Experience on the Air Force UNIVAC

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The purpose of this paper is to discuss those factors the Air Force finds to have the most impact on electronic-computer reliability. In order to accomplish this purpose, I shall tell the story, in a general way, of the Air Force's experience with the UNIVAC for the past 18 months. During this time it has been under the sole control of the DCS/Controller, Headquarters, United States Air Force. I shall correlate these experiences with the reliability aspect of electronic computation.

It might be well to start with an understanding of what we tentatively consider to be the meaning of the term reliability. As a representative of the engineering group, I find that reliability means essentially one thing, and that is: Is the computer available to do computation right now? This may seem to be a harsh definition to engineering personnel, but it must be realized that our electronic computer is merely a tool for certain groups of people to get a lot of work done fast. You need only to talk to people in the programming group, the mathematicians, the operators, or your boss, to find that this definition is the one they go by. Remember now, I'm talking about a computation installation where a huge volume of work is to be turned out, which in turn is the justification for the electronic computer in the first place. I am not referring to a manufacturer's plant where a computer is under test, or to a laboratory where a computer is a research tool or experimental device.

An electronic computer is a complex system of equipment, and as such is dependent upon all the many components that constitute an installation. The computer proper may be operating, and could do work if a required part were available to fix it. Or, perhaps, the main power lines are at fault because a power transformer was burned up. The fact still remains that the computer cannot function. These two simple but very realistic examples illustrate the inclusiveness of what we consider to be reliability. If you start making distinctions, an endless number of definitions become possible. Our definition is the one more and more customers will be going by as well.

It is worth noting that the use of this criterion is of some historical significance for the computer industry. Until operating computers were available which were more than research instruments, the definition would have been irrelevant. The definition expresses correctly enough the belief that the reliability of a computer can be compared to the reliability of a tractor, or a bomber, or to a desk calculator. With the aid of such a definition, I can best convey information at our disposal.

Before relating the specific factors that have affected the reliability of our operation, I am going to tell something about the circumstances that had a direct bearing upon these factors.

Starting approximately June 1951, Air Force personnel were sent to the Eckert-Mauchly Division of Remington Rand in Philadelphia. No training program existed at this time. The computer itself was being checked out by the test engineers and, therefore, was not available for use by the trainees. A technical manual was well under preparation which covered the Central Computer. It was this manual and the constant questioning by the Air Force trainees of the test engineers that made up the training that was received. From time to time, as could be arranged, lectures were given by the Eckert-Mauchly test engineers covering various phases of the computer. I would like to pay my respects to those test engineers who suffered the continuous bombardment of questions by the Air Force trainees during the period June 1951 through February 1952. They were most helpful, most accommodating, and most all-knowing. During December and January 1952, the computer was occasionally made available during the hours of 12-8 a.m. for simulated trouble-shooting. This was the first and only real experience we had on the UNIVAC prior to its installation.

In early 1952 the machine passed its acceptance test, and in February it was shipped to the Pentagon for installation by the manufacturer's engineers. This was the first UNIVAC to undergo this transformation. From February to June 25, 1952, installation, checking and limited operation went ahead, and on that date the machine was formally transferred to the Air Force; the test engineers returned to Philadelphia, and we were left with the UNIVAC. It was quite a sensation.

During the training period, and especially at the start, there were indications of slight uneasiness on the part of the Air Force trainees at the prospect of servicing the computer. As the strangeness of the equipment began to wear away another form of uneasiness prevailed, not by the trainees now, but by persons associated in various ways with the installation. This latter uneasiness, however, turned out to be a blessing in disguise, because it constituted a challenge which made us all the more determined that the UNIVAC would be serviced only by the Air Force group without any help from "outside." This was a bold attitude: in a more practical light, it might be considered plain foolishness. As it turned out, however, the attitude was vindicated by results.

From the start it was decided to operate the UNIVAC on a 24-hour-per-day, 7-day-per-week arrangement. The personnel consisted of 11 people to perform all servicing on the Central Computer, the Unitypers and

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Uniprinters, and the test equipment used for servicing. It has been no mean task. Of the group of 11, two persons were assigned, in a general way, to the Unidypers and Uniprinters, one for the mechanical features and the other for the electronic features. This was a situation that came about as a result of the natural bent of the individuals concerned, rather than any other reason.

