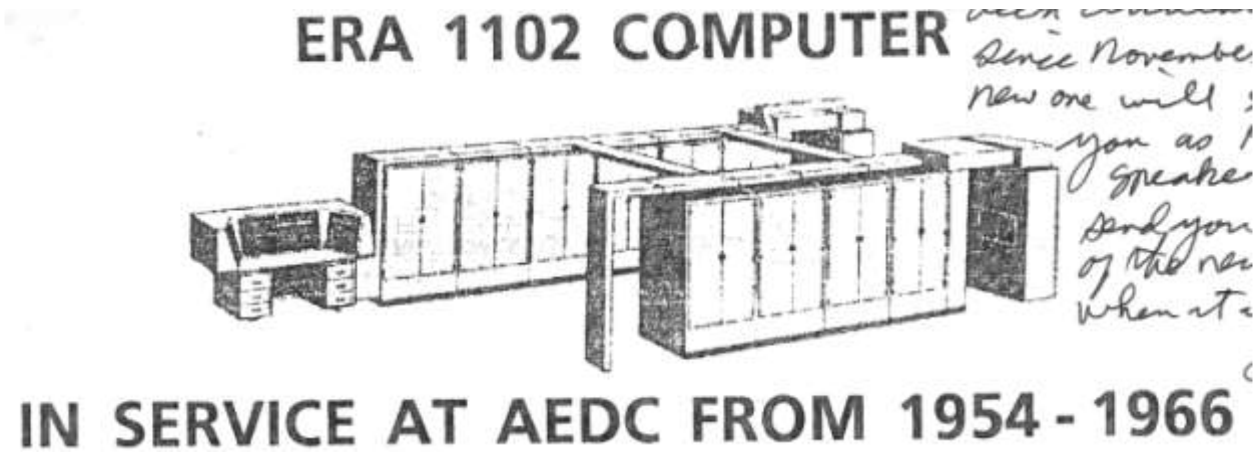
Introduction



Three Engineering Research Associates (ERA) 1102s were contracted by the U.S. Air Force for the Arnold Engineering Development Center (AEDC) in October 1952. For almost twelve years, they made significant contributions to the military and space programs of the free world. This is believed to be the first ever application of on-line data acquisition and reduction using a production model, large scale, general purpose digital computer.

Warren P. Burrell was the ERA 1102 Project Engineer, June 1952 – August 1954. Warren was the AEDC guest speaker - February 6, 1994 exhibit opening of 'The ERA 1102 Computer' at the Mitchell Museum at South Jackson Civic Center, 404 South Jackson Street, Tullahoma, TN.

This paper has three sections, 1) An AEDC summary extracted from materials provided by Mr. Burrell, 2) An unpublished chapter of computer history chapter drafted by George Chapine, and 3) some written data and comments given to the Legacy Committee by Warren in November, 2009.

Arnold Engineering Development Center (AEDC) Summary[1]

Arnold Engineering Development Center is named for the man responsible for its conception – General of the Air Force Henry H. "Hap" Arnold. Shortly before the end of World War II, General Arnold asked Dr. Theodore von Karman, one of history's great aeronautical test scientists to form a Scientific Advisory Group to chart a long range research and development course for the future U.S. Air Force. The Center was dedicated in 1951 by then President Harry S. Truman. The first test complex went into operation in 1953. As of 1993, development testing had encompassed the Atlas, Titan, Minuteman, and Peacekeeper ICBMs; the space shuttle, F-15, F-16, F/A-18, F-22, F-111, F-117, C-17, X-29, B1, and B2 aircraft; Navastar Global Positioning System satellites, the

[1] Office of Public Affairs, Arnold Engineering Development Center (AEDC) Arnold AFB, TN 37389.

Inertial Upper Stage, the anti-satellite program, Trident submarine launched ballistic missile, Tomahawk, Air Launched Cruise Missile, and the Advanced Medium Range Air-to Air Missiles.

