ESD-TR-67-67

AIR FORCE CONCEPTS FOR THE TECHNICAL CONTROL AND DESIGN VERIFICATION OF COMPUTER PROGRAMS

M. S. PILIGIAN
CAPT J. L. POKORNEY

APRIL 1967

TECHNICAL REQUIREMENTS AND STANDARDS OFFICE
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
United States Air Force
L. G. Hanscom Field, Bedford, Massachusetts 01730

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FOREWORD

This paper was originally prepared for presentation at the Spring Joint Computer Conference, 18-20 April 1967, at Atlantic City, New Jersey, sponsored by The American Federation of Information Processing Societies.

REVIEW AND APPROVAL

This technical report has been reviewed and is approved.

Frank E. Brandeberry

FRANK E. BRANDEBERRY, Colonel, USAF
Chief, Tech Rqmts & Stds Office

ABSTRACT

This paper presents Air Force developed concepts for technical control and design verification of computer programs. Starting with the definition of a computer as a deliverable contract end item requiring a design and development effort, management procedures for controlling the design and development process are explained. Technical control of computer program design through periodic design reviews is outlined and test concepts for verification of computer program performance are presented. The techniques discussed are based on an exchange of technical information between the contractor and the procuring agency at a series of discrete milestones throughout the design and development process. The milestones, including design reviews, qualification testing, etc., are described and the relationship of these milestones to the design and development of a computer-based system is illustrated. The techniques are directly applicable to any large computer-based system whether it be military or commercial and they can be easily tailored to fit a small computer system.

INTRODUCTION

While much has been written about the design and development of large scale computer-based systems, little has been published about the testing of these systems and, in particular, about the testing of computer programs within the context of a system. Similarly, while extensive techniques for design control of system hardware have been developed by the Air Force over the past five years, technical control and design verification procedures for computer programs have not been aggressively investigated. An Air Force project was established at the Electronic Systems Division (AF Systems Command) to rectify this situation. Concepts resulting from this investigation are presented and current procedures to insure design integrity of computer programs by technical reviews of the designer's efforts and by tests during program development are summarized.

UNIFORM SPECIFICATIONS

Fundamental to Air Force management of computer program design, development, and testing is the definition of computer programs as deliverable contract end items (CEI's) and the adaptation of the Air Force uniform specification program to these end items[1,2]. The uniform specifications[3], both at the system and computer program contract end item (CPCEI) level, consist of two basic sections: Section 3, performance/design requirements section; and Section 4, the quality assurance or test requirements section. It should be realized that even as early in the design process as the preparation of the system and end item specifications, the methods of testing end item performance against technical requirements should be known. It is a waste of time and money to specify technical requirements if a method of performance verification is not available to evaluate the computer program once it is developed. Generally, a one to one relationship exists between Sections 3 and 4 of the specification. Thus, each requirement of Section 3 will have an appropriate test requirement and test method identified in Section 4. The specified requirements form the basis for three formal technical reviews throughout the system/CEI / design and development. Concurrently, the specification test requirements are the basis for subsequent test planning documentation and system testing at both the CEI and system

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[1] ESD Exhibit EST-1, Configuration Management Exhibit For Computer Programs. Test Division of the Technical Requirements and Standards Office, Electronic Systems Division, Air Force Systems Command, L.G. Hanscom Field, Bedford, Massachusetts, May 1966.

[2] AFSCM 375-1, Configuration Management During Definition and Acquisition Phases. Andrews AFB, Washington, D.C. Headquarters, Air Force Systems Command, 1 June 1964.

[3] Liebowitz, B.H. The Technical Specification--Key to Management Control of Computer Programming. SJCC Proceedings, 1967.

performance levels. The relationship between the specifications, design reviews, and test program is illustrated in Figure 1. The lower blocks of the figure identify the design reviews during the system life cycle each of which will now be discussed in more detail.

SYSTEM DESIGN REVIEW

The System Design Review (SDR) is held late in the Definition Phase* of the system life cycle[4]. The purpose of this first review is to study the contractor's system design approach. At the SDR a critical examination is performed to insure that contractor's design reflects a proper understanding of all technical requirements. An analysis of contractor documentation in the form of functional diagrams, trade study reports, schematic diagrams, initial design specifications, etc., is conducted. A prime objective of the SDR is to review the allocation of functional requirements to the various system segments and CEI's. Thus, for computer programs, the SDR must insure that only those system requirements that can be realistically satisfied by computer programs have been allocated to CPCEI's (i.e., operational, utility, diagnostic, etc.). Prior to the conduct of the SDR, trade-off studies concerning equipments versus computer programs must have been completed to provide a cost effective allocation of requirements. Satisfactory completion of the SDR permits preparation of the Part I specifications ("design to" specifications) for all CPCEI's. These specifications form the basis for the second technical review in the design process.