Two were assigned, in addition to their engineering duties which always came first, to a combination of responsibilities which covered such things as procurement of spare parts, personnel administration, dealings with programmers, and scheduling of preventive servicing. To visualize the communication problem, remember that with three shifts a day, seven days per week, contacts were limited to fifteen minute lap-over periods and written notes. At least two of the eleven were required to attend the UNIVAC at all times, performing computer operation, preventive servicing, or trouble shooting, as circumstances required. These two persons were familiar with all phases of UNIVAC servicing and operation rather than being specialists in any particular aspect of the computer such as a power-supply expert. This policy of shying away from specialization resulted, we believe, in greater reliability in utilizing our minimum number of personnel and, in addition, offered an opportunity for widening their interests and increasing their versatility. As we look back at this staffing arrangement, we realize we were undermanned.

A big problem in computer engineering personnel is to have a pool of trained people to slip into niches left by anyone who may leave. Based upon our experience, it takes approximately eight months to train a qualified person, and by that I mean an electrical engineer, a physicist, or a mathematician with a physics minor and a course in electronics. At the end of this time, he is almost ready and has started to have confidence in his own ability, so that he can take the responsibility of an operating shift. The work of servicing equipment such as the UNIVAC could be seriously hampered if too many engineers were to leave at one time, or if too much specialization was permitted in their training.

Another big problem concerns working hours. Anyone entering the computer field must immediately resign himself to the fact that he is going to have unusual working hours for a good percentage of the time. In many ways this can be compensated for by differential pay, true overtime, and a personnel policy that places a value on the services of employees.

An important Air Force accomplishment that has affected reliability was that of obtaining UNIVAC spare parts. While this may seem to be a routine task, it took a good portion of the time of two people for the better part of a year. The first step in securing adequate spares was that of obtaining a list of parts that would serve for immediate procurement purposes. A spare-parts list fairly adequate for this purpose was made available at the time of installation. It is possible that some of the burden of procuring spares could have been detoured at this time by obtaining a package of spares from the manufacturer. This was not done. Instead, we bought as many items as possible on the open market. As a result, we obtained valuable experience in procurement difficulties and established an excellent system of government procurement through Air Force Headquarters.

A serious problem that arises owing to the lack of an up-to-date and complete parts list of everything used in the computer is the continuing discovery of new parts that have never been ordered. This is a most serious factor in effecting computer reliability, for usually the component required is one that requires special ordering. In these cases, emergency procurement from the manufacturer is called for. At the start of our operations this problem was handled extremely well. Certain of the vendor's personnel were authorized to accept emergency calls from us at any time of the day or night, secure the part from stock and either bring it down personally or see it on its way by the most rapid means. This system worked extremely well and due credit must be given to the vendor and the individuals responsible.

After one year of this system's successful operation, this service was withdrawn. It is true that the service had not been used a great deal, and the manufacturer naturally discounted its importance to us. After losing computer time in a few emergencies, we suggested that the service be reinstated. This has been done. We have concluded that this kind of service is an important aspect of reliability since it is the one link that permits a computer installation to function, in spite of oversights on the part of both vendor and customer.

At this point, it might be well to discuss what spare parts have to be stocked by an installation using a UNIVAC. At the beginning, the selection was based on many intangible factors. One of them was: given such an amount of money, how much can I buy? This question certainly does not provide a very helpful spare-parts philosophy. When going into large scale computation with electronic computers, one might just as well budget for a generous supply of spare parts, rather than a minimum supply, since the difference in cost represents only a small fraction of the over-all cost of a large scale computer installation such as the UNIVAC. The compensation for this difference in cost is increased reliability.

Another important consideration in the achievement of greater reliability is the electronics work and storage area. The original Air Force plans merely provided for bare space which could serve as a work and storage area. Cabinets, shelves and benches have been added continuously, and the layout modified many times. Original ideas as to arrangement have been discarded and new ones developed continuously to take advantage of experience. Since no model existed to serve as a guide, we have no qualms about discarding existing arrangements in favor of more efficient servicing.

Arrangement of this work area has been dictated by factors which originally were not visualized. From the
experience gained in our tube testing program, for example, we have concluded that a set-up for preheating a large number of tubes at one time is necessary. This has required bench area which we originally had not contemplated. We will continue to make changes as experience dictates.

As may be expected, the components giving rise to most of the computer troubles are tubes. To date the Air Force’s UNIVAC installation has replaced approximately 2,100 tubes of all types to remedy failures. In addition, approximately 1,300 tubes have been discarded because they did not pass specifications and were rejected before even being used.

Several choices can be considered for meeting the procurement requirement for tubes. One of them is to buy pretested tubes from the vendor, if such are available. An alternative is to do your own selecting and testing. We have elected this last alternative.