An Unpublished Book Chapter, 3.4 1102

Also in the early 1950's, … In the same period, ERA built magnetic drum 1102 computers for on-line data reduction and open-loop control of experiments at USAF's huge Arnold Engineering Development Center in Tennessee. … Following WWII, American forces captured in Germany and returned to the U.S., plans and some of the equipment built for advanced aerodynamic test facilities. The plans and equipment were used to construct the Arnold Engineering Development Center near Tullahoma, Tennessee.

In October 1952, ERA was awarded a contract for the design, development, construction, and installation of three 1102 data reduction computer systems for the Arnold Engineering Development Center. The initial contract covering all work on three identical systems was one million dollars. These systems consisted of a processor, drum storage, cooling, console, raw data scanner and recorder, four plotters, five output tabulators, D.C. generators, motor-alternators, and electronically regulated power supplies. Subsequent contracts for building and delivery of three additional raw data scanner/recorder systems brought total funding to approximately 1.4 million dollars.

The three major test facilities, each to be equipped with one of the data reduction computer systems were:

- Engine Test Facility (capable of testing any existing or projected jet engine under simulated Operating speed and altitude conditions).
- Propulsion Wind Tunnel (capable of testing a jet engine. pod and wing section in its sixteen feet by sixteen feet throat at transonic and supersonic speeds, and at simulated operational altitude conditions).
- Gas Dynamics Facility (capable of testing aircraft models at supersonic and hypersonic speeds).

Architecture of the 1102 was adapted from that of the Task 29, Task 32, and the 1103 commercial computer (then in development) with word size scaled down to 24 bits. Its architecture was one's complement, synchronous-logic, parallel-operation, 24 bit word length, single-address instructions. The instruction set was similar to that of the 36-bit 1103 machine with the addition of instructions tailored to the data reduction application. Format of the instruction word was as follows:

Instruction Word

Op Code		S	C	Y	
23	18	17 ---15	14 - 13	12	0

OP CODE = Operation Code: 6-bits;

S = Skip Code: 3-bits; Controls the increment by which the Program Address Counter (PAK) is advanced between storage references. The three s-bits are directed into any of the thirteen stages of the PAK by a manual selector _switch associated with each s-bit. The s-controlled increment is in addition to the normal PAK incrementing, which is itself controlled by a manual selector switch. Normal PAK incrementing is manually selectable in increments from 20 to 212.

C = Supplementary Control Code: 2-bits;

i_{14} = 1; Optional Stop (all but FINAL STOP, INTERMEDIATE STOP, TABULATE. MULT., MULT. ADD.)

i_{14} = 1 (TABULATE); punch 7th level on tape

i_{14} = 1 (MULT., MULT. ADD) change sign of product

i_{14} = 1; Operand read from or stored in a register (all except ADD, SUBT. AND SEQ. DEV.)

i_{13} = 1 (ADD AND SUBT); replace (y) with (Q) and left shift (A) (final) by k places.

i_{13} = 1 (SEQ. DEV.); take next instruction from Q

Because of the single application of the 1102 system (data reduction), no instruction mix performance criterion was required or calculated. The one specific performance requirement was the scanning of 250 input data sources in 12.5 seconds; a rate of 20 per second. Vacuum tube technology was used in the 1102 with basic logic circuits taken directly from the 1103 design.

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Control logic was clocked at 500KC, with 1/4 microsecond clock pulses, AC coupled via pulse transformers. Inter-chassis connections were made by single conductor “pole line" wiring isolated on stand offs, or via bundled twisted pairs."Suitcase" chassis with 74 pin screw-jack connectors were similar to those of the 1103, but pre-perforated component boards were used rather than the custom-drilled boards of the 1103. Back panel channels were mounted vertically, each containing two columns of four chassis positions. Vacuum tube filaments were powered by transformers mounted at the base of each chassis channel. Filament voltage was supplied at 5.7 volts as well as the normal 6.3v. The low filament voltage was used on start-up to reduce thermal shock to the tubes', and also applied (selectively) as a test to detect marginal vacuum tube operation.

