XI. 17

Oct 1963

PRACTICALITIES IN AUTOMATED MANUFACTURING CHECKOUT

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INTRODUCTION

A little over two years ago, Marshall Space Flight Center (MSFC) decided that the Saturn space vehicle checkout and launch programs should be automated by using digital computers for remote control and evaluation. This was a logical follow-on to programs which had been in existence about a year and a half at that time. One of these programs was the development of a computer controlled system for launch of the Saturn I. The other was the development of a system for automated manufacturing checkout of the Saturn I first stage at Marshall. These two programs had indicated that although there were many unanswered questions, it was both feasible and desirable to establish an automated checkout and launch for all Saturn vehicles.

Today there still are unanswered questions. However, through the efforts of four major stage contractors in the Saturn program, and the overall coordination of MSFC, many answers have been found, and many standardizations have been set forth. This paper will present a number of these solutions and standardizations, which I have chosen to call practicalities. It will also point to some others that are yet to be established. The paper to follow this one in the symposium will then pinpoint development items that are needed to allow us to automate more fully than we are able to do today.

PROGRAM SUMMARY

With the exception of the S-IV stage, the second stage of the Saturn I vehicle, all manufacturing checkout for Saturn stages today is either being controlled by computers, or, when checkout first begins, will be controlled by computers. (Chart I shows these stages and the computers used.)

The last S-I stages to be built at MSFC are under construction at the present time. This is the first stage for both the Saturn I and IB programs. Mechanical systems checkout is partially automated under computer control; electrical and electromechanical systems tests are almost entirely under computer control, and have been for approximately ten months, with highly satisfactory results. Effort is continuing to improve techniques and extend control further. Manufacture of this stage is now beginning at the Michoud plant in New Orleans; stage checkout there will repeat the pattern at MSFC. Checkout of this stage is the only instance in the Saturn program where a multiple computer complex is used.

As previously indicated the S-IV stage checkout is not automated. Although manufacture of this stage began well after manufacture of the S-I stage, the S-IV stage checkout was not previously performed at MSFC. As a result, there was no previous attempt to automate, and none will be made in the foreseeable future.

The Instrument Unit of the Saturn I, IB, and V vehicles is somewhat different for each vehicle; it contains the guidance and most of the tracking systems. These units are treated as stages, and are built and checked out at MSFC using the launch site computer. Neither of the computers used in the Saturn I or Saturn IB programs will be the launch site computer. All equipment for use at the launch site will be designed and supplied by MSFC.

In the Saturn V vehicle, there are three stages. The S-IC stage, to be built in New Orleans, will be checked out using the launch site computer. The stage will be mounted immediately upon the Launch Umbilical Transporter upon arrival at the launch site. Since the base of the transporter will already contain the MSFC-provided launch site computer and other launch equipment, this equipment will be used for immediate checkout of the S-IC. The Marshall automation program requires that checkout of individual stages at the launch site be as nearly like manufacturing checkout as feasible, considering the difference in facilities and geographical location. Therefore, manufacturing checkout of the S-IC uses the launch site computer.

The second stage of the Saturn V, the S-II, will undergo manufacturing checkout in California, utilizing the same computer for control and evaluation as the S-IVB stage. When these two stages arrive at the launch site, they will undergo checkout as individual stages, utilizing basically the same equipment as that provided for manufacturing checkout. Basic knowledge gained during the manufacture of the S-IV stage was used to create a stage which is larger and quite different from the S-IV stage. This is the S-IVB stage, originally intended for use only as the Saturn V third stage. Since the Saturn V program required that manufacturing checkout for all stages be under computer control, the S-IVB was included. It will undergo checkout under computer control, therefore, even when built to be the Saturn IB vehicle second stage.

STANDARD APPROACHES

Computers: In a program as complex as the Saturn program, it is most desirable, as long as capability and flexibility are maintained, to use completely standard equipment insofar as possible. This is particularly true in the case of computers for stage checkout. However, certain practical considerations dictated that not all stage checkout computers be exactly the same.

The previously existing S-I stage programs had provided a wealth of background experience and development. Checkout of the S-I stage, therefore, has continued with the same checkout system. It has several individual test stations controlled by a central computer complex which includes several Packard Bell 250 computers. The individual test stations are a grouping of stage interface equipment peculiar to particular stage subsystems.

The reason for choosing the RCA 110 launch site computer for the S-IC stage has already been indicated. It was possible to take a new approach with the S-II and S-IVB since these stages were under development at the time the computer was chosen. A computer was chosen which was later state-of-the-art, and which had more built-in features than previous ones. This computer, the Control Data 924, had inherent limitations with regard to input-output capability. When these limitations were discussed with the computer manufacturer, he proposed a modification to overcome the difficulties by providing buffered input-output registers. This resulted in the 924-A version of this particular computer.

We who have used computers in stage checkout realize that all things cannot be done with computers. To assume that a computer is a magic wand, rather than a complex, flexible, and advanced tool for stage checkout, would be a serious mistake. Unfortunately, this mistake is made by too many management people.

Since the use of computers for stage checkout is comparatively new, test procedures controlled by computers are quite similar to manual checkout procedures. Consider the following example however, to see improvements gained by the use of computers.

> A particular test on the Saturn I stage requires gimballing the rocket engines individually in increments of a few degrees and reading the static position feedback voltage at each position. Since there are a large number of steps for each engine involved, and a total of four engines to be tested, the entire test normally took, using manual equipment, about two and a half days. This allowed one reading per step and data was manually reduced. Approximately twenty steps gave twenty pieces of data per engine. When computer controlled stage checkout began, the entire test was finished in a few hours. Performance of the test took less than an hour. Additionally, thirty data points were taken at each engine position and averaged to obtain the best value for that position. Instead of twenty data points per engine, six hundred were obtained. If the test is rerun, it is certain that it will be repeated exactly as before.