For the UNIVAC it has been found that the tubes of Manufacturer A have been much better than Manufacturer B, whose tubes have become gassy, and Manufacturer C, whose tubes have lost most of their emitting characteristics after 2,000 hours of operation. Actually, it was known that Manufacturer A’s tubes were desirable, but at the time of procurement only B and C’s were readily available. Following the experience with the tubes of B and C, only A’s tubes have been in use. Steps have also been taken to work out a procedure for conducting our own tube testing on a wholesale basis. It has been found important in tube checking to allow sufficient time for the tube to warm up to temperatures approaching those in the computer. Tubes that will not show shorts under testing conditions may do so if allowed to reach operating temperatures existing in the computer.

The most curious type of defect exhibited by discarded tubes has been a G2-K short. Not a dead short, but rather one that varies from approximately 10,000 ohms to 400,000 ohms. This situation, of course, gives rise to many intermittent-type troubles in the machine, because different circuits would react differently to various values of shorts. In most cases, even a 50K short should not make any difference. However, in many cases, the short condition evidently takes on values considerably lower than this. Of the order of 10K, and this is the condition that causes the intermittent and, consequently, the most frustrating trouble. It has been in the practice, until recently, to remove all tubes that show a short condition of the order of 1 megohm. This might seem like a terrible waste of tubes until we see the reason for it. An experiment was conducted to determine the nature of the offending shorted tubes. The envelopes of many of the most common tubes used in the UNIVAC, the 25L6GT, were removed and the deposition of cathode material on the second grid has been observed. It has been determined that this deposition is caused by excessive heat within the UNIVAC. This condition, especially prevalent during the hot summer months, has caused cathode material to be torn loose and deposited on neighboring elements, in this case G2. Therefore, once a tube shows a short between G2-K, we assume that the condition will get worse and discard the tube. We believe, from a long-range viewpoint that this practice has served to increase reliability.

The UNIVAC is cooled by drawing in outside-temperature air without refrigeration and using it for cooling. An intake fan driven by a 20 hp motor pulls in air at a rate that was designed to be 30,000 cubic feet per minute. After being blown through the central computer and power supply, it is exhausted by a fan driven by a 15 hp motor. Despite these design figures, which are considered adequate to afford satisfactory operating temperatures, we started burning out selenium rectifiers at a rather alarming rate. Investigation led to the disturbing fact that the airflow was 18,000 rather than 30,000 cubic feet per minute. When this was discovered, some temporary measures were immediately taken, and the flow increased to approximately 25,000 cubic feet per minute. A definite program is underway to increase this flow to at least the original design figures, and it is expected that this modification will be installed in the very near future. In the meantime, the extra replacements caused by this difficulty decrease the reliability of our computer. This is all part of the computer game.

A rather serious consequence of the heat problem in the UNIVAC was its effect on personnel operating in the work area. The Pentagon Building, where the computer is installed, is air-conditioned all year round, and the summer temperature is in the neighborhood of 72 degrees F. The temperature in our work area hovered at 88 degrees during the summer, and 82 degrees during the winter. This is hardly conducive to comfort, and measures have been taken to remedy the condition. We hope that this problem will be recognized and avoided in all future electronic computer installations.

A unique feature of the UNIVAC is its input power. Many of you know that the UNIVAC was built in Philadelphia, a city of many old traditions including two-phase power. Perhaps this explains why the UNIVAC requires two-phase power. Since three-phase power is available in most installations, the only practical (and here I use the term very advisedly) solution to this problem is to convert available three-phase power to two-phase power via that enigma of the power men, a Scott transformer. To date, we have burned up two Scott transformers, and the third is presently operating successfully, we believe, only because we have installed a blower system over it. We have a new transformer on order which is 25 per cent larger in rated power than the one we are now using. We hope that it will cure our power failure problems.