Programming of the 1102 was by means of machine language coding only, as no assembler, compiler or any higher level language was available or developed for this system.

Operating software for the three facilities was developed by Arnold personnel; each customized for the application. Customer software was used with simulated input data, both to verify the software and the 1102 hardware operation after installation. Customer supplied switch panels were used for the simulated data which was input via the raw data scanner.

The programmer had 8192 words of drum storage (total) to work with, for both program and data storage. Loading of programs and data was done via paper tape, except that in on-line mode, data words (15 bits) were input directly from the raw data scanner. A drum address interlace plug board permitted variation of drum address interval to best suit the specific program in process.

The main (and only) storage in the 1102 system was provided by the type 1120A1 magnetic storage drum. This drum was an extension (with greater capacity) of the type 1119A1 drum previously developed for use in the Card-to- Tape Converter system.

The type 1120A1 drum storage capacity was 8192 24-bit words. The drum rotor was 4 3/8” in diameter and 15 ½” long, and the external shroud mounted 240 miniature heads. A small 120 cycle alternator was used to power the drum, via a direct-drive motor, at 7200 RPM. Maximum access time per drum address (drum rotation period) was 8.3 MS. and average access time was 4.2 MS.

An address-interlace plug board permitted the selection of numerically sequential addresses to be varied in increments of one or more physical storage positions around the periphery of the drum. The interval between program instruction references was controlled by variable incrementation of the program address counter. The time interval between physical address locations could thus be optimized to a given programming application.

A fixed compliment of input-output equipment was initially supplied with each system. Univac later supplied three additional Raw Data Scanner and Recorder systems. Arnold personnel also made direct procurement of analog-to-digital converters, and it is known that alternative plotting equipment was being considered.

Program instructions and input data (previously recorded by the Raw Data System paper tape punch) were loaded into the 1102 via a Ferranti Mark II high-speed paper tape reader. The Ferranti reader read the tape perforations photo-electrically, and was capable of operating continuously at a rate of 200 characters per second, or in a start/stop mode, as required by the type of input operation.

Data read from tape was assembled under control of a wired-in load routine, for program loading, or under program control, for data input from paper tape.

Five output tabulators (10-characters per second, modified Flexowriters) each directly addressable under program control, were provided on each system. The commercial Flexowriter typewriter with auxiliary paper tape punch was modified for the application by addition of cams and synchronizing contacts, and the addition of an external, binary-to-Flexowriter code translator. The tabulators were capable of operating remotely from the 1102 processor at a distance of up to approximately 1000 feet. Typically, the tabulators would be located at or near facility control centers, as well as at the computer room.

Four Librascope Inc. plotters, each directly addressable under program control, were provided on each system. The plotters could produce either point or continuous plots, with a full scale traverse time of one second. Accuracy was 0.1%. Plotting was done on a concave surface. The plotter stylus motion was horizontal (x-axis) and rotational (y-axis). An 18 bit binary word from a computer output register supplied both axes of the plot, and a converter, external to the plotter, performed digital to analog conversion for plotter operation.

As with the tabulators, plotters could be located at the computer site. or remotely at a distance of up to approximately 1000 feet.

Power to the 1102 computer system was obtained from a 460 volt, 60-cycle, 3-phase AC source. The input power was supplied to a motor generator set which consumed 24 kilowatts, and to two air conditioning units which consumed 12 kilowatts. Both of these loads were at 85% power factor. The motor generator set included a 50 hp, 3 phase induction motor driving an alternator and two DC generators. Voltage sensors were supplied on +5. -15, -25, and 80 volt supplies, and an out-of-tolerance condition on any of these voltages would result in a system power shut down. All voltages were monitored and controlled by a central control panel and power to the 1102 was applied and removed by an automatic sequence controller. Cooling of the 1102 equipment was accomplished through use of two mechanical refrigeration units using water cooled condensers. Cooling air from the air conditioners was conducted through a plenum in the base of each cabinet. Protective equipment in the 1102 consisted of voltage interlocks on all cabinet doors. If the doors were opened without the interlocks being bypassed, an automatic shutdown of power was initiated. Environmental sensors were supplied in each cabinet. At the temperature of 85^{o}·F exhaust air, a warning light was lighted on the cabinet and at the central control position. If the temperature increased further to 120^{o} F, an automatic power-down sequence was initiated. Additionally, an air vane sensor switch in each air conditioning unit warned of the loss of cooling air.