Displays: Display of information during stage checkout is of particular importance at this stage of our steps toward automation. Each stage is somewhat different from other stages; different information requirements therefore exist during checkout. Further, information to be displayed is determined, to some extent at least, by the type organization doing the stage checkout. MSFC requires that information be presented to the test operators so that it may be read and interpreted in familiar terms and so that operators may judge the test and develop a "feel" for the operation. Except for certain special situations, this obviously precludes the presentation of checkout data in such forms as binary or octal code. The checkout equipment proposal of each stage contractor is reviewed carefully and in detail by MSFC to determine that the information presentation capability is both sufficient and satisfactory.

Two types of information display equipment are being provided: standard items such as lights, meters, and in-line indicators; and cathode-ray tube (CRT) displays. (See Figure 1.) Almost everyone who deals with the general problem of stage checkout using computers believes that CRT displays, generally in alphanumeric form, are desirable. This may be more a matter of experienced engineering judgement than a particular knowledge or expectation of many individual things to be presented on the displays. Great inherent flexibility exists in the combination of a CRT display and the programming capability of a computer.

Those who propose to use CRT displays think in the direction of what can be presented, and what the display is able to do. Little is said about what is mandatory for the checkout. This is true of experienced people both inside MSFC and among stage contractors. For this reason, the ground rule for the Saturn automation program on CRT displays is that they will exist, but will have limited initial use. The three Saturn V contractors are pursuing slightly different approaches with displays in their own programs. Effort has been limited, however, to allow each stage contractor to develop and build a single display which will be used in his mockup facilities. He will test the entire stage mockup together with its automated ground support equipment. When all displays have been demonstrated and used, determination will be made as to whether such a display is needed at all, and, if so, which is the best approach. It will then be possible to apply that single approach to all stages.

Ground Equipment Testing: Experience at Marshall has indicated that it is essential that a complex of stage checkout equipment be tested after installation as it is assembled and mated with the local facilities, but before the stage is connected. This will be done using a Ground Equipment Test Set. The Ground Equipment Test Set is a comparatively simple device, basically manual in operation, which serves as a stage interface substitute for use with the stage checkout equipment. It consists mostly of relays, lights, and patch boards, and has allowed for satisfactory checkout of an automated complex. Its simplicity and use of common equipment keeps the cost of such a device quite low and makes it additionally attractive. Doubtless, much more elaborate and complicated equipment could be used to do the same job. The simple approach, however, proved to be definitely acceptable and by far the least expensive.

Data Acquisition: In order to provide improved information transfer from the Saturn V vehicle, it was decided some time ago that Pulse Code Modulated (PCM) telemetry would be utilized. Consideration of stage checkout caused a further decision to extend the system to allow information to be brought out from the stage on a coaxial cable through the umbilical connectors. This permits a more complete evaluation of the instrumentation system of the stage, particularly during launch pad operations, than was previously possible. This approach utilizes the front end of the PCM telemetry system, and is called the Digital Data Acquisition System (DDAS). The design approach to the airborne and ground equipment for this system has been standardized, and established by Marshall as policy for the Saturn V. (See Figure 2.)

Proper calibration of the flight instrumentation system, to insure the best in accuracy and completeness of information, requires more elaboration in performing instrumentation checkout than most organizations are willing to give. Use of the DDAS allows for this necessary elaboration of testing without requiring extra connection of test equipment into the stage. Further, provision is made in the airborne instrumentation system that, during a semi-static situation such as a stage checkout, information from other telemetry systems can be transferred to the ground by means of the DDAS, where the response in this semi-static condition is within the capability of the DDAS.

It was originally expected that the DDAS would provide much information for evaluating stage checkout, even though each instrumentation transducer to be used as a data source for stage checkout must be calibrated prior to checkout use. Recent studies have indicated that reliance upon data from flight transducers is minor at the present time. Whether this is because a previous calibration cycle is necessary, or because of the present difficulty of accessing stage information has not yet been determined. Where orbital checkout is necessary, reliance on flight transducer information is essential. At this time, however, it is not possible to accurately predict whether the DDAS will merely enhance the calibration of the flight instrumentation (which is saying a lot in itself), or whether, in addition to that, it will greatly aid access of information for stage checkout.

Discrete Signals: Much information that is used for evaluating stage status during checkout is derived from discrete, on-off type signals. This alone indicates that use of the Digital Data Acquisition System will not be as extensive as previously thought. Nevertheless, the problem of accessing, recording, and evaluating the discrete or event signals is a major and a serious one. Almost everyone in the missile and space industry relies today on drag-pen recorders which change level in some fashion to indicate an "on" or an "off" condition. When recording five hundred to one thousand discrete channels is required, especially during a launch, the problem of evaluating these recordings becomes monumental.

Several years ago, it was realized at Marshall that this problem was becoming more severe, and that it would be desirable to have a device which could digitally record channel number, whether the event switched "on" or "off," and the specific switching time. A market survey was conducted, and no such device was found. Therefore, specifications were written to allow for development of such a device. Results of the initial development proved highly satisfactory in use. Unfortunately, the device itself was unreliable, and therefore, a second effort is currently underway.

Much thought has been given to providing the capability for event recording within the checkout computer itself. However, the record must, in general, be accurate to about two milliseconds; five hundred to one thousand channels of information are necessary for a major stage checkout; during certain periods major events occur, such as simulation of lift-off, which produce a number of simultaneous changes of state.