PRELIMINARY DESIGN REVIEW

The Preliminary Design Review (PDR) is normally held within 60 days after the start of the Acquisition Phase. Concurrently, the preliminary design of the CPCEI can progress based upon the approved "design to" specifications for the end item. The purpose of the PDR is to evaluate the design approach for the end item, or group of end items, in light of the overall system requirements; thus, the prime objective of the PDR is achieving design integrity. A review of the interfaces affecting the CPCEI is an important element of a PDR. Emphasis is placed on verification of detailed interfaces with equipment and with other CPCEI's. At the PDR the instruction set of the computer to be used must be firmly established. The programming features of the computer, e.g., interrupts, multiprocessing, time sharing, etc., must be known. All external data formats and timing constraints must be identified. The computer program storage requirements and data base design are reviewed for technical adequacy at this time. The structure of the CPCEI is also reviewed at the PDR. During the initial design process for a complex CPCEI,

*Phases as discussed here (i.e., Conceptual, Definition, Acquisition, and Operational Phases) refer to the four phases of the System Life Cycle as defined in AFSCM 375-4, System Program Management Procedures.

[4] Ratynski, M.V. The Air Force Computer Program Acquisition Concept. SJCC Proceedings, 1967.

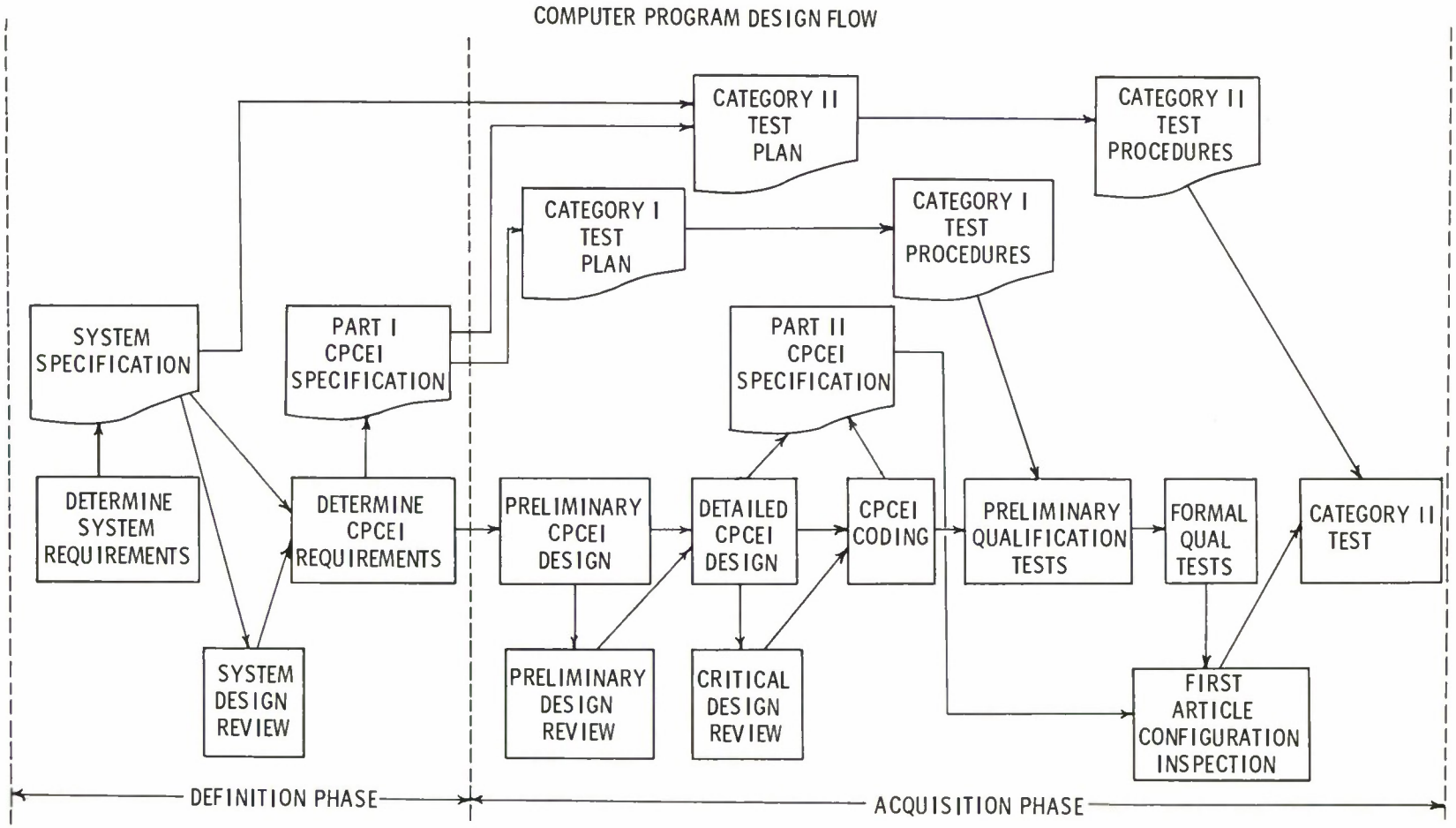
COMPUTER PROGRAM DESIGN FLOW
CATEGORY II TEST PLAN
CATEGORY II TEST PROCEDURES
CATEGORY I TEST PLAN
CATEGORY I TEST PROCEDURES
SYSTEM SPECIFICATION
PART I CPCEI SPECIFICATION
PART II CPCEI SPECIFICATION
DETERMINE SYSTEM REQUIREMENTS
DETERMINE CPCEI REQUIREMENTS
PRELIMINARY CPCEI DESIGN
DETAILED CPCEI DESIGN
CPCEI CODING
PRELIMINARY QUALIFICATION TESTS
FORMAL QUAL TESTS
CATEGORY II TEST
SYSTEM DESIGN REVIEW
PRELIMINARY DESIGN REVIEW
CRITICAL DESIGN REVIEW
FIRST ARTICLE CONFIGURATION INSPECTION
DEFINITION PHASE
ACQUISITION PHASE

