposing faults and providing a demonstration to the user that the installed site is ready for operational use.

(1) The relation of the System Testing and Implementation Testing should be one of decreasing complexity and sophistication. To the extent that system performance requirements set forth in the system specification have been demonstrated by System testing, a complete repetition of the effort for each follow-on system is not warranted. Rather, specific functional performance measures which acequately define

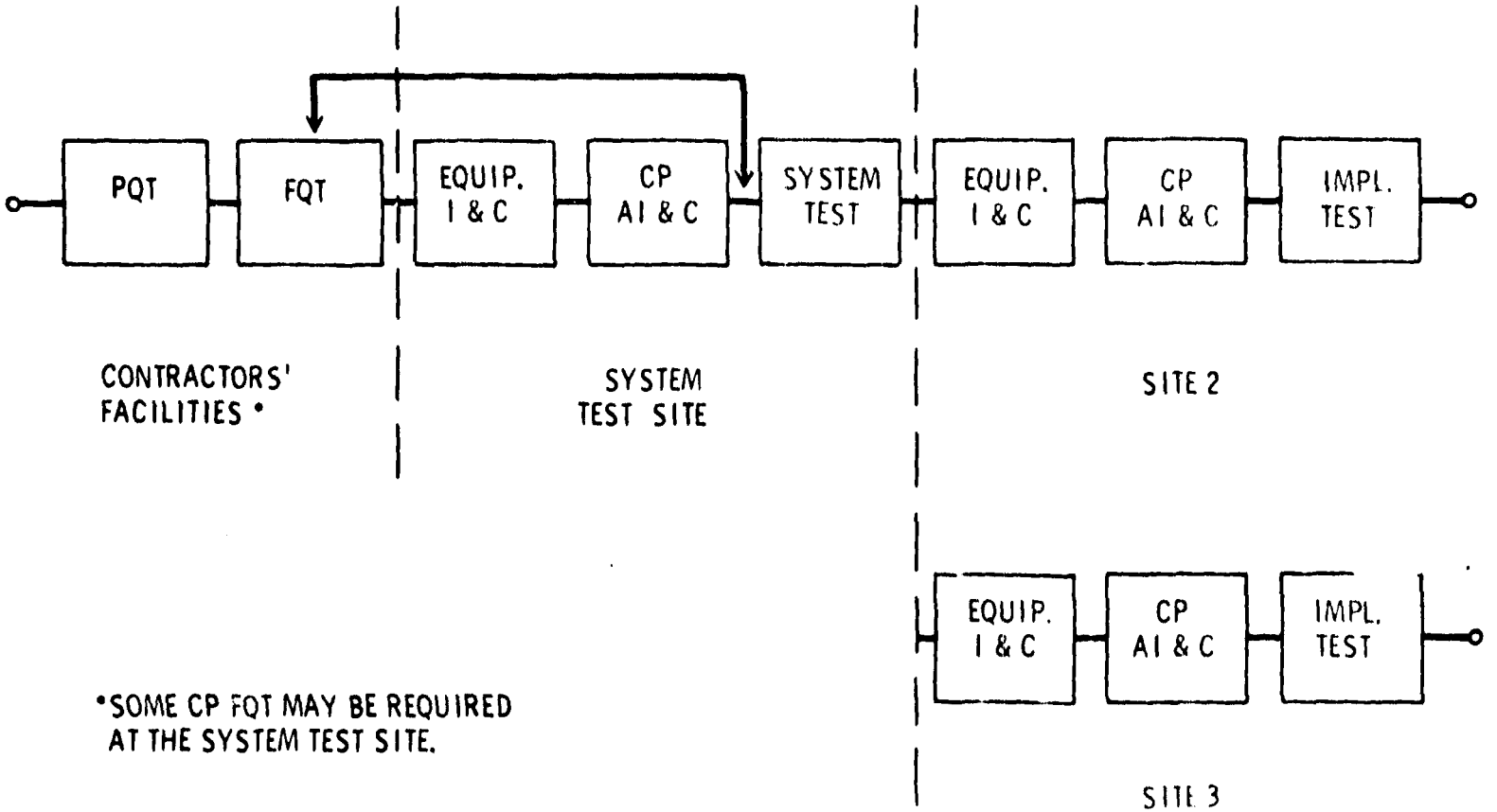

Figure 2. Computer Program Adaptation, Installation, and Checkout for a Multi-site System

system response are identified at an early point in time, and the actual values for such performance measures (figures of merit) are determined during System testing. These figures of merit are used during Implementation Testing as the criteria by which to gauge functional adequacy of the system. In general, Implementation Test should not attempt to duplicate the comprehensive testing accomplished during System testing.