Discrete recording alone would occupy almost the entire time of the checkout computer. Requirements for one or two millisecond resolutions and absorbing simultaneous changes of state make this development most difficult. Present direction to stage contractors, therefore, is that drag-pen recorders will continue to be used for event recording until a device has been developed and proven by Marshall for this use. Instructions will then be given to stage contractors to change to the new device.

The use of a digital event recorder will greatly aid in recording of running or cycle time on flight-critical hardware, since switching for this hardware can easily be incorporated into event channels. Further, if access to the computer for off-line updating of time information is provided, either through direct cabling or through use of magnetic or punched paper tape, evaluation, updating of historical records, and other valuable information processes will be simplified considerably.

Initial Operations: As previously explained, in the beginning automated checkout procedures and operations will closely resemble manual operations. This was true in the initial programming and operation of the S-I stage automated checkout at Marshall. The enormous capability and flexibility of computers, however, provide the ability to go well beyond this. It may be confidently expected that this extended use will proceed at a rapid rate, once test organizations have begun to use computers. A standard requirement of the Saturn automation plan is that the operator be provided controls and displays that are nearly as flexible as in a manual system. It is fully intended, however, that the computer be in control of both stimuli and evaluation of responses.

For example, requirements have been incorporated for what has been called "local control." This allows the operator, upon receipt of a manually switched "permission" from the test conductor, to control his stage interface equipment locally. By manipulating switches, he follows the same control route within the test station as the computer. He may accomplish nearly anything of which that particular test station is capable. The intent is to fully automate, and yet, at the same time, provide sufficient flexibility that test organizations can retain a great deal of confidence in their flexibility and capability to react to emergencies.

Mockups: A further standard approach to automating of the Saturn V stage checkout has been to allow each stage contractor to provide or have access to a mockup facility. This includes a mockup of his stage, and an actual installation of all his electrical stage checkout equipment. The extent to which the mechanical stage checkout equipment exists in the mockup is determined, to some considerable extent, by the elaborateness of the stage mockup. Reproduction of much of the propellant-sequencing mechanical system in the stage mockup is desirable. This allows proving the performance of the automated system with the stage system, and further permits solution of those built-in timing problems which cannot be foreseen but which, particularly in a computer operation, must be covered.

For example, during automated instrumentation calibration of the S-I stage, the stimulus applied by the computer caused a periodic change in transducer conditions, requiring a settling-out time before a reading of the return signal could be taken by the computer. If the reading was taken prior to the settling-out period, the value was incorrect in almost every instance. The computer speed is high, and the computer is quite capable of taking the reading too soon.

Proving-out of stage checkout procedures is also possible and desirable before stage checkout begins. It is not absolutely essential, as long as considerable care is taken with the first live stage checkout. No mockup facility for the S-I stage or its automated stage checkout equipment existed; the first real proof of operation of the equipment took place on a flight stage. A mockup facility, however, provides a very good insurance policy.

WHAT TO LOOK FOR IN A COMPUTER

A test operator performs many actions without consciously thinking of them. For example, when the power supply is switched on, a quick glance at the meters indicates that the voltage has risen to the proper value. If so, the test proceeds. If not, corrective action is taken before proceeding with the test. This is true of many steps within any test procedure. The English-language version of the test procedure need not call this out, because the operator has done it many times and knows what to do without thinking. Unfortunately, a computer does not think. Therefore, the test engineer must provide all necessary thinking for the computer in advance. In many respects this is good, because it forces him to think through troublesome situations before they arise. He then builds a provision into the computer program for an alternate routine in case of anticipated difficulties or symptoms. The problem can then be solved, or at least isolated, by the alternate routine. To provide this in a language useful to the computer, however, is a different problem. For one thing, the language which the computer speaks is extremely precise. This, to say the least, is not true of the language which the test people speak. Nevertheless having worked together for some time, they can communicate with reasonable effectiveness, although their wording is not, perhaps, as exact as it might be. Conversion, then, of the actual thoughts of the test planner must be performed so that the machine can do its job properly. The easier this conversion can be made, the more likely the job is to be done properly.

Besides the conversion, there are operations which are sometimes more than just iterative and/or just series operations. They could become complex, even when carried out manually. Some tasks which must be accomplished with equipment which is, in effect, in parallel with the automated equipment, so that one part of the task is accomplished manually while another part is accomplished automatically. Any one of these things could cause difficulties. When one must consider all of them together, which is true in every stage checkout, then ease of computer programming becomes a primary consideration. Computer commands which accomplish a multiple function are important because of saving computer steps. A single command, for example, to allow a readout and a high-low comparison would be preferable to a requirement for a command for the readout, a second command for the high, and a third command for the low comparison. Further discussion of programming will follow in a subsequent paragraph.

System Control: Another important consideration for a checkout computer might be called "fingers into the system." Even a fast computer which consumes much time in information transfer into and out of the machine, is inherently limited in control or supervision of a system. In a space vehicle stage checkout, many things occur simultaneously, particularly during simulation of the flight sequence; commands must be given rapidly and readings taken quickly. The computer for stage checkout should have as many paths as reasonably possible into the control of the system itself. The total number of paths probably could be specified for any particular task, and then built into a single machine; but what is optimum for one situation is not for another. Marshall experience has indicated that a single path is definitely not satisfactory. Three, to perhaps as many as ten or twelve, would be the optimum number of paths for a control computer for stage checkout.

Simultaniety: A further desirable feature, and one which ties in almost directly with the previous paragraph, is that capability of the computer which is generally referred to as simultaneous read/write/compute. The checkout computer should utilize a small percentage of its time to bring in or send out information. A benefit realized during stage checkout from this capability is ability to control and manage several systems, or several parts of the same system, simultaneously. A computer with comparatively few paths into the system can gain, effectively, additional paths through having simultaneous read/write/compute capability.