Figure I

the requirements of the Part I specification which are function-oriented are allocated to computer program components or modules. The relationship of the components of a typical CPCEI to the functions identified in a Part I CPCEI specification is shown in Figure 2. The allocation of functions to computer program components within the CPCEI is examined at the PDR. The primary product of the review at this level is establishing the integrity of the design approach, verifying compatibility of the design approach with the Part I specification, and verifying the functional interfaces with other CEI's in order that detailed design of the CPCEI and its components can commence.

CRITICAL DESIGN REVIEW

The Critical Design Review (CDR) is a formal technical review of the design of the CPCEI at the detailed flowchart level. It is accomplished to establish the integrity of the computer program design prior to coding and testing. This does not preclude any coding prior to the CDR required to demonstrate design integrity, such as testing of algorithms. In the case of a complex CPCEI, as the design of each component proceeds to the detailed flowchart level, a CDR is held for that component. In this manner, the CDR is performed incrementally by computer program components, and the reviews are scheduled to optimize the efficiency of the overall CDR for the end item as a whole. Due to the varying complexity of the parallel design efforts for CPCEI components, it would be unreasonable to delay all of the components being developed to hold one CDR for the CPCEI.

At the CDR, the completed sections of the Part II CPCEI specification (detailed technical description) are reviewed along with supporting analytical data, test data, etc. The compatibility of the CPCEI design with the requirements of the Part I specification is established at the CDR. "Inter" interfaces with other CPCEI's and "intra" interfaces between computer program components are examined. Design integrity is established by review of analytical and test data, in the form of logic designs, algorithms, storage allocations, and associated methodology. In general, the primary product of the CDR is the establishment of the design as the basis for continuation of the computer program development cycle. Immediately following the CDR, coding of individual components takes place and the process of checkout and testing of the components begins.

COMPUTER PROGRAM TESTING

System testing as defined by the Air Force is divided into three classes or categories of testing, two of which, Category I and Category II[5], are

[5] AFR 80-14, Testing/Evaluation of Systems, Subsystems, and Equipments. Washington, D.C. Department of the Air Force, 14 August 1963.