(2) To insure operational validity, the user as well as the system designer must participate in Implementation Test planning. The user is interested in a test that will uncover technical incompatibilities or functional and operational deficiencies. Thus, the manner in which the system is to be employed is a vital factor in test planning.

(3) The Implementation Test Plan and Procedures are contractor-prepared documents obtained under DID T-118-1. The Implementation Test Plan defines the overall scope of the implementation tests, the objectives, methods, and support requirements for the conduct of this phase of testing. The Implementation Test Procedures (one set of procedures for each test conducted) outline a step-by-step set of instructions and criteria for each test specified in the plan. Test results are reported under DID T-119-1.

(4) The computer program contractor(s) prepare inputs to the Implementation Test Plan/Procedures much the same as for the System Test Plan/Procedures. Since implementation testing is at the system level, emphasis will be placed on those aspects of the computer program performance which depend upon complex interactions with other CPCIs, personnel, equipment, and data links during operation of the entire system.

(a) Special emphasis will be given to those portions of the CPCIs (generally the operational CPCI) which vary from site-to-site, i.e., environmental data values, special adaptation parameters, unique-to-site interfaces, and site-peculiar program routines.

(b) Inputs to the Implementation Test Plan relative to computer programs should be similar to the inputs to the System Test Plan (DID T-106-2). In general, they should emphasize those aspects of system performance which are closely associated with or dependent upon performance of the CPCI(s). Frequently, the inputs may represent a selected subset of the System Test Plan (DID T-106-2) inputs.

4. Section 4, CPCI Part II Specification. Normally, Section 4 of a CI Part II Specification will contain quality assurance provisions and acceptance test requirements for follow-on production items. However, unlike equipment items, there is no follow-on production process for a computer program item; thus, the concept of acceptance tests for production items will not apply to a CPCI. Instead, Section 4 of a CPCI Part II Specification should contain two subsections:

a. Test Plan/Procedure Cross Reference Index. This subsection should contain a cross-reference diagram depicting each function (as delineated in the CPCI Part I Specification) and relating these functions to the corresponding test plan/procedures that were used to qualify the individual requirements of the CPCI.

b. Other Quality Assurance Provisions. This subsection should reference and/or specify the test/verification requirements, methods, and procedures which apply to preparation and duplication of the computer program (i.e., tapes, card decks, etc.).

SECTION III

COMPUTER PROGRAM CI/SUBSYSTEM TESTING

1. Introduction. The CI/Subsystem testing of CPCIs serves a fourfold purpose:

a. To establish each CPCI as a qualified end item suitable for entry into the System Test Program. This qualification is accomplished by verifying the performance and design requirements of the CPCI Part I Specification.

b. To furnish the procuring agency with the proper visibility required for effective management of the system. This is accomplished through judicious scheduling of PQTs, thus establishing milestones which will provide insight into the progress of the CPCI design and development. If problems are encountered in the computer program area, early detection can be made and more effective management and engineering can be focused on these potential problem areas.

c. To serve as a standard or "straw man" about which the contractor can develop his internal verification procedures.

d. To develop a comprehensive test (called FQT) which can be utilized after FCA as an ongoing test tool/procedure for retesting the CPCI. FQT is not only used for formal verification prior to FCA but will be continuously updated and used to retest the CPCI whenever changes are made to the program.

2. Types of CI/Subsystem CPCI Testing. CI/Subsystem testing of CPCIs can be broadly divided into two types--informal testing and formal testing. The basic difference between these types stems from the documentation requirements; informal testing utilizes the contractor's internal test documentation, controls and procedures; formal testing is conducted in accordance with Air Force approved test plans and procedures.

a. Informal Testing. CI/Subsystem informal testing (referred to as Computer Program Test and Evaluation, CPT&E) will usually form the bulk of the contractor's CI/Subsystem test effort. It is designed to be the contractor's "in-house" testing and requires no government approved test plans/procedures. Generally, the entire informal test effort will be documented internally by the contractor, and such information will be made available to the procuring agency only on demand. Informal testing begins when the first subprogram is coded and continues throughout the Full Scale Development Phase.

