The process of residue division has certain interesting properties and quite possibly has applications in respect to special problems. Unfortunately, the residue division process is not a substitute for normal division. It appears that the only way in which division can be effected in the residue code is by the utilization of techniques similar to those employed for division in a consistently weighted number system. The division process then requires trial and error subtraction or addition and the greater than or less than relationship. The division algorithm could also include trial multiplication, since in the residue system addition and multiplication require the same period of time.

Conclusions

The material of this paper forms a preliminary investigation of the applicability of residue number systems to the arithmetic operations of digital computers. The residue system has been found attractive in terms of the operations of multiplication and addition. It is possible to realize practical logical circuitry to yield the product in the same operation time as for the sum, since the product is not obtained by the usual procedure of repetitive addition. The main disadvantages of the residue number system are associated with the necessity of determining absolute magnitude. Thus, the division process, the detection of an overflow, and the determination of the correct sign of a subtraction operation are processes which at this stage of the investigation seem to involve considerable complexity. Nevertheless, many special-purpose applications are certainly well-suited to the residue code. In particular, there exists a class of control problems characterized by the absence of the need for division and the existence of a well-defined range for the variables, and also by the fact that the sign of the variables is known. For the problems of this class, the use of the residue code should result in a reduction of the over-all computation period and should yield a computer with a higher bandwidth than obtainable with the conventional number system.

The ultimate usefulness of the residue code will probably be determined largely by the success of the circuit designer in perfecting circuitry ideally suited for residue code operations.

The material of this paper is essentially Chapter 5 of the author's doctoral dissertation.[5] At the time of the completion of the dissertation, the author was unaware of the work of M. Valach[6] and A. Svoboda[7,8] in Czechoslovakia. Additional literature[6–8] was obtained from recent visitors to the Soviet Union. The author wishes to take this opportunity to acknowledge the work of Valach and Svoboda.

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System Evaluation and Instrumentation for Military Special-Purpose Digital Computer Systems

A. J. STRASSMAN† and L. H. KURKJIAN†

Introduction

TESTING and instrumentation are essential prerequisites for the completion and operation of any new system. A system can be defined as a number of components that are amalgamated or integrated together to perform a desired operation. Throughout this paper a "component" is considered to be a complete functional part of a data processing system such as an arithmetic unit or a buffer. To ascertain if a component in the system is going to perform correctly its specific function, it is sometimes necessary for the implementation of tests to be more complex than the component undergoing the testing. This becomes apparent when the component is a part of a large system and has many inputs and outputs.

To prove the system feasibility or operation of the components it is necessary to do either of two things: 1) duplicate and maintain an entire system and use it as one master test fixture to evaluate each functional component; or 2) provide individual test facilities for the evaluation of each of the functional components. The second approach requires the design of simulation equipment to provide the necessary inputs (control signals and data) to check out completely the operation of each

† Hughes Aircraft Co., Fullerton, Calif.

individual component. It is believed that this approach offers the greatest advantages for large special-purpose digital computer systems.

System Organization Determines Work Organization

It is necessary to provide the proper work organization for the evaluation of these computer systems. A differentiation can be made between small and large systems and the work organization can be adjusted accordingly. Although the basic philosophy of test remains the same, the details evolved for the testing or evaluation of a small system will be different from that evolved for a large system. Since the flip-flop is a basic element in many digital computers, the number of flip-flops can be used as an indication of the size and complexity of the system. For the purpose of this paper, in which the evaluation and instrumentation of a large system is described, a "large" system is defined arbitrarily as one that contains more than 500 flip-flops.

In the case of a small system, all the work can be handled by a small group which will perform the necessary tasks from system design to final evaluation. Fig. 1(a) shows the work flow for the "small system" organization. The work usually begins with a proposal outlining the new system. This is followed by system design, logical design, circuit design, testing, evaluation, and delivery. It is admitted that to be able to perform all the tasks included, the technical personnel associated with a small system must have a broader background than those required for the evaluation of a large system.

The actual limitations of time, complexity of large systems, and efficiency of utilization of personnel, necessitates the use of specialists in each specific work area to perform all the necessary tasks to complete the large system. Specialization is indicated by the fact that the system design is done by a group of systems engineers whose function is to define the necessary components needed to implement the system and their interrelationships. Logical design and circuit design are two functions that are performed in an analogous manner by logicians and circuit engineers who are specialists in their respective realms. The test and evaluation of the system is also handled in a specialized manner. Each component is assigned to a circuit or unit engineer whose responsibility is to 1) design the logical circuitry of the component from the Boolean equations, 2) design the test fixture, 3) write the necessary procedurals, and 4) test the component when it is fabricated.