Memory: Much can, and has no doubt, been said with regard to the memory of computers. Work is continually going forward to improve computer memories, to reduce their size, and to do other things which would optimize them. There are three outstanding features which should be considered in terms of memory for a checkout computer. Considering further the discussions in the previous two paragraphs, that computer memory which is most immediately and directly accessible is that which is the most useful. The memory operation is for the ultimate purposes of system operation, and is one which might be considered "overhead." Memory accessibility, therefore, is the first important memory feature.

A second important memory feature is that it be permanent. Frequently during a stage checkout, situations arise which require a quick switch-down of power, or which, perhaps, blow major breakers in the electrical system and cause power to be lost. In bringing power back on to the system, great care must be taken to see that all things are in proper order so that the stage is not damaged or destroyed. A computer which has a memory which can "lose its mind" upon loss of power, can make this situation very much worse.

The third important memory feature of a checkout computer is size. This feature is almost inseparable from ease of programming. The memory capacity of a checkout computer must be able to hold necessary executive routines, trouble-shooting or other types of subroutines, and to hold the test to be performed and that data derived from it and used in it. The more auxillary equipment external to the computer which is used, such as cathode-ray tube displays, line printers, magnetic tape transports, and typewriters the more memory is required to manipulate these devices.

Speed: Considerable emphasis has been given to the speed of computers. In a checkout computer, speed has considerably more significance than just a reference to the clock-rate of the computer. There is always a problem of how much electro-magnetic interference can creep into any system which is as diverse and as scattered as the checkout system for a stage. This becomes more true when digital signals and digital speeds are involved. Therefore, as the clock rate of the computer goes up, one could expect more difficulties with checkout computers. A clock-rate of approximately two megacycles has not yet offered much difficulty.

In most cases, the computer will be sufficiently fast that it is waiting on the stage system under test. The stage system, being mostly an electro-mechanical system, is naturally much slower than a computer. On the other hand, if event recording within the computer is attempted in addition to all other things, the point of external-to-internal power transfer or simulated lift-off causes many discrete events to occur simultaneously. The speed of the computer then becomes extremely important in the terms of the clock-rate. This is worse still when calculations must be performed or detection of a certain event within a particular time frame is necessary for sequencing. Speed in a checkout computer, therefore, is closely interwoven with ease of programming, paths for system control, simultaneous read/write/compute, and memory access time. It is additionally affected by the magnitude of the task to be done internally, as opposed to the external tasks, such as event recording, provision for external equipment to have internal storage, signaling, refresh rates (in the case of displays), and so on. Speed must be a rather fine balance between, not only the capability of the computer and its clock-rate, but the expected environment in which the computer is to operate with regard to electro-magnetic interference and external equipment capability. A new system design can obviously provide more external capability than an old one upon which a computer is superimposed for control.

Reliability: Certainly a major factor in a checkout computer is reliability. In terms of stage checkout, reliability also tends to acquire a different meaning from that for a computer in other applications. In the first place, space vehicle programs are low-volume, high-complexity programs. Until space technology evolves into a true transportation system similar to the airline systems, space programs will be operated by highly skilled, technically trained people. In this situation, those who are using the computer or who are benefiting from its use are technically skilled and are therefore capable of taking into account, not only the intricacies of the computer itself, but perhaps also its reliability quirks. Further, a daily self-check program, to any necessary level, can be performed on the computer to establish that it is operating reliably. Experience will indicate the time that continued reliable operation can be expected. Experience with stage checkout computers at Marshall Space Flight Center has indicated excellent reliability.

The greatest fear of the checkout man who has not used automated equipment previously is that something will happen to this equipment during a test to cause an emergency condition which he cannot control. The precautions which one usually takes with any type of checkout equipment are the type precautions to take with computers in checkout. The results, in terms of reliable operation during a particular test, are quite satisfactory. Manual stage checkout equipment which has been used for many years is equally susceptible to having emergency fault conditions cause a checkout crisis. Computers are assembled with printed circuit cards, generally of silicon, and are very regularly checked for proper operation. The frightening part of computer use to the checkout man is, first, that he is, generally speaking, not as acquainted with computers as with previously used equipment and, therefore, does not know what to expect; and second, a computer appears to be at least somewhat more complex than the equipment he normally uses. Once again, he does not know what to expect. His real fear, therefore, is of the unknown, rather than fear of something which could happen to him with computers but not under his present circumstances.

THE "INTERFACING" APPROACH TO STAGE CHECKOUT

It appeared some time ago to be desirable to have equipment for checkout of individual stage subsystems at a single location and within a single group of cabinets. This single group should be all necessary equipment for a subsystem. Subsequent experience has indicated that a somewhat different approach will probably give, in many cases, more desirable results. This approach I have called the "interfacing" approach to stage checkout. This term simply means to consider all interfaces needed for the stage checkout equipment and design for interfaces rather than equipment grouping. (See Figure 3.)

In an automated checkout, there is a stage to be checked out and a computer to control and monitor this checkout process. All equipment used other than stage and computer is defined as stage checkout equipment. The stage checkout equipment, therefore, interfaces in three ways: with the man who is monitoring the checkout, with the stage, and with the computer. In the original concept, all three of these interfaces for a given subsystem were a single physical group of equipment mounted in a single physical group of cabinets. This concentration is not essential as long as each of the three interfaces is provided for each stage subsystem. The stage interface equipment, however, for a particular subsystem should be grouped within a single group of cabinets physically located adjacent to one another, insofar as possible. This will simplify trouble-shooting greatly. This is a natural result of good design in most cases. Let us then attempt to determine those things which are practical with regard to these interfaces.