(1) Informal testing is required on three levels for a step-by-step validation of the CPCI:

(a) Subprogram level (parameter tests)

(b) Functional level (assembly tests)

(c) CPCI level (assembly tests)

(2) Parameter tests are tests of the information processing logic of the individual CPCs. Sets of inputs are prepared which cause all the logic paths to be exercised. The resultant outputs are checked against hand calculations which show whether the CPC has been coded correctly.

(3) Assembly tests are tests of groups of CPCs which perform a function of the CPCI, or in later stages, many or all of the functions of the CPCI. Interfaces between the CPCs as well as overall information processing are tested. Simulated inputs to the CPCI are used, and the CPCI is operated in real-time or simulated real-time mode.

(4) The informal test activities are conducted solely for the purpose of providing information required for the developmental process. As such, they do not require recognition by the procuring agency and would not normally be identified in the CI/Subsystem Test Plan. The planning and conduct of informal testing is carried out in accordance with the contractor's internal management procedures, and within the time constraints imposed by formally scheduled reviews and qualification testing. Each CPC or subprogram must pass through a series of stages and iterations, consisting of such operations as desk checking, elimination of illegal instructions, parameter tests, functional testing with controlled data inputs, assembly with additional components of the CPCI, assembly testing, performance testing with simulated inputs and, finally, performance testing in the system under conditions of live operations.

(5) The CI/Subsystem Test Plan will not generally include planning information for contractor testing which is conducted as an integral part of the design and development process. However, the plan will typically detail the contractor's requirements for government facilities and other support required for conducting the tests. These will include requirements for computing and peripheral equipment which must be furnished or otherwise made available for the contractor's use on an appropriate schedule during the Full Scale Development Phase. Where formal qualification of the CPCI is scheduled to occur at the System test site, it will normally be preceded by a phase of contractor test and evaluation associated with adaptation, installation, and checkout of the CPCI(s) at the site. The CI/Subsystem Test Plan should include (or reference other planning documents which include) requirements for scheduled use of the facility, system equipment, other computer program CIs, personnel, and other items needed to support the conduct of these contractor tests.

b. Formal Testing. CI/Subsystem formal testing is that portion of CI/Subsystem testing which is conducted in accordance with Air Force approved test plans/procedures. Thus, the Air Force has explicit control of the type, number, and frequency of tests to be performed.

(1) The CI/Subsystem formal test effort is divided into two distinct types of testing--Preliminary Qualification Testing (PQT) and Formal Qualification Testing (FQT). PQT is designed to be an incremental process which will provide the procuring agency proper visibility and control of the computer program development during the time period between the Critical Design Review (CDR) and FQT. FQT is designed to be a complete and comprehensive test of the CPCI in a "one step" fashion just prior to FCA.

(a) Preliminary Qualification Testing (PQT) is composed of function level tests (assembly tests) which are conducted in accordance with Air Force approved test plans/procedures procured under DID T-103-1. PQT is to be an incremental process which occurs between CDR and FQT of a CPCI's development process. For each function (of the Part I CPCI Specification) which is designated for testing during PQT, a separate test procedure is written and a formal test conducted. Note that, generally, not all functions of a CPCI are tested during PQT since experience has proven that it is both too costly and too time-consuming. Instead, only designated functions of the CPCI are tested during PQT; thus, the problem becomes one of the selection of those functions which should undergo PQT. Selection of these functions should be based on the following:

1. A PQT should be conducted for each function that is "time-critical" to the development of the CPCI, subsystem, or system. For example, the compiler function of a utility CPCI may be designated "time-critical" if the development of the remaining computer programs depend on the timely development of a compiler to be used for compiling the other programs. The development of the executive function of an operational CPCI may also be designated "time-critical" since the orderly progression from parameter testing to assembly testing of the operational CPCI would require the timely development of the executive function.

2. A PQT should be conducted for each function that is "performance-critical" to the development of the CPCI, subsystem, or system. For example, the executive function could be designated "performance-critical" as well as "time-critical" due to the utilization of various exotic scheduling techniques. As another example, the tracking function of a CPCI for an on-line radar system might be designated "performance-critical" due to the utilization of new tracking, smoothing, and filtering techniques.