Since a large system requires many individuals to complete these tasks, the question of communication between groups of specialists becomes a problem. This is an important item especially when the decision of one group vitally affects the work of another group or groups. To maintain a continuous flow of data in both directions which enables each group to perform their tasks more efficiently, information feedback loops are provided in the form of signature control and written

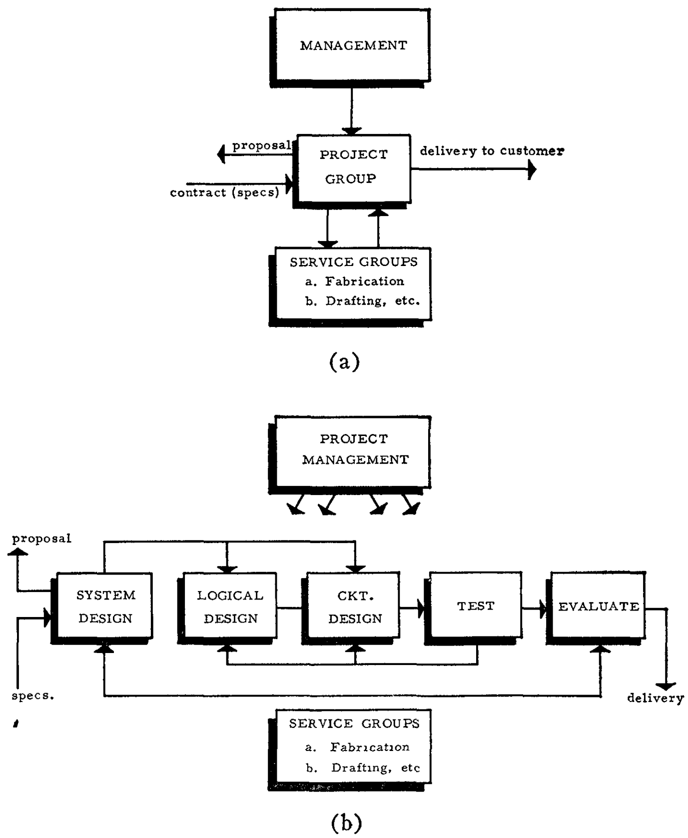

Fig. 1—Work organization for typical small (a) and large (b) systems.

reports. Fig. 1(b) shows the interrelationship of all groups from system design to delivery.

The philosophies contained within this paper led to the basic planning considerations for the test and evaluation of a large special-purpose military data processing system, parts of which will be described in later paragraphs. This data processing system contains approximately 1500 tubes, 2500 transistors, 250,000 diodes, and 3500 flip-flops. Each flip-flop in the system has four transistors, making a total of 16,500 transistors in the entire system. This qualifies the described system to be classified as a large system.

Types of Tests to be Performed for Evaluation

The basic parts of any large system can be broken down into five categories which are listed in their order of complexity: 1) elements, 2) units, 3) components, 4) subsystems, and 5) systems. If these basic parts of the system are evaluated and tested in order of complexity, the sequential building of testing integrity gives us the understandable advantage of solving small problems first before becoming involved with the intricacies and troubles inherent in any large system. The first type of tests to be performed therefore would be element tests.

Element Tests

The basic computing elements are usually flip-flops, logical followers, drivers, shift registers, diode cards,

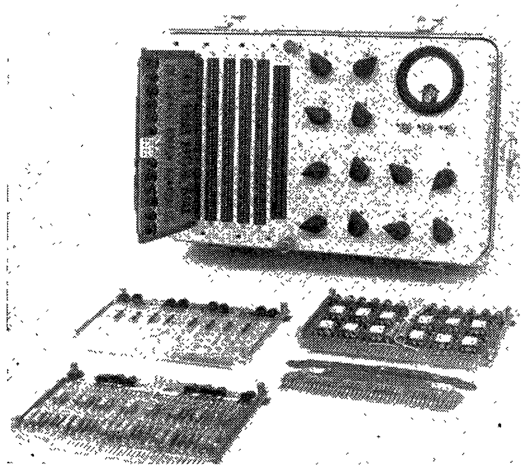

Fig. 2—Standard elements and standard element test fixture.