The Stage: First consider the stage interface. Stage design has evolved from a series of compromises, beginning with the mission of the flight of the entire space vehicle. The mission has caused decisions for optimum staging, and these have determined how many stages must be used. The number-of-stages decision has then bracketed the nature of each stage. Definition of individual stages and the entire vehicle have determined a pattern for how the vehicle will be launched. Design of individual stages can then progress, based on the determination of what a particular stage must be like, and how it must be handled during the launch operation.

Manufacturing checkout must determine, among other things, that the stage will mate properly with launch site equipment. Manufacturing checkout equipment then must be determined by launch considerations and by the individual stage itself. Some things aboard the stage will be designed in a manner to facilitate utilization of digital equipment; other things will be designed along the older and more conventional patterns, and use of digital equipment for these will require some type of conversion. Launch considerations will further determine types of stimuli to be put into and received from the stage umbilical connectors. The pattern for the stage checkout equipment interface with the stage is then established, based upon all of the listed considerations.

In many cases the most desirable provision for performing a stage test will not be built-in aboard the stage, because a compromise has been necessary in the stage due to weight, environmental conditions, safety considerations, or other things. The stage checkout equipment which interfaces with the stage will be an aggregation of some digital systems and some analog equipment. All of this will interface with the stage through the stage umbilicals, and, since we are speaking of manufacturing checkout, through other test connections.

Use of test connections other than normal stage umbilicals may meet with some disagreement. It would be more desirable in all checkout to connect the stage umbilicals as for a launch. The capability for this, however, will be determined almost entirely by what checkout provisions are designed into the stage. If full capability for accomplishing manufacturing checkout were designed into the stage, umbilical-only connecting would be possible. Even then, however, one would have to consider mating with the other stages. Proof of mating capability requires a connection at the forward and aft end of the stage to some device which simulates the interface between the stage under test and the adjacent stages. Since the purpose of this paper is not to discuss in detail the desirabilities for doing a proper stage checkout, let it suffice to say that we will assume that connections other than umbilical connections are necessary.

The Computer: Inherent capabilities of the checkout computer determine much of what must exist in the stage checkout equipment. Those checkout capabilities required which cannot be supplied by an overloaded or inadequate computer must be supplied in the stage checkout equipment. What is supplied there will reflect directly into the interface of this equipment with the computer. An additional consideration is what information must be presented to and commands taken from the man controlling the testing.

A simplification of the computer interface may be obtained by building the stage checkout equipment with basic digital hardware, such as printed circuit cards and so on, obtained from the computer manufacturer. This can eliminate logic level conversions, word structure conversions, and other like things. However, equipment previously used by the stage manufacturer on other programs may already be available and require minimum modification for use in the current effort. These, and other considerations such as schedule time and cost may well dictate a practical engineering compromise to use available hardware, even though it does not match directly with the chosen computer.

As a general consideration then, it is safe to assume that a computer interface device, to be connected between the computer and stage checkout equipment, and to provide necessary conversion, will be used. This compromise, however, provides a happy side benefit: Exchange of the interface device, as appropriate, allows different computers to be used in other locations if necessary, as long as the minimum computer capability required in the original design is supplied. This does not negate the fact that it is always more desirable to have manufacturing checkout resemble launch site operation as nearly as possible to insure a successful launch operation. It does, however, offer an approach which permits other considerations.

The Man: The degree of human participation, in any individual case, will determine the nature of the interface between the man and the stage checkout equipment. This interface looks in two directions for control and information: toward the stage checkout equipment, and toward the computer. As previously indicated, present experience of checkout people with automated, digitized equipment is very slim. Therefore, computer contolled stage checkout today is quite similar to manual operations. In the man interface there is much display equipment, in particular such things as in-line readouts, lights for discrete indications, cathode-ray tube displays, and other sources of visual information. It also provides for taking over test control under certain circumstances, in particular those which are concerned with safety. Direction to Saturn stage contractors has been along conservative lines. Hard wire connections are provided for safing functions, with positive, manual, over-riding initiation. In all tests, provision for trouble-detecting and trouble-correcting subroutines will be made within the computer. If indications are received that an unsafe condition is about to occur, the computer will jump to a subroutine to save the stage. In most cases, the speed of the computer will have the stage in a safe condition before the operator recognizes that an unsafe condition has existed. Regardless of this, however, it is necessary to provide, first, for the possibility that the unsafe condition may not have been conceived previously, and therefore allowed for in the computer programing, and second, that some item of digital equipment will fail and that the human can intervene to save the stage. Even if the manual safing equipment is never actually used, it provides that extra margin of confidence for operator assurance that his system is completely under his control.

Those things which are true of safety are no doubt true of other controls and readouts which appear, at the present time, on the man interface to the system. That is, whatever is provided in the computer program in the way of stimuli, recognition of sequencing, evaluation of data, and so on, will probably be handled more quickly and more efficiently by the computer, and at such a speed that the human will only recognize after-the-fact that it has been handled. This is clear from Saturn automated testing already under way. Further, as anyone knows who has conducted tests on large stages, there is a certain "feel" about a test which, after the test has run, allows the operator to judge its relative success. This "feel" is developed through a number of things, including glances at individual instruments, patterns of light indications, general sounds of the test as it progresses, and so on. A test performed in complete isolation, with no indications, meters, or sounds, would delete this capability. Although it is inexact, and certainly not subject to hard engineering scrutiny, the experienced operator recognizes this valuable tool for addition to the concrete data for test evaluation. This is more particularly true when a test is not satisfactory; the "feel" of the operator can then guide the trouble-shooting activity.