The types of troubles that occur in the UNIVAC have never lent themselves to any sort of a pattern, other than to say that there are some types of troubles that recur. I want to attempt to outline these difficulties starting from the more prevalent to a less prevalent
type. A very common trouble is blowing of fuses in the Direct Current lines. The UNIVAC is endowed with an alarm circuit which causes a grasshopper-type fuse to blow and drop all Direct Current supplies at the same time. Little data has been gathered to determine the exact nature of these fuse blowouts, other than when a dead short was discovered. However, in all instances where measurements were made, no case revealed a higher than rated current to be flowing through the fuse in question. This has led us to believe that the heat problem previously mentioned has been one of the causes of fuse blowouts. The blowing of a grasshopper fuse is usually nothing more than an annoyance, but, in rare cases, can be serious when the supply is one of the clamping voltages, because then it may take with it many of the clamping diodes. This can be a rather annoying procedure, because it means checking every chassis that uses this voltage, and removing the bad diodes. This can easily consume the better portion of an 8-hour shift. At the beginning of our operation, we were consuming diodes at the average rate of 1½ a day for all reasons, but mainly because of blown fuses. At the end of six months this usage had dropped to almost nothing, and was coincident with our increased cooling effort. Our present diode replacement consists almost entirely of removing doubtful diodes of manufacturer X, and replacing them by manufacturer Y, or the more positive, but less occasional, situation of removing a burned-out diode which can occur when a clamping voltage fuse blows. To date, we have consumed a total of approximately 230 diodes.

Components, such as resistors and capacitors, have had negligible replacement factors; also fitting in this category are most of the other items including relays, lever switches, transformers, and chokes. While it may appear from these statements that only a small stock of spare parts need be kept on hand, the question then comes up: Which ones shall we stock? Can we afford to take a chance on the other items, remembering that regular procurement may take as long as six months, and securing it from the computer's manufacturer not less than 8–24 hours depending upon the circumstances? It must be remembered that one never knows what components might cause trouble and be weak links in the computer installation. So, it appears that until computers are much more common than they are today, it is almost mandatory that the computer user stock his own spare parts in a quantity allowing for self-sufficient operation.

We have found three kinds of problems associated with the use of magnetic tapes. The first problem is related to their shipment. The density and composition of a reel of tape is such that movements during shipment can cause layers to slide with respect to one another and produce folds in the tape. Each fold is a source of read trouble when the tape is used. This problem is being reduced by strict packaging methods. The second problem is an accumulation of dust and dirt on the tape surface. This is a cumulative process, and it is difficult to say when it starts becoming serious. However, there is no question that dirty tapes cause read-and-write errors that are time-consuming. The third type of problem is tape breakage, usually caused by some mechanical difficulty. Tape breakage requires tape repair, and at the present time, the only means we have for effecting this is to return the broken tapes to the manufacturer. Although each of these problems deserves continued attention, and still constitutes an annoyance, they have had only a minor effect on our reliability.

It might appear from the foregoing that there is little to recommend electronic computers, and the UNIVAC in particular. Despite the obstacles that stand in the way of reliability, the UNIVAC possesses many features that have more than tipped the balance in favor of reliability.

The mercury memory system has proven to be one of the most stable and reliable items in our operation. Except for some minor troubles causing poor heat control in some of the intermediate or "short tank" storage registers, we have never had trouble with the memory other than tube failures in recirculation loops.

Univac No. 2 is equipped with eight Uniservos, devices for transmitting information on magnetic tape to and from the computer. The Uniservos have proven to be essentially reliable. There have been many repetitive types of troubles: consistent failure of a specific transformer; periodic replacement of many components; and continuing need for adjustments. While not serious in themselves, these troubles do cause loss of time. Practical experience with the Uniservos has helped to increase their reliability. This has come about by a better understanding of their idiosyncrasies and methods for coping with them. One of the ways to reduce lost time owing to Uniservo difficulties is to secure at least one Uniservo over the number required for any expected type of computation. In this way a "spare" is present.

Prior to completion of the acceptance tests for the Uniservos, the reading heads over which the magnetic tape passes were wearing out at a rapid rate owing to the continuous friction of the metal tape against the head. This wear was reduced to practically zero by a modification that provides a thin spacing material between the head and the tape. The material does not reduce signal strength, but does reduce wear. This one modification has been a major factor in increasing computer reliability.

Probably the single most desirable characteristic of the UNIVAC, from the reliability standpoint, is the self-checking feature. Self-checking provides a built-in facility for servicing those parts of the computer with the duplicated circuits. When a trouble occurs in the duplicated part of the machine, it is rare that it takes place at exactly the same point in both paths of the duplicated circuits. Isolating trouble under these conditions may then consist of checking waveforms along the suspected path until a difference is observed.
Also, it has been generally agreed by all persons using the UNIVAC within the Air Force, that to our knowledge the UNIVAC has never introduced a mistake in computation. It has always stopped computation when an error was detected.