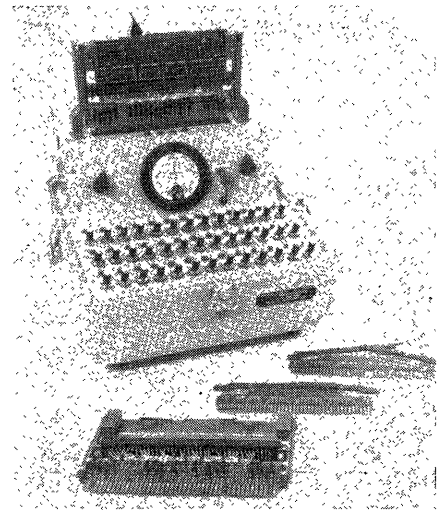

Fig. 3—Matrix assembly and matrix tester.

and pulse regenerators, etc. These items are referred to as "standard elements." The functional requirements of each of these standard elements determine the design of the test fixture necessary for evaluation. The test fixture for a flip-flop contains the necessary steering circuitry which makes the flip-flop a modulo 2 counter. When more than one flip-flop is built on a standard card, the fixture can be expanded to make the flip-flops count in any prescribed manner. Shift registers, followers, and drivers most commonly are evaluated by inserting specific computer word patterns at the input and observing the appropriate outputs. Simple sequential relay circuits are used to step through the forward and reverse characteristics of diodes on standard diode cards. Typical standard elements of a digital computer system along with a standard element test fixture are shown in Fig. 2.

The electronic implementation of the digital computer logic that is represented in Boolean notation is formed from the standard diode card and specific resistor networks on the matrix card assembly. The wiring of the resistors to the diodes on each individual matrix card determines its logical function. The logical function of each card can be statically evaluated by a "matrix card tester" which simulates each input term to the card. The output of each gate is monitored as logical true and false levels are placed at the inputs to the gate. A meter is used to indicate to the operator the result of the simulation of any of the logical terms under test. Fig. 3 is a photograph of a matrix assembly and a matrix card tester.

Unit Tests

Each module of the system under discussion is called a unit and contains up to twenty-one element cards. A unit module is shown in Fig. 4. The combinations of, and connections between, the elements in the unit provide a portion of an over-all computing function that is to be performed by the system. Evaluation of units is difficult because units are incomplete functional items

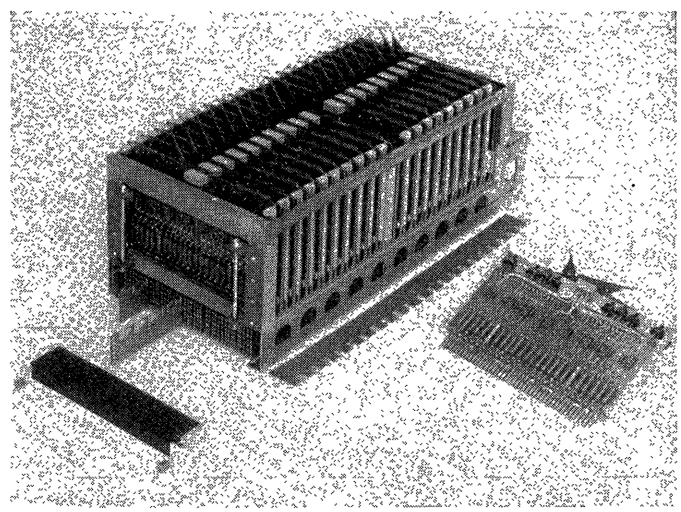

Fig. 4—Unit module.

and therefore the amount of simulation becomes large and complex. However, it is considered that this step in the system evaluation is critical. It is therefore necessary to ascertain that each unit has been tested to th maximum. This obligates us to perform the most exhaustive tests possible on the unit level within the framework of the computer. Provisions to accomplish this can only be done by generating ideal simulated signals that the unit would expect in system operation. This type of simulation has been achieved by the design of equipment referred to as the "unit tester." The unit tester provides combinations of static and dynamic signals to the unit under evaluation. All system timing signals, synchronizing signals, and data inputs are generated in the unit tester. Each connection in and out of the unit under test is available on a patch panel on the unit tester. The choice of four signals is available at each point. The point may be 1) connected to a logical true signal, 2) connected to a logical false signal, 3) connected to a special function (sync, timing, data, etc.), or 4) unconnected if it is an output of the unit that is to be observed. The unit test insures that the interelement wiring and the input-output wiring of the unit is correct and at the same time provides a semidynamic test to the various element configurations. Many of the logical functions can be completely evaluated during this phase of test. The unit test can be easily modified for production testing of each module by simple automation techniques. In Fig. 5 a unit is shown under test with the unit tester.