In beginning to automate a stage checkout, therefore, experience indicates that definite provisions should be made for operator control, operator override, and operator information reception. These, in turn, build operator confidence so that he begins to place more trust in this new and highly complex test device, the computer, because he can see with his own eyes that it is actually doing its job properly. Having this confidence, he then will begin to devise new means of using it, and as a result will move more toward full use of the capability of the computer.

External Equipment: The general tendency with Saturn automation has been to attempt to have external devices which can stand on their own. For example, in cathode-ray tube displays, such things as automatic refresh, internal storage, internal character generation, and so on, are almost essentials. As computer use increases, and as use of the capability of computers increases, as it will do when people become accustomed to them, external capability will become even more important than at present. Tests will be combined, so that several of today's tests will be run as a single sequence. The more that is to be accomplished in any single test or test procedure, the more capability is required, given a specific computer.

PROGRAMMING FOR CHECKOUT

One of the areas which has caused a great amount of concern in providing automated stage checkout has been how to provide necessary computer programs so the computer does its job properly, and to insure that it does not fail to do necessary things, particularly in the case of an emergency situation. Much of this concern, no doubt, has been the result of a lack of understanding as to exactly what was involved in computer programming and the capability of this programming by people who have had a good knowledge of operational systems and flying stages. As computer use has increased, and particularly in industrial-control type applications, more and more engineers have received training which provided fundamental knowledge of computers and computer programs. This basic training, together with systems knowledge from experience, has aided greatly in establishing the fact that because a computer operates only with ones and zeros, it is not necessarily incapable of doing complex tasks in stage checkout. A gap, however, still exists between the computer programmer and the systems engineer responsible for a stage checkout. At present, it appears easier to train the programmer in systems, than it is to train the systems engineer in programming. Unfortunately, most automatic checkout programs are needed in a hurry. The necessary time-consuming cross training to insure good communication between the test engineer and the programmer simply is not possible. A basically different approach is needed to establish means whereby the thoughts of the test engineer can be translated most directly and placed into the computer program to do the checkout task properly.

Within the Saturn program there are three different computers being used. Presumably, for future programs a more advanced computer can be used, if available. If not, one of the present computers will, no doubt, continue to be used. In either case, a desirable feature for computer controlled checkout would be a single language which could be spoken by all persons concerned with checkout and operation of the computers, and in which all words and phrases would mean the same things to all people. Further, the problem of translation of this language into the language of the computer would then be greatly reduced.

A start toward the solution of this problem has been made at MSFC. A programming technique has been developed for sequential tests which requires only two computer programs to be written for each combination of computer and checkout equipment. The two programs may be considered to be translator operations.

The first step in writing a test procedure with this technique is for the test engineer to set down, on a standard form, the steps he wishes to accomplish, together with specific information concerning each step. This is then punched into cards, and the card deck is fed into the computer in an off-line operation. The first translator program is used in the computer to provide a conversion and produce a punched paper tape. It also produces a printed copy of the test which may be used by the test engineer for verification, and for following the test as it is performed. The second translator program is then loaded, and, in an on-line operation, the tape is played into the machine. The translator converts the tape steps directly into system actions.

This technique has been used for two different types of computers, using the exact same format for getting information from the test engineer. Obviously, variations to the procedure are possible. The significant advantage is the need to write only two computer programs for each combination of computer and stage checkout equipment. Once these are established as correct, any number of tests may be written without further dependence on programming. Test modifications may be easily made ahead of time by exchanging cards in the deck before going through the first translator routine.

This type of programming has been used successfully with sequential tests where the next computer operation is dependent on receipt of a time-bracketed signal indicating that a previous operation has been successfully accomplished. It has not yet been possible to apply this approach in a completely satisfactory manner to the type of testing in which the procedures are largely iterative, as, for example, instrumentation calibration. Further work is being done with reasonable success in an attempt to extend this technique to make it more universal and, therefore, more useful. Obviously review of test procedures for correctness and sufficiency is made much easier by this method.

Once the two translator programs are established, they are fixed for the particular computer and set of equipment, and do not change. If it is established that these programs are correct, it is then only necessary to verify that the form which is filled out by the procedure writer or test engineer contains the necessary and sufficient information to perform the test as desired.

Another desirable feature for programming of computers for stage checkout is a technique within the programming method which will allow for ease of on-line change. During the time that a test is being performed it is frequently found that something is not performing properly, that some particular piece of flight hardware has been changed and the new hardware has different parameters, that the characteristics of some particular piece of flight hardware is different from a previous one, that some modification has been installed into the system since the program was written, and so on. Changes in the test procedure are then necessary to allow for these changed test conditions. Ease of change, therefore, under conditions when testing is imminent, must be one requirement of checkout programming. This, unfortunately, is not a requirement which has been solved as yet. It is therefore necessary to maintain the conservative approach indicated previously whereby the man interface has controls to allow him to handle unprogrammed situations. The type of programming just described probably comes as close to permitting this change as anything determined to date. However, even that type of programming requires first the filling out of a format, and then the feeding of punched cards into a computer in an off-line operation. Therefore, even this is not optimum. Change, however, should not be so easy that it is possible for an inexperienced operator to perform a few manipulations, and thus change the basic intent of the writer of the test procedure, or to place the stage into a dangerous condition.

In summary, a start has been made in programming for checkout using a single language which includes ease of translation, ease of review, ease of communication from engineer to computer, but does not yet provide for that very necessary ease of change in programming to accommodate unexpected situations during test.