(b) Preliminary Qualification Tests (PQTs) should normally be conducted at a contractor's development facility (i.e., contractor's

plant or other location of available equipment), typically using controlled inputs specifically prepared for the test/demonstration purpose. The Test Plan should outline the sequence of individual and/or assembled CPC tests, identify the CPCI performance/design requirements to be verified at each PQT, and identify special simulation/recording equipment or other support requirements for the PQT program. Each Test Procedures document should be completed by the contractor and submitted to the monitoring agency sufficiently in advance of the scheduled test session (i.e., two to four weeks) to permit review and analysis of the procedures prior to witnessing the testing operations. The format and content of a typical Test Procedures document are specified in DID T-103-1.

(c) Formal Qualification Testing (FQT), unlike informal testing and PQT, is not an incremental process. FQT is designed to be an integrated and comprehensive functional test of the CPCI as a whole, and usually is conducted in one continuous time period just prior to FCA. Each function of the CPCI (as delineated in the CPCI Part I Specification) is tested during FQT, regardless of the amount of informal testing and PQT conducted previously. Since PQT is conducted during the on-going design process, the PQT test procedures become obsolete within a few weeks after the PQT tests. In contrast, since FQT is conducted after the design process culminates (just prior to FCA), the FQT test procedures can be maintained and updated and used throughout the remainder of the Full Scale Development and Deployment Phases. Thus, each time a change is implemented in a CPCI, the FQT procedures can be used as a test tool to retest the CPCI and ensure that it still functions in accordance with the functional requirements set forth in the Part I Specification.

1. For the less complex CPCIs, or for those (i.e., utility) which are relatively insensitive to the system operations, formal qualification will usually be conducted at the contractor's development facility. However, for a large operational CPCI, the sheer complexity of the performance requirements may dictate that FQT can only be conducted in the context of the operationally-configured system, including personnel and communications. Hence, for these cases, FQT may often not be conducted at the contractor's plant (development facility), but may require use of the System test site prior to the beginning of System testing.

2. In the event that a complex operational CPCI is scheduled for formal qualification at the System test site, scheduling of the FQT will normally be prior to the start of formal System testing, but following a period of contractor adaptation, installation, and checkout of the CPCI in the previously installed and tested operational equipment/facilities.

3. In either case, FQT will involve the use of simulated and controlled inputs which can be designed to cover the expected ranges of variables, system operational modes and conditions, including

capacities and limits. Full qualification of certain functions may depend upon subsequent System testing with live inputs and communications.

4. The procedures for Formal Qualification Tests (ref DID T-103-1) will be in the same format as the FQT procedures prepared during design and development. However, these procedures will emphasize verifying that all functional requirements are met, based on the demonstrated performance using the complete CPCI. Since the FQT procedures require approval by the monitoring agency, they should be submitted initially in preliminary form. Review and analysis may result in proposed changes which must be resolved and reflected in revised preparations for the testing activity. Hence, the preliminary document should be completed in sufficient time (i.e., three months prior to scheduled FQT) for this potentially lengthy process to be accomplished.

3. Levels of CI/Subsystem CPCI Testing. As mentioned earlier, testing of a CPCI is required at three levels: subprogram level, functional level, and CPCI level. Regardless of the type of testing to be performed (i.e., informal versus formal testing), these three levels apply equally to each. This relationship is portrayed in Figure 3.

a. Subprogram Testing. Subprogram testing, sometimes called parameter testing, is directed toward ensuring that each subprogram (CPC or lesser entity) interprets its inputs correctly, successfully performs all tasks defined in the subprogram coding specifications, and adheres to prescribed coding conventions and standards. Subprogram testing is the most detailed and basic testing that is performed upon computer programs. Since concentration is on testing basic, easily managed units of code, the detection, isolation and correction of errors that are exceedingly difficult to detect, isolate and correct in later phases of testing is greatly facilitated. Therefore, detailed attention must be given to the specification of rigid test requirements so that errors are not overlooked that will later cause unnecessary testing and analysis. Each subprogram should be specifically tested for arithmetic and logical accuracy and limitations, usually without requiring communication with related subprograms or external equipment. Subprogram testing commences following the development of a set of coded instructions that have been subjected to detailed visual verification (code checking) by the responsible programmers, and automatic code analysis by the applicable compiler and/or assembler to eliminate errors in keypunching, formatting of code, etc. In addition, a thorough technical review of the subprogram should be conducted by contractor personnel to ensure that violations of coding conventions and standards have been corrected prior to on-computer testing. The subprogram is then operated with a range of data that forces use of all decision points and processing paths. The test results are analyzed to determine whether the derived results are consistent with the input data, the results expected from the selected input parameters, and the operation of the subprogram as defined in coding specifications.