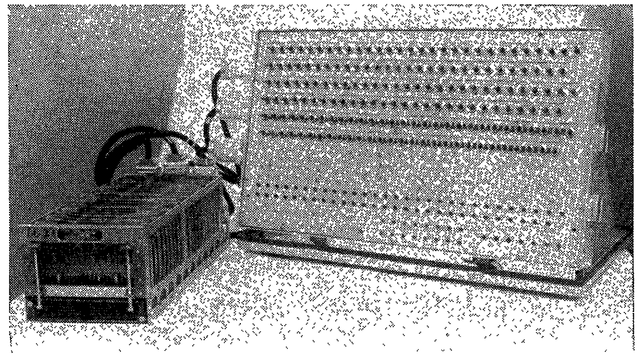

Fig. 5—Unit tester.

Component Tests

A system component is a unit or group of units that has been defined in the system to perform a particular computing or data processing function. Examples of typical components are the arithmetic unit, the various buffers, the computer controls, and the buffer controls. It is at this level that the simulation of external signals is very important, as the completeness of testing at the component level determines the ease with which it is possible to test and evaluate the entire system. The component test provides for the testing of all of the logic contained within the integrated units by means of external simulated signals. These external signals are developed by a special test fixture that is unique for each component. A component consisting of eight units mounted on its test fixture is illustrated in Fig. 6. The test fixture is designed to simulate the complete system to the component. This test is basically dynamic and as a consequence logical errors can be discovered during this phase of evaluation. The simulation equipment consists of the appropriate switches, function generators, and timing and synchronizing signals that the component would operate from if it were in the system. Procedurals are written which outline the detailed steps necessary to evaluate the component function as specified by the system design. This test actually proves or disproves the component logic with the test fixture as the system simulator. Both the test fixture and the procedurals are designed and written by the cognizant circuit or unit engineer who is charged with the responsibility of this component and has by necessity a complete grasp of the functional operation of this component. Typical examples of system components and an idea of their complexity are given in the following paragraphs.

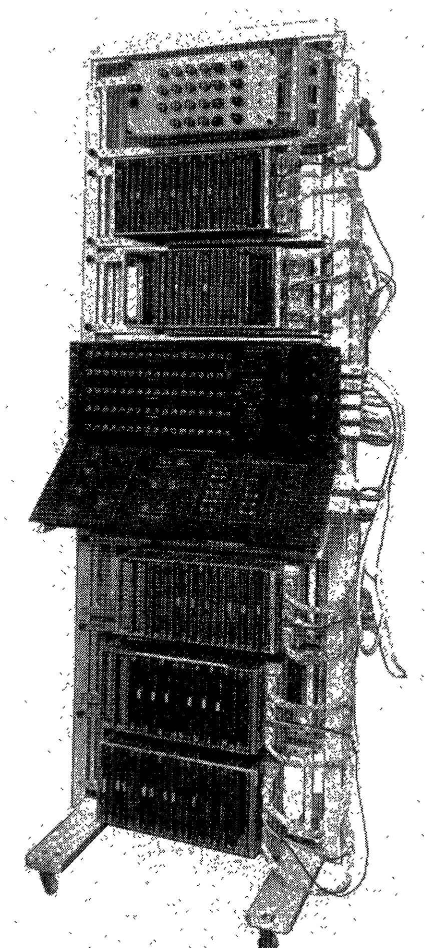

Fig. 6—Component test fixture.

1) The coordinate extrapolator updates coordinates on the basis of velocity stored in the memory. This component requires twelve flip-flops, eight logical followers, and 180 diodes. The logic written in Boolean notation consisted of three typewritten pages and the test procedural was nine pages long. The control and addition logic in this component were evaluated by means of a component test fixture which simulated the system input coordinate data, velocity, and time by means of variable word generators and counters.

2) The computer control is a special-purpose wired program computer that controls information from and to three arithmetic units. Its outputs include control signals and generation of appropriate constants needed during the various steps in the wired program. The component was implemented with 15 units which contained 148 flip-flops, 384 logical followers, and 6350 gating diodes. The logical equations in Boolean notation comprised 26 typewritten pages, and the test procedural was 114 pages long. The control signals and the terms of the constant generators were checked by a test fixture which simulated the essential control signals required to cause the computer to perform each program step.