Development of the 1102 computer system started in October 1952. The initial work was done in an office area in building 6 of the Minnehaha Avenue plant. Within a short time: the project was transferred to an area in the west end of the Minnehaha Avenue Plant, which had been undergoing renovation just prior to this time. An office area and a prototype area immediately adjacent to each other were assigned to the project. The initial work consisted of design of the 1102 system elements using the 1103 basic circuits, logic and hardware as a starting point. None of the original design engineers had prior digital design experience though all of the people on the project at the start had prior industrial experience, and the project engineer had prior experience within ERA. There were however, many new logic and circuit requirements, and in these areas the work started from scratch.

Any component not already a part of the 1103 hardware had to be selected from available commercial sources. Specifications were established, samples acquired and after approval – procurement of the prototype qualities initiated.

As the various elements of the 1102 system design were completed, fabrication was initiated on a piecemeal basis. Some of the fabrication took place in an adjacent manufacturing area in the same building. Other elements were built at a temporary manufacturing location at 2295 University Avenue, just west of Raymond Avenue in St. Paul. During the design phase, the prototype area was also utilized as a laboratory in which circuit development was accomplished on all portions of the system where the design was new to the 1102. Among the areas involved in the latter category was an analog-to-digital converter which had originally been included in the contract with the Air Force. After several attempts at producing a usable converter, starting the design from scratch, these efforts were abandoned and the contract amended to drop that requirement. Additional areas requiring new design and laboratory test were the Teletype high-speed paper tape punch, the Flexowriter output tabulators, the Librascope plotters, and the Ferranti high-speed paper tape reader. One additional area where some basic investigation was carried on during the development of the 1102 concerned that of the output plotter. Basic experimental work was conducted aimed at development of a flat X-Y plotter to satisfy the plotting application. The work consisted of using sensitized paper with an orthogonal grid of conductors on each side. An electric field was applied to the matrix lines in an attempt to create a usable plot. This work was not a part of the contract requirements but was an attempt to determine whether a feasible plotting system could use this approach. The work was not carried very far and was abandoned after the Librascope plotter was selected for this application.

The final assembly of the first 1102 system (there was no separate prototype) was carried out in the project area using personnel from the manufacturing organization as well as from the project. On completion of the first system, operational tests were conducted on each of the elements of the system and finally, on the system as a whole. On completion of testing, the first system was torn down, shipped to Tullahoma, Tennessee, and installed at the Engine Test Facility. The period of installation was from July 20 through July 31, 1954. This first installation was not complete because the control room for the Engine Test Facility was still under construction. However, all equipment had been delivered at the time the basic system was installed. The Scanner/Recorder, remote tabulators and plotters were finally installed at the Engine Test Facility in the period of September 12 through September 25. 1954.

The second and third systems were assembled, tested, and delivered in a similar manner. The second system installation at the Gas Dynamics facility took place during the 12th through the 22nd of December of 1954. The third system, for the Propulsion Wind Tunnel facility, was installed during the 7th through the 19th of February 1955.

Installation of the three systems as described completed the initial contract work for the Air Force. However, the customer had determined that they would require additional raw data scanners and recording systems. Consequently, under a separate contract, three additional systems of this nature were developed, intended for off-line recording of raw data. These systems were similar to the basic 1102 scanner/recorder systems but included a self-contained power supply. The three additional raw data scanner and recorder systems were built and delivered in the period from April 1955 through July 1956.