ALLOCATION OF PERFORMANCE FUNCTIONS

TO

COMPUTER PROGRAM COMPONENTS

	ATR	BAG	MIM	RST
RADAR INPUTS				X
TRACKING	X	X		X
IDENTIFICATION		X		
DISPLAY CONTROL		X		
DATA TRANSFER	X			X
(N) FUNCTIONS				

COMPUTER (M) PROGRAM COMPONENTS

Figure 2

important in development testing of Air Force systems and will be discussed here. Category I tests for CPCEI's are conducted by the contractor with active Air Force participation. These activities, when properly planned and managed, will normally proceed in such a way that testing and functional demonstrations of selected functions or individual computer program components can begin early during acquisition and progress through successively higher levels of assembly to the point at which the complete CPCEI is subjected to formal qualification testing. Since the total process is typically lengthy and represents the major expense of computer program acquisition for the system, the test program includes preliminary qualification tests at appropriate stages for formal review by the Air Force. While the tests are preliminary in nature (they do not imply acceptance, or formal qualification), they do serve the necessary purpose of providing check points for monitoring the contractor's progress towards meeting design objectives and of verifying detailed performance characteristics, which, because of sheer numbers and complexity, may not be feasible to verify in their entirety during formal qualification testing. Category II tests are complete system tests, including the qualified computer program end items, conducted by the Air Force with contractor support in as near an operational configuration as is practicable.

Computer program testing is accomplished in accordance with Air Force approved test documentation as illustrated in Figure 3. As previously discussed, test requirements and corresponding test methods (to the level of detail necessary to clearly establish the scope and accuracy of the methods) are contained in Section 3 and Section 4 of the CEI specification. The Category I test requirements are further amplified in the contractor-prepared Category I Test Plan. This document contains comprehensive planning information for qualification tests; complete with schedules, test methods and criteria, identification of simulated versus live inputs and support requirements for test equipment, facilities, special test computer programs and personnel. The Test Plan forms the basis for Category I Test Procedures which are also prepared by the contractor. These describe individual Category I qualification tests in detailed terms, specifying objectives, inputs, events, recording/data reduction requirements and expected results. Actual test results are reported in a formal Category I Test Report.

CATEGORY I (QUALIFICATION) TESTING OF COMPUTER PROGRAMS

The Category I test program verifies that the CPCEI satisfies the performance/design requirements of the Part I "design to" CPCEI specification. The test program must be designed to insure that all of the functional requirements, as translated into computer program components, are tested and that requirements are not lost in the translation. The program is divided into two major classes of tests: Preliminary Qualification Tests (PQT) and Formal Qualification Tests (FQT). The former are designed to verify the performance of individual components prior to an integrated formal qualification of the complete CPCEI.