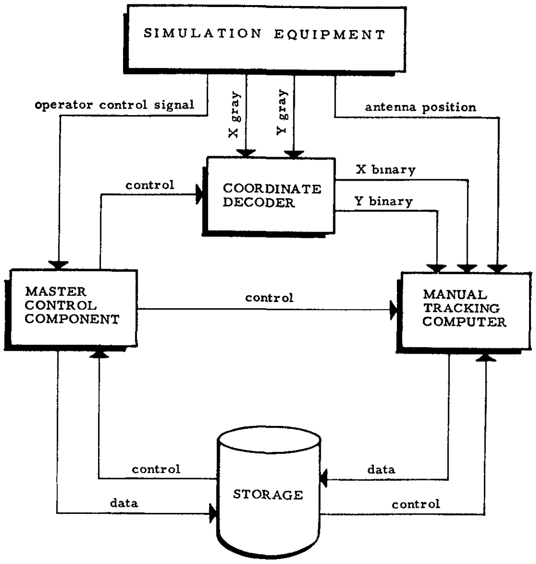

Fig. 7—Typical subsystem block diagram.

Subsystem Test

After the component has been completely evaluated, the next step for system completion is to integrate the components together into the various subsystems as determined by a logical sequential build-up. Fig. 7 demonstrates an integration of one subsystem consisting of four components. Simulation equipment needed in this phase is less than during component test. The example shows control and decoder components that have the facility for entering data into a special-purpose computer which steps through a wired program cycle and stores information of a magnetic drum. Parts of this information are used in the control component during system operation. This makes the sub-system a small closed loop within the system. Logical tie-in and timing errors can be found and solved during this part of system completion. Simulation equipment for subsystem test usually consists of inhibiting signals that affect the closed loop operation and generate all those other signals which are necessary to make the loop operate. In the example shown, X and Y coordinate data in Gray Code, simple operator control buttons, and radar antenna position signals were the only signals needed to be simulated. Parts of existing component test fixtures can be used during subsystem test as they contain the necessary simulation equipment.

System Test and Evaluation

This phase is the culmination of all the test and evaluation effort that has been performed previously. All the elements, units, and components have been proved to perform within the framework of the several subsystems and now it is necessary to prove complete system operation. This is done in two phases. Since the final military installation is a vehicle that has limited working space, a laboratory mock-up is provided. This mock-up as shown in Fig. 8 simulates the trailer installation as closely as possible, yet provides ample working space for many more of the engineering personnel so that much system testing and trouble shooting can be carried on simultaneously in many areas of the system. An additional advantage gained by this 2-step operation is provided by the ability to modify the final wiring installation as required as problems are encountered in the mock-up test phase. All system errors will be discovered in the mock-up phase and corrections can be made to the equipment before installation into the vehicle. Upon completion of the tests in the mock-up area, the equipment is then transferred to the vehicle and the complete system can be integrated with a minimum of personnel due to the fact that the system has been completely tested and all system errors removed. In fact, the only difficulties to be encountered are wiring errors caused by human inefficiencies. The vehicle interior working area is shown in Fig. 9.

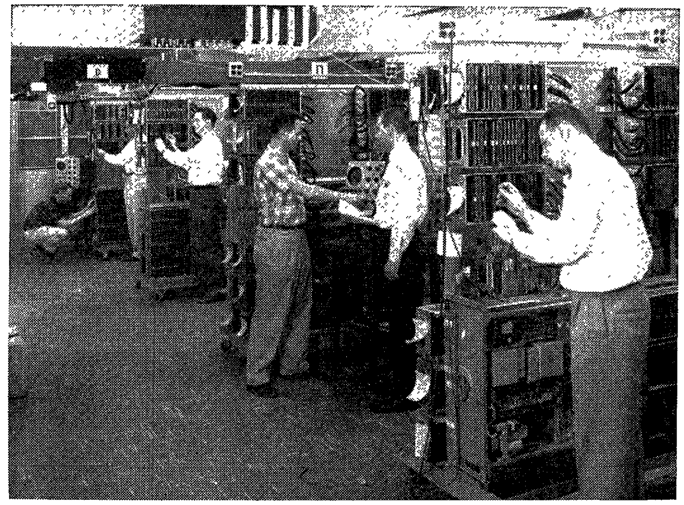

Fig. 8—System mock-up fixtures.