From the start of full-time operation until September 4, 1953, the computer had never been purposely shut down. As of that date, it was necessary to relinquish the 168-hour week in favor of a 120-hour week, owing to a decrease in the number of personnel. The machine was shut down at 12:45 a.m. on Saturday morning, September 5, and turned back on again for the first shift Monday at 12:15 a.m., September 7. The succeeding week produced a total of exactly 8 good hours of computation. The remainder of the time was used in servicing the computer. This first shut-down really took its toll. We removed bad tubes, especially marginal ones, by the score. The following weeks the situation improved, so that now, shutting down for a week-end has no serious effect. What caused the extremely bad week was the fact that marginal tubes never returned to their original condition. The result was many tube failures. When these marginal tubes were removed, normal conditions returned. It is also interesting to note that the first five or six weeks after the heaters were turned off, the practice was to turn out all the lights in the UNIVAC area and conduct a search for open heater tubes. Since it was necessary to wait until the mercury tanks came up to temperature anyhow, two or three people could cover the entire machine in about thirty minutes, and in this way remove all cold tubes. In succeeding weeks, the quantity of cold tubes decreased continuously until about the sixth week, the machine went right to work without any trouble shooting. Marginal checking right away raises its head at this point. The Air Force has evolved a simple method for marginal checking. The preliminary work has been done, and we expect to have it installed soon.

Discussion of the technical problems involved in computer utilization is important, but there remains the one salient question: how much good time can one expect from a computer such as the UNIVAC in the hands of a crew such as ours? When we first put this computer on the air, we were determined to measure the time actually available for computation. We have made these measurements in the following manner: At the control panel of the UNIVAC are some switches labeled in accordance with the categories we wish to measure:

- **OFF**—This covers week-ends or other time when the machine is not used.
- **INSTRUCTION PREPARATION**—This is time used by the programmers to debug their routines.
- **PRODUCTION AND PROCESSING**—This is time for actual computation.
- **PREVENTIVE SERVICING**—Scheduled down time.
- **DOWN TIME**—Unscheduled down time.

The items which constitute good time, i.e., time available for computation, are the sum of **INSTRUCTION PREPARATION** and **PRODUCTION AND PROCESSING**. The appropriate switch is thrown, in accordance with one of the foregoing categories, and there it stays until the situation changes. Any difficulty during a computation that consumes more than a few minutes is charged down time.

This log has been kept as faithfully as possible, and any errors owing to the wrong switch being thrown are corrected when the reading is taken at the end of every eight-hour shift. With this explanation of how we arrived at these figures, I would now like to give them to you. For the approximate 18-month period from June 25, 1952 to December 4, 1953, the Air Force recorded:

<table>
<thead>
<tr>
<th>Time Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GOOD TIME</strong></td>
<td>61 per cent</td>
</tr>
<tr>
<td><strong>PREVENTIVE SERVICING</strong></td>
<td>20 per cent</td>
</tr>
<tr>
<td><strong>DOWN TIME</strong></td>
<td>19 per cent</td>
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For figures of this kind to have any meaning, they must be gathered over a long period of time. Certainly no less than a six-month period: preferably at least a year. Our highest monthly average was 74 per cent good time, the lowest 49 per cent. But on a day-in, day-out basis, the figures I’ve quoted are the ones actually compiled. Are they good? I can only answer this from the standpoint of the people I work for, and say that we’ve done an enormous amount of computation since the UNIVAC was installed. Could they be better? Most certainly, but only with additional people to allow much more preventive servicing than we’ve done. Given an 8-hour shift to do preventive servicing, your accomplishments are a function of available man hours. If six people could be put on an 8-hour shift, it stands to reason that we could do much more than the usual two persons we schedule. Available personnel are directly coupled to the amount of preventive servicing that can be done. Given these additional man-hours for this servicing, the amount of good time should be increased.

A question that may arise at this time, is what is the future outlook for more computational time for UNIVAC No. 2? Personally, I believe it must decrease; not very much, but some. We are just starting to get serious trouble from mechanical failures. I expect this to increase in the near future. Many items have run well past their specified life test. Most of these items, in the case of the UNIVAC, pertain to the input-output equipment, the Uniservos. They have always been rather ticklish propositions, and crochety old age isn’t helping the situation any. Many of our relays are bound to give trouble as time goes on. This holds true for most all mechanical equipment. Also many of our undesirable crystal diodes of manufacturer type X are starting to go over the permissible tolerance in the forward direction. The result has been marginal trouble. With over half of the crystal diodes of this type, we can expect more failures. In fact, a series of troubles experienced in the past two months has been traced to crystal diodes which appear satisfactory under test conditions, but lead to intermittent difficulties when employed in the computer.

What all this adds up to is the fact that about three-fifths of our time has been put to computational use.