TESTING LEVEL / TESTING TYPE	SUBPROGRAM LEVEL	FUNCTION LEVEL	CPCI LEVEL
INFORMAL TESTING	CONTRACTOR IN-HOUSE PARAMETER TESTING	CONTRACTOR IN-HOUSE ASSEMBLY TESTING AT THE FUNCTION LEVEL	CONTRACTOR IN-HOUSE ASSEMBLY TESTING AT THE CPCI LEVEL
FORMAL TESTING	N / A	PQT PERFORMED FOR DESIGNATED FUNCTIONS	FQT FOR DEMONSTRATING ENTIRE CPCI

Figure 3. Types and Levels of Computer Program Testing.

b. Functional Area Testing. Functional area testing, sometimes referred to as string or assembly testing, is directed toward ensuring that selected sets of functionally related subprograms interpret all inputs correctly, successfully perform all processing tasks specified in performance specifications, and generate output data that satisfies the input requirements of other interfacing functional areas or equipments. Functional area testing is an extension of subprogram testing with emphasis being placed on inter-program communications and processing of data within a defined grouping of subprograms or components. Subprogram testing, on the other hand, concentrates on intra-program communications and data processing. Examples of functional areas are radar inputs processing and correlation, data link inputs processing, and weapons guidance. Each functional area is composed of one or more subprograms that must accept as inputs other functional area outputs, or inputs received via the operating hardware, and process them in accordance with functional performance specifications. It must also prepare data for use by other sets of functionally related subprograms as specified in detailed coding specifications. In some cases, (i.e., tape read), functional area testing may be the first phase of testing performed. This will most often occur when subprogram testing requires the excessively expensive simulation of interfacing hardware.

(1) Functional area testing is usually the first point at which interactions with a control subprogram are examined. Ideally, the executive or control function is the first to enter the functional area test phase, since the other functions can be more conveniently tested with it. In actual practice, however, the control function may not be available or far enough along in development for this purpose. In this event, other methods for control may be utilized. Although many functional areas are usually being tested at the same time, the scope of testing gradually increases through higher and higher levels of assembly as functions become verified until the computer program is ready to undergo CPCI testing. In practice then, functional area testing begins as "high-level" subprogram testing and phases out as "low-level" CPCI testing.

(2) Throughout this phase of testing, the performance of the computer program is checked against that specified in performance requirements decisions and limits that result from an interface between subprograms. Therefore, conditions that are of consequence to only one subprogram, such as proper exits in subroutine decision paths, are better tested in the subprogram test phase when the problems of defining and establishing the proper test situations are not so complex. In addition to differences in levels of concentration, functional area testing examines interactions between all functionally related components while CPCI testing concentrates on interactions between functions. Also, internally stored inputs that are provided to the subprograms during the functional area test phase usually result from the insertion of test data by a test input tool. CPCI testing, on the other hand, uses CI level inputs that are provided either by other CPCIs, or by system input data generators.

c. CPCI Testing. CPCI testing is directed toward ensuring that the total package of computer program components that comprise the CPCI correctly interprets all input message types and values, accepting those that are legal and properly disposing of all others; properly processes all internally stored data; and correctly formats, arranges, and outputs all required system data. Thus, CPCI testing verifies that the CPCs operating as the CPCI fulfill the requirements of performance specifications. Whereas subprogram testing concentrates on verifying the correct operation of individual computer program components, and functional area testing emphasizes inter-program communications within separable functional areas, CPCI testing concentrates on verifying that the complete set of computer program functional areas correctly interacts with each other. Therefore, CPCI testing must be accomplished after functional area testing and prior to, or in parallel with, testing with other CIs. CPCI testing can be conducted at either the contractor's in-plant test facility or an installation facility (either operationally employed or a nonoperational test site). During the initial stages of CPCI testing, the bulk of the testing is conducted in-house using simulated inputs. This provides a high degree of confidence prior to the release of a CI to a site location. During the later stages of CPCI testing, emphasis shifts from the testing of functional communication to verification of overall CPCI performance in an operational (or very nearly so) environment.