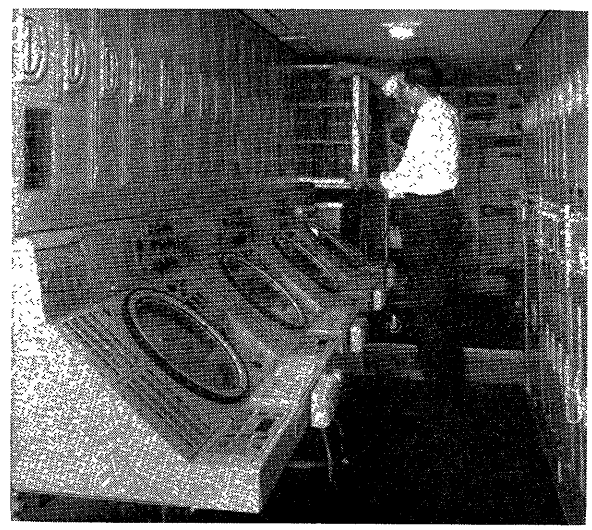

Fig. 9—Final system installation.

In the process of the design of the laboratory test equipment, many of the simulation concepts evolved are readily useful and on occasion can be incorporated into the system as self-test features. This equipment can be utilized in the initial system evaluation as well as later during normal test modes of system operation. Since the end user of this equipment will be military personnel, many self-test and automatic indicator devices were incorporated to decrease the training requirements for operation and maintenance of this equipment. Another requirement that is very often specified for military equipment is that of providing operation for 23 out of 24 hours. This fact dictates the requirement for having a very rapid means of performing operational and preventive maintenance checks by semiskilled personnel.

Military requirements include a controlled complete system test to prove that the system meets the initial specification. A comprehensive system test plan is most often written by the system engineers to test all the functions of the system. During this test only external system inputs must be simulated; following the test, the system is ready for operational use and field evaluation.

System Test Personnel Training

The previously mentioned steps in providing for sequential testing of all components up to the complete integration for system test and evaluation allow certain personnel to acquire gradually system knowledge necessary to perform efficiently and rapidly the complex task of testing such a large system. It is obvious that no one individual, no matter how magnificently endowed with mental powers, can be expected to understand all necessary details of such a complex system containing equipments involving such diverse fields as displays, conversion, and data processing. A plan was evolved for certain specialists to become facile in the over-all system concepts, yet utilize the certain portions of their specialty to a large extent as possible. This control is achieved in the following manner: in the initial design phases, each component or allied group of components is assigned to a cognizant circuit engineer whose responsibility during this phase is to design the logical circuitry for the component, or in the case of the display subsystem, to implement the original specifications. Once these data have been released for equipmenting and packaging, this same engineer proceeds to design and build the necessary unique test equipment for component evaluation. As part of this task the engineer also writes the procedurals to be followed in the testing of the component. This is the first step in causing the engineer to investigate external requirements of the component assigned to him. As the component is integrated into a subsystem area, it is necessary for the engineer to become more familiar with the input-output requirement of the adjacent components, so that, while he remains a specialist for his assigned component, his system knowledge must perforce increase because of interdependency of the components in the subsystem. Since all components have been completely tested, there need be only one engineer now assigned to each subsystem. The remaining component engineers, however, are available for consulting as needed. When all the components are finally integrated as a system, there remain but a few engineers necessary for systems testing, each with a broad knowledge, rather than many component engineers with limited specialized knowledge. Final installation can be completed more efficiently with a minimum of personnel.

Conclusions

It is apparent that any complex system can be tested and evaluated by a step-by-step instrumentation. Providing the necessary special-purpose instrumentation has proved to be more rapid and economical than the accumulation of general-purpose testing devices. In the testing of special-purpose computer components within a system, there are many instances in which general-purpose instrumentation devices would not suffice, no matter how much and how varied the instruments could be interconnected. In each of the stages of the system integration, particular classes of errors and failures can be uncovered. During element tests, electronic part failures and mechanical errors are discovered and corrected. After element testing, each element is considered operative and the troubles found in unit tests cannot be attributed to the elements. During unit testing, logical and timing design errors can be uncovered and intra-unit connections are ascertained to be correct. At the completion of the unit test, each unit is considered to be completely operative. Therefore, during the component test phase, any difficulties discovered cannot be attributed to the unit, but rather to logical tie-in errors between units and inter-unit wiring. Similarly, the problems within the subsystem test are related to only those difficulties encountered in integrating more than one component because of the completeness of the component evaluation. System testing is merely an extension of the previous statements, but now referring to problems encountered in integrating subsystems. The sequential building of test complexity gives us the advantage of solving small problems first before becoming involved with the intricacies and troubles inherent in any large system integration.

Finally, the experience of the personnel involved in the test build-up enables a better understanding of the system operation, thereby decreasing the time required to integrate a large system made up of many discrete and special components.