Though the 1102 system used architectural concepts and adapted circuits previously developed for the 1103 computer systems, it did mark the first application of several new hardware development areas and also new applications of the computer. This certainly must be considered as an early if not the first, application of computers for on-line data reduction. Another first, at least for ERA, was the operation and control of the Teletype high-speed paper tape punch. In fact so new was this device that the engineering prototype of the Teletype punch was obtained through U.S. Air Force contacts for use in the first 1102 system. Other first time, or early applications employed by the 1102 were the increased capacity small high-speed storage drum, the remote tabulators and plotters and certain simplification and cost reducing aspects which were designed into the basic hardware. By making use of previously established technology, architectural and logical design concepts, the 1102 development was accomplished in a relatively short period of time with few, if any, fabrication, test or installation problems. The useful life of the 1102 systems at Arnold is unknown {editor's note: at the time this paper was drafted}. However, it is known that all systems performed their function in a highly satisfactory manner and it is likely that only the advent of newer and lower cost technology and higher performance requirements eventually caused the obsolescence and replacement of these systems at Arnold Engineering Development Center.

Warren's Recollections

Those who refer to the 1102 as merely an upgrade of the 1101 demonstrate a severe lack of understanding. When I was assigned to this project, I could not understand how ERA got the job with the Jim Miles' proposal of a weak form of the Harvard Mark III! I learned 40 years later from the AEDC people that they had expected something based on the 1101 irrespective of what the bid specification said. With Gordon Welshman as my sounding board, I planned a 24-bit processor (ATLAS 1101) architecture but with the improved hardware speed and effectiveness of Task 9 [1103]. I had had detailed experience in all three! Gordon arranged for Al Roberts [Arlington] to review this plan and he determined that it could meet the Acceptance Test Requirements. We got merely a nod of Al's head – Nothing More – I took this as a firm YES!

The ATLAS I and ATLAS II were both specified under one NAVY contract for what became known as an NSA classified information processing. ATLAS II was much enhanced by 3 levels of storage, [including electrostatic] and magnetic tape, etc. In Task 29 for ATLAS II considerable improvement in hardware allowed 2-address operations [particularly the Repeat Instruction.] As one of the early designers of the 1103, I was confident we had the basis for designing and building 1102's at a reduced cost. On the 1102 project, I had Jim Wright use the partially designed 1103 arithmetic section which I had used as a model for the 1102. Likewise, Roger Gardner for the 1103 Power System and so on.

We were the first to use pre-punched circuit boards and avoid the hi-cost of Navy required 'LeRoy' component lettering. We used the Larry Reid modular cabinets, no false floor, and over head wiring. We relied on Jack Hill's drum development group to increase speed and reduce costs. Ernie Wold designed the relay switching between memory for increased capacity and alternative wind tunnel operations. Later I learned that AEDC had incorporated magnetic core storage via the same access path. The Drum incorporated a knurled timing track compared to the original ATLAS I timing via separate oscillator.

Bob Bedner designed a switching relay network for many, many inputs of tunnel transducers – over 100 of them. Dick Oman bread-boarded (on a wooden relay rack) an analog-to-digital converter, which at that time was the best available. But, it could not offset selection and other in service losses. With emerging digital devices at the source end, the contract for analog inputs was modified to digital. The contract savings were used by Art Engstrom to procure digital devices.

I was pleased to receive the invitation to the 40th anniversary at AEDC. One of the pleasant results of the development of my efforts under Jack Hill was to reduce emissions of fading vacuum tubes by reducing filament voltages. For the 1102's, the process was refined prior to Wind tunnel operation. AEDC originally doubted that we were expecting a 6 year computer life – but were happy to get twelve years of service.

I was also overwhelmed by the enthusiasm of users learning to program 1102s. One programmer went on to form a programming service business. Another programmer had come to AEDC after working with a Wide Marshert Calculator for Dr. Robert Oppenheim at Oak Ridge TN.