TEST DOCUMENTATION

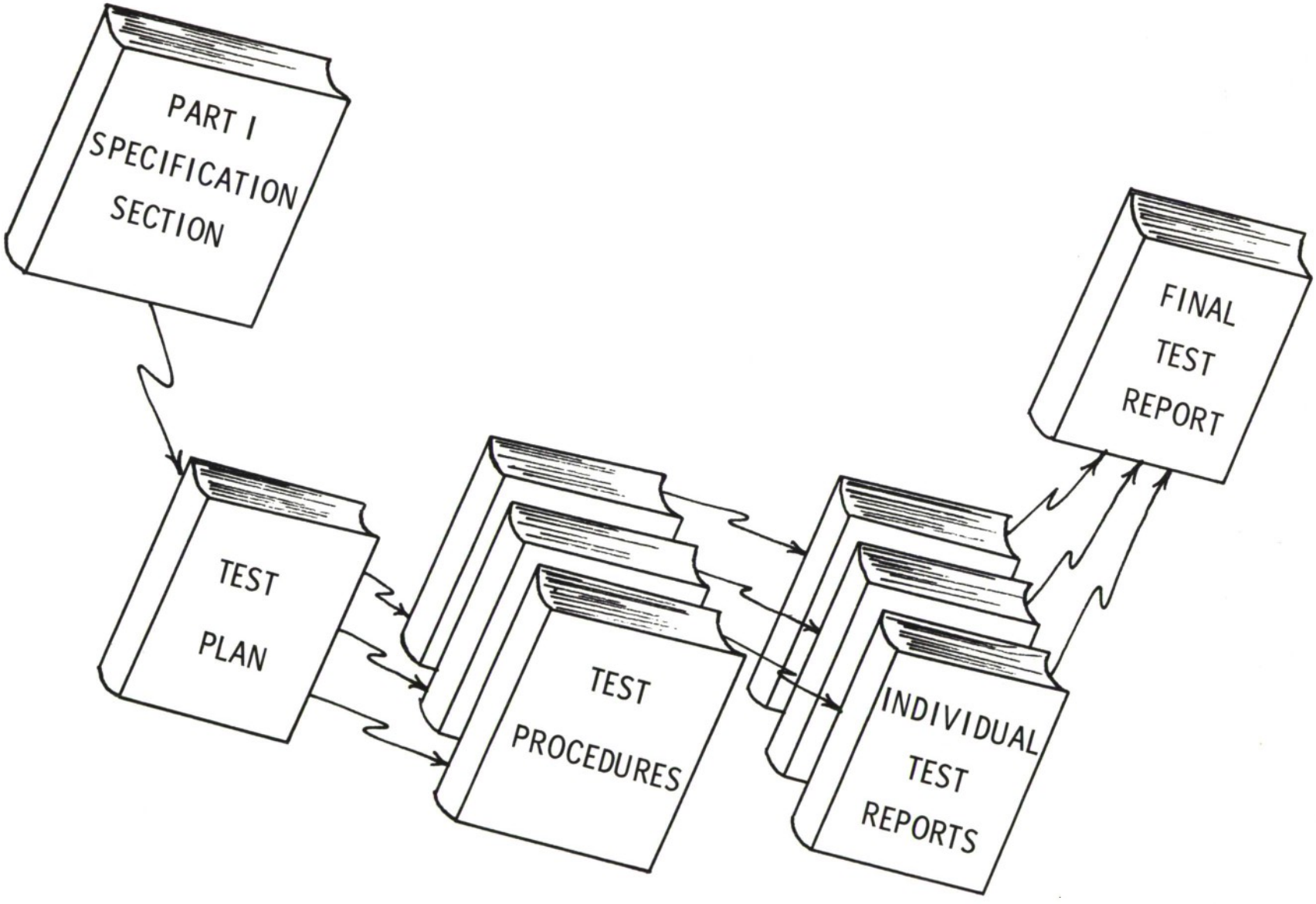

Figure 3

PRELIMINARY QUALIFICATION TESTING

The PQT phase is conducted incrementally by components in the same manner as the CDR. Figure 4 depicts the relationship between CDR and the Category I test program. The crosshatched blocks in Figure 4 indicate coding of individual computer program components. The PQT's are modular and a "building block" effect occurs as testing progresses. As each computer program component is added and each PQT conducted, increased confidence develops in the CPCEI being tested. Generally, parameter tests are conducted prior to and in parallel with PQT's[6].

Parameter tests are those designed to prove that an individual subprogram satisfies the detailed design specification, not that the program performs as coded. These tests compare the actual operation of each subprogram against the design specification. Parameter testing usually requires a utility system incorporating sophisticated parameter test tools, which are computer programs themselves, allow more efficient testing because they increase the ease with which a test can be specified, implemented, and analyzed. They allow a programmer to easily input data, make corrections, and record results. In addition to the test tools, the programmer needs the compiled or assembled program, the Part I specifications, the test plan, and the test procedures.

In parameter tests, the programmer must input a simulated program environment to the computer. The environment should include the broadest range of anticipated inputs, including some illegalities. The program is operated in this simulated environment, and the actual outputs are compared with the expected outputs. After each test run, the programmer analyzes the results and makes corrections to the code. All corrections are verified by submitting them to a parameter test once again.

Assembly testing verifies that the computer program components in the CEI interact according to design specifications. It is conducted with simulated inputs in order to minimize the effects of people and equipment and allows a broad range of input conditions to be simulated. Elaborate test tools, such as input simulation, recording, and reduction programs, are required to conduct assembly tests. Since these programs take time to prepare, test requirements such as instrumentation must be anticipated. For example, provision must be made for core storage to accommodate test control and test recording programs along with the program being tested.

At the conclusion of Preliminary Qualification Testing, all of the computer program components will have been integrated and tested and the CPCEI is being readied for formal qualification and acceptance.

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[6] Farr, Leonard A. A Description of the Computer Program Implementation Process. System Development Corporation, TM-1021/002/00, 25 February 1963.