CONCLUSIONS

Operation with automatic stage checkout under computer control for approximately a year, and consideration of the necessary means for doing this for various stages and under various conditions for several years, has indicated that there are a number of highly practical approaches which must be taken. Additionally, there are methods and approaches which are generally desirable but are not absolutely essential. There is no question that it has been well established through experience that automated checkout of a space vehicle stage, utilizing a computer for control and monitor of the results, is probably the most flexible and powerful thing that has happened to stage checkout since it first began. There are many projections which can be made as to utilizing the full capability of the computer in performing this task and improving the general state of the checkout art as it now exists. These are things which must be built on what we have already done and what we already know. The building must be practical and yet not reluctant, in a way that is forward looking, and yet is not extravagant, and in a way that allows us to maintain the gains which have made to date in space vehicle technology and the successes we have accomplished in space vehicle launchings. At the same time we must rapidly push forward the state-of-the-art such that we can have a successful space transportation system even as we now have a highly successful air transportation system.

CHART 1

MANUFACTURING CHECKOUT COMPUTERS
SATURN PROGRAM

	STAGE	COMPUTER	LOCATION
SATURN I	S-I	PB 250	HUNTSVILLE/NEW ORLEANS
	S-IV	-	-
	INST. UNIT	RCA 110	HUNTSVILLE
SATURN IB	S-IB	PB 250	NEW ORLEANS
	S-IVB	CDC 924A	HUNTINGTON BEACH
	INST. UNIT	RCA 110A	HUNTSVILLE
SATURN V	S-IC	RCA 110A	HUNTSVILLE/NEW ORLEANS
	S-II	CDC 924A	SEAL BEACH
	S-IVB	CDC 924A	HUNTINGTON BEACH
	INST. UNIT	RCA 110A	HUNTSVILLE