Some 60 years later I got an apology from Sid Green who said that he'd given me a severe bat time when he took over after Pete Patton's departure. All that time he was jealous because I looked too young to do the 1102. Bob Pope {Editor's note: *Bob was an 'Arnold' employee, later worked for UNIVAC and became a regular at the First Friday lunches*.} worked on the project with me- he knows that this AEDC was the 1st Real-Time Data-Reduction General Purpose machine.

In the 1950's time frame I was a participant of a road show of our ERA computer expertise at the Cape area in Florida. From this I believe that we got a Request for Price (RFP) for missile tracking, range safety, etc. Byron Smith was then responsible for receiving all RFPs. I became a proposal participant, was given a proposal text baseline which focused on reliability. I updated this draft with whichever data was available from the Magstec and Transtec test beds. The proposal was to focus on which technology was most likely to be the better solution. Erv Tomash wanted me to tell our story and technology to West Coast Defense Management AF group headed up by then Major G. Probst. Frank Mullaney allowed me to go only if I only talked about what was written in the proposal. We subsequently got the Athena project (and later G. Probst as a General Manager.)

Principal 1102 Project Personnel

- Warren P. Burrell, Project Engineer
- Bob Bednar, Scanner design
- Dick Oman, A/D Converter, Plotter/Printer, paper Tape Prep, Unit Tester
- Roger Gardner, Power Supply and distribution
- R. Gray, Documentation
- Herb Somermeyer, Main Control Logic
- Jim Wright, Arithmetic
- Ernie Wold, Magnetic Drum Storage
- D. Wetherbee, Mechanical
- Frank Mullaney, Supervisor
- Arnold Cohen, Director

Supporting 1102 Personnel

- Jack Hill, Magnetic Drum Design Group
- Larry Reid, Mechanical Design Group
- Bob Simon, Analysis and Program Group
- Al Roberts, ERA Office in Arlington VA
- Gordon Welshman, Office in Arlington VA
- Bill Winget, Contracts
- Al Slindee, Production Control
- Bernie Ecklund, Scheduling
- Bob Kalb, Engineering Management
- Art Engstrom, Engineering Coordination
- Jim Miles, Sales
- Don Messerich, Wrap-up & second/third 1102
- George Hanson, Training

ERA 1102 Unique items at that time

- Three computers
- 7200 RPM Magnetic Drum for 2 x 4096 24-bit words
- No false floor, but modular cabinets with cooling plenum and overhead cable raceways
- Pre-punched chassis component boards and component designation by coordinates
- Drawings, hand-letter versus LeRoy lettering
- Significant System Design Changes:
  - Deleted direct analog inputs
  - Doubled storage capacity
  - Optimized main control design
  - Introduced quick (Sequence Deviation) instruction
- Met the customer R/T performance requirements
- Shipped by Van Line Truck
- Was considered for Process Control Applications
  - 5-double width output printers
  - 4 output plotters

- Convinced Teletype to continue fast punches

Pre-1102 Time Line

- December 1950 – ERA's 1101 operating at CSAW site – first large scale computer to user site from a factory
- Fall 1950 – IBM contracted with ERA for magnetic drum storage add-on to IBM card/programmed electronic calculator. This changed to a design plan for a drum based computer which preceded IBM development of their IBM 650
- September 1950 – Initiated design of what became the 1103, later upgraded with core memory to the 1103A which was called the UNIVAC Scientific.
- 13 April 1951 – AEDC RFP Exhibit
- 14 September 1951 – ERA proposal to AEDC, PX29614

Warren Burrell Careers

- USAF, Radar & Weather Officer
- ERA to Sperry UNIVAC, Computer System Design Engineer
- State of Minnesota, Telecommunications, Data, Video System Design Engineer

Editor: Organization and editing by Lowell A. Benson, UNISYS employee - July 1960 to February 1994 and VIP Club Legacy Committee Co-chair.