COMPUTER PROGRAM CONTRACT END ITEM
CRITICAL DESIGN REVIEW AND CATEGORY I TESTS

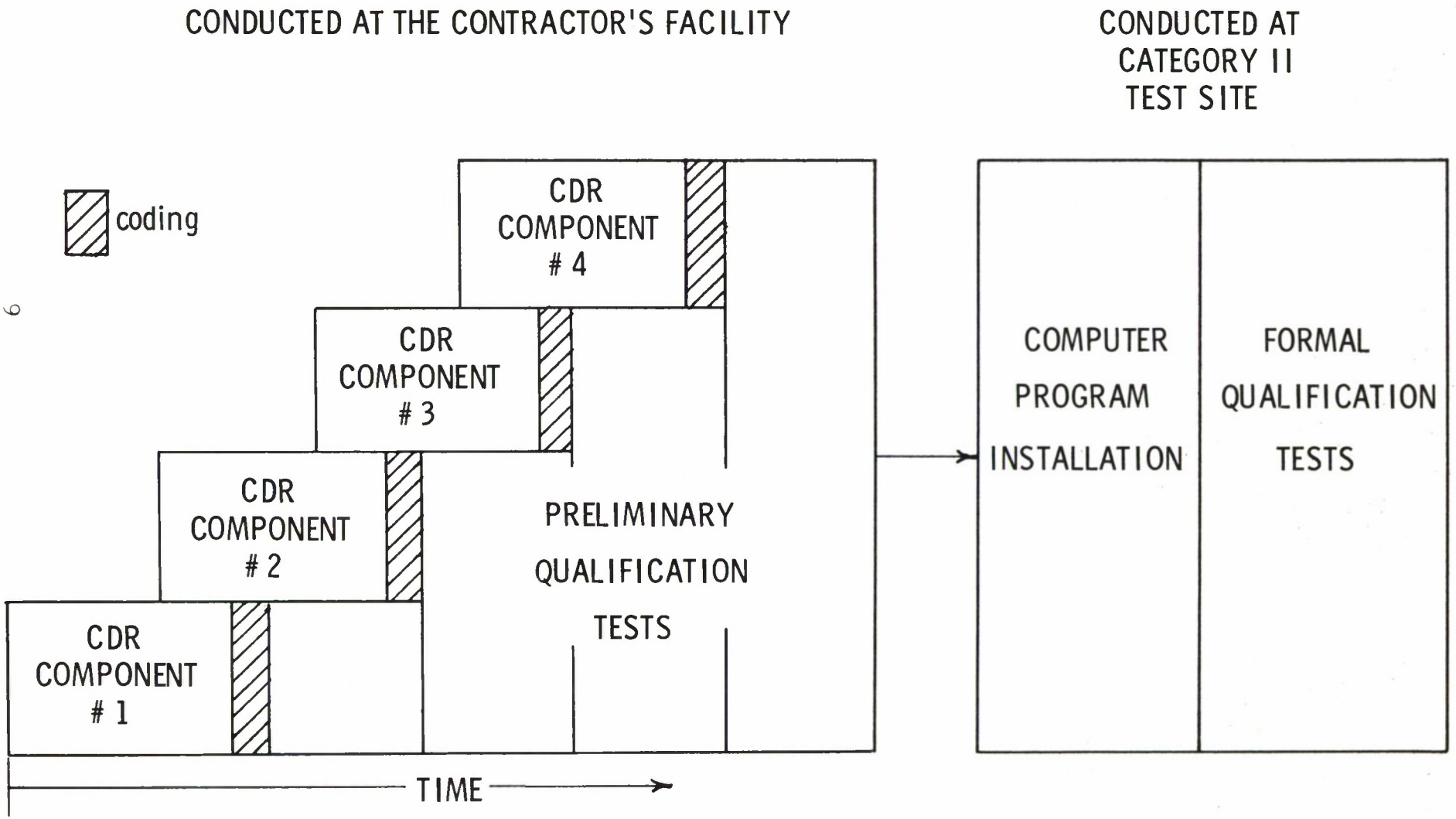

Figure 4

FORMAL QUALIFICATION TESTING

Qualification testing of a complex CPCEI requires extensive use of simulation techniques. The use of these techniques is dictated by the high cost of providing overhead computer facilities or by the unavailability of new computers undergoing a parallel design and development effort. Although PQT's will make maximum use of simulation techniques, the FQT's of an operational CPCEI will require live inputs, live outputs, and operationally-configured equipment. A prerequisite, then, of FQT is usually the installation and checkout of the CPCEI in an operationally-configured system at the Category II test site. The exception would be in the case of a support CPCEI such as a compiler that would require live inputs, e.g., radar data, and could be fully qualified at the contractor's facility. To provide reliable data during FQT, the CPCEI installation requires fully installed and checked out equipment CEI's. The first opportunity for FQT will normally occur at the Category II test site after equipment CEI's that have successfully passed First Article Configuration Inspection have been installed and checked out and an operationally-configured system exists. FQT is conducted subsequent to installation and checkout of the CPCEI. The conclusion of FQT signals the end of the Category I test program. The CPCEI will have been fully qualified and all of the requirements of the Part I specification should have been satisfied except for those requirements of the Part I specification that can only be demonstrated during a Category II system test. After successfully passing this phase of testing, the CPCEI is fully integrated into the system and is ready for system testing.

FIRST ARTICLE CONFIGURATION INSPECTION

With CPCEI design and testing essentially completed, Part II of the CPCEI specification is available for review. The Part II specification provides a complete and detailed technical description of the CPCEI "as built," including all changes resulting from prior testing. It will accompany the CPCEI to each installation or site and functions as the primary document for "maintenance" of the CPCEI. Consequently, the technical accuracy and completeness of the Part II specification must be determined prior to its acceptance by the Air Force. The First Article Configuration Inspection (FACI) provides the vehicle for the required review; thus, it is an audit of the Part II CPCEI specification and the CPCEI as delivered. The primary product of the FACI is the formal acceptance by the Air Force of: (1) the CPCEI specification (Part II) as an audited and approved document; and (2) the first unit of the CPCEI. Air Force acceptance of the CPCEI is based on the successful completion of the Category I Test Program and the FACI, but it does not relieve the contractor from meeting the requirements in the system specification. Subsequent to FACI, the configuration[7] of the CPCEI is essentially controlled at the machine instruction level so that the exact configuration of the CPCEI is available for Category II system testing.