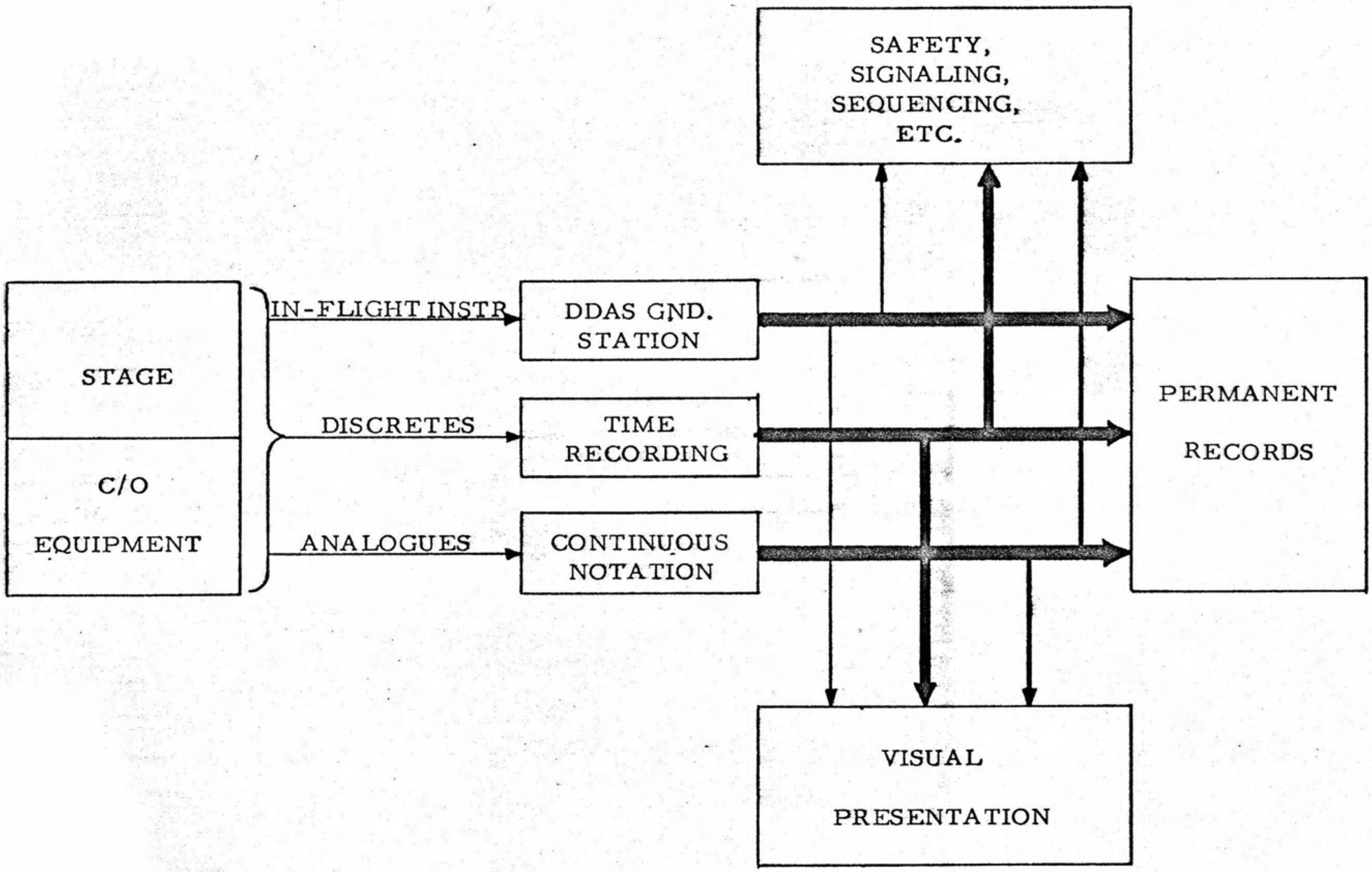

FIGURE 1 INFORMATION FLOW IN STAGE CHECKOUT

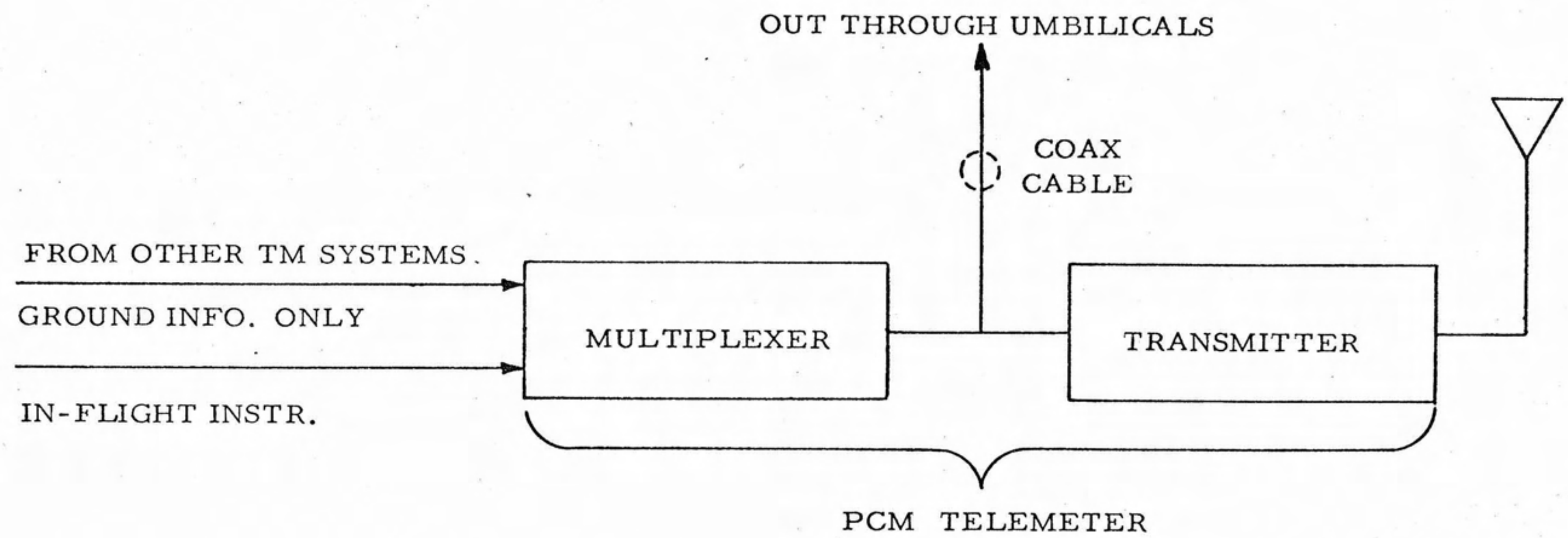

FIGURE 2 INFORMATION FLOW IN PCM/DDAS SYSTEM

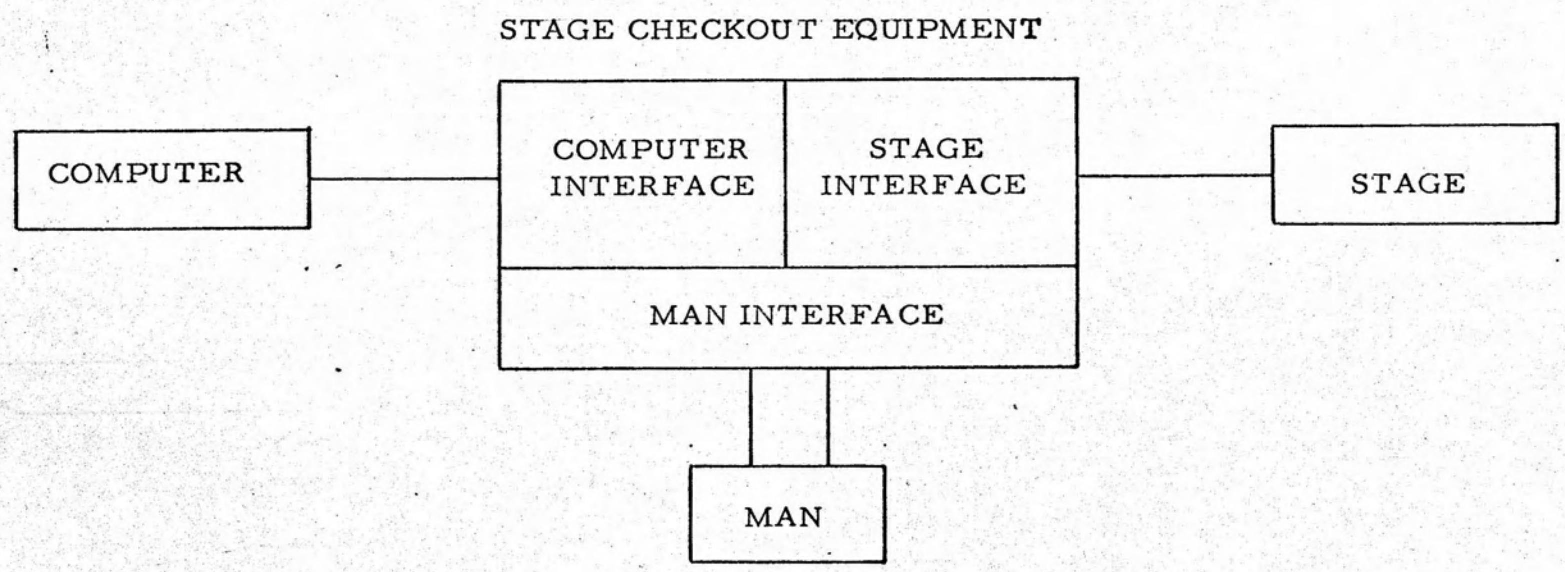

FIGURE 3 THE INTERFACES, AND SIGNAL FLOW