Air Force concepts for the technical control
and design verification of computer programs

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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 com­
puter programs within the context of a system.
Similarly, while extensive techniques for design con­
trol of system hardware have been developed by the
Air Force over the past five years, technical control
and design verification procedures for computer pro­
grams 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 investi­
gation 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 con­
tract end items 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 speci­
fications, 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 verifica­
tion is not available to evaluate the computer program
once it is developed. Generally, a one to one relation­
ship exists between Sections 3 and 4 of the specifi­
tion. 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 through the system and contract end item design
and development. Concurrently the specification
test requirements are the basis for subsequent test
planning documentation and system testing at both
the contract end item and system 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 con­
tractor 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 contract end items. Thus, for computer
programs, the SDR must insure that only those system
requirements that can be realistically satisfied by

*Phases as discussed here (i.e. Conceptual, Definition, Acquisition
and Operational Phases) refer to the 4 phases of the System Life
Cycle as defined in AFSCM 375-4, System Program Management
Procedures.
computer programs have been allocated to computer program contract end items (i.e. operational, utility, diagnostic, etc.). Prior to the conduct of the SDR, trade-off studies concerning equipments vs. 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 computer program contract end item 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 computer program contract end item is also reviewed at the PDR. During the initial design process for a complex CPCEI, 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 contract end items 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 computer program contract end item 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 computer program end item.

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 II are 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 computer program CEI 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.

Figure 3 - Test documentation

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. The Category I test requirements are further amplified in the contractor-prepared Category I 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 Plan. This document contains comprehensive planning information for qualification tests; complete with schedules, test methods and criteria, identification of simulated vs. live inputs and support require-
Conducted at the contractors facility

- CDR Component #4
- CDR Component #3
- CDR Component #2
- CDR Component #1

Preliminary Qualification Tests

- Computer Program Installation
- Formal Qualification Tests

Figure 4 - Computer program contract end item critical design review and Category I tests

Design Review. 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 Preliminary Qualification Tests 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 Preliminary Qualification Tests.

Parameter tests are those designed to prove that an individual sub program satisfies the detailed design specification, not that the program performs as coded. These tests compare the actual operation of each sub program against the design specification. Parameter testing usually requires a utility system incorporating sophisticated parameter test tools. These 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 contract end item 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 ready for formal qualification and acceptance.

Formal qualification testing
Qualification testing of a complex computer program contract end item 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 Preliminary Qualification Tests will make maximum use of simulation techniques, the Formal Qualification Tests 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 computer program contract end item. 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 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.

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.

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