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[7] Searle, L.V. and Neil, G. Configuration Management of Computer Programs by the Air Force: Principles and Documentation. SJCC Proceedings, 1967.

CATEGORY II SYSTEM TESTING

After acceptance of the CPCEI, the Air Force conducts an extensive Category II system test program with the objective of demonstrating that the total system meets the performance/design requirements specified in the System Specification. Insofar as the computer programs are concerned, Category II testing will verify the CPCEI's compatibility with the system elements and its integrated performance in meeting system requirements in the live environment, with operational communications, personnel, etc. Residual design and coding errors discovered in this phase of testing are corrected prior to the system becoming operational.

SUMMARY

The techniques for design reviews and testing presented in this paper provide a means of insuring the design integrity of computer programs during the lengthy design and development cycle. It provides the Air Force with technical control, at discrete phase points, which was not before available. To provide this control, existing Air Force Systems Command management techniques were assessed and adapted to computer programs. No attempt has been made to equate computer programs with equipments; rather, the requirement for similar technical controls has been recognized with due consideration for the inherent differences between computer programs and equipment. While these techniques were developed for computer programs within the context of large computer-based systems, they are and have been readily adaptable to small individual computer program procurements. More detailed information on requirements and procedures are included in ESD Exhibit EST-1 and ESD Exhibit EST-2, published by the Electronic Systems Division.

Though the above techniques have been used on contracts at ESD, none of the programs have progressed through the complete cycle. The limited experience to date indicates that the techniques are feasible, they do provide vitally needed Air Force technical control and visibility and, in turn, they have been useful to the contractors as a formal management scheme and a means for mutual understanding and problem resolution.

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Electronic Systems Division
Technical Requirements and Standards Office
L. G. Hanscom Field, Bed Ford, Mass. 01730

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b GROUP
None

3. REPORT TITLE
Air Force Concepts for the Technical Control and Design Verification of Computer Programs

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*
M. S. PILIGIAN
CAPT J. L. POKORNEY

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
APRIL 1967	14	7

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	ESD-TR-67-67
c. In-House Report	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	None

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	Electronics Systems Division L. G. Hanscom Field, Bedford, Mass 01730

13. ABSTRACT

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DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
systems management computer program testing computer program design reviews						

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