

Burroughs Guidance Computer Historical Summary

Summary

Burroughs started development of the computers as part of Weapon System 107A-1 (Atlas ICBM) in 1955 under Contract No. AF 04(645)-23. Most design of the computer is attributed to Burroughs engineer Isaac Aurbach. He had a difficult task to perform, designing a transistorized guidance computer for a missile that was still in its engineering phase. Until that time, guidance computers had been designed using vacuum tubes. Transistor technology was still in its infancy; they were expensive and very unreliable. One of the most challenging tasks Aurbach relates in a 1992 interview was the high failure rate of transistors coming from his primary source. Only by setting up a special production line was the vendor able to deliver consistently reliable transistors. That aside, Aurbach had to design transistorized logic circuits that had never before been created. Transistors



had been used primarily in small battery-powered radios that were becoming extremely popular with teenagers. Aurbach's resulting design included a remarkable set of simple direct-coupled logic circuits that could be assembled in different ways to produce complex digital computer modules.

A total of 17 Research and Development (R&D) and operational computer systems were delivered by Burroughs to various United States Air Force missile sites. Installations include Cape Canaveral, San Salvador BWI, Keesler AFB, Vandenberg AFB, Warren AFB, and Offutt AFB.

Six of the 17 computers were used in the radio guidance and range safety function on the boost phase of flights from Cape Canaveral Air Force Station (Eastern Test Range) and Vandenberg Air Force Base (Western Test Range) between 1957 and 1978. Burroughs data (*table below*) from 1 September 1965 summarizes flights to that time.

Range	MOD I Guidance	MOD I Range Safety San Salvador	MOD II Guidance	MOD III Guidance and Range Safety		Total
	ETR	ETR	WTR	ETR	WTR	
Atlas ICBM	10	38*	2	70	67	149
- Mercury		2*		10		10
- Able	3*			3		3
- Vela				3		3
- Ranger				9		9
- Mariner				4		4
- FIRE				2		2
- EOGO				1		1
- Other Agena		1*	39	2		41
- Snapshot			1			1
Thor Able	9					9
Titan ICBM		18		46	1	65
- Gemini				5		5
Polaris				2		2
Total	19	18	42	157	68	304

* Not included in totals since these missiles appear in the total of another computer which performed guidance.

Among the more notable missions, Burroughs computers performed ascent guidance for the Atlas-Able lunar satellite, the Thor-Able series (Transit navigational satellites and Courier delayed repeater communication satellites), the MIDAS (Missile Infrared Detection Alarm System) satellites, the Agena-B reconnaissance satellites, the Project SCORE "talking satellite," Project Mercury "man-in-space" flights and Project Ranger (impact on the moon).

Reliability

The reliability of the Burroughs guidance computer was a prominent factor in the success of the Atlas program and has become somewhat legendary. The minimum contractual reliability specification was 0.96 and the design reliability objective was 0.994. The actual result was an operational reliability of 0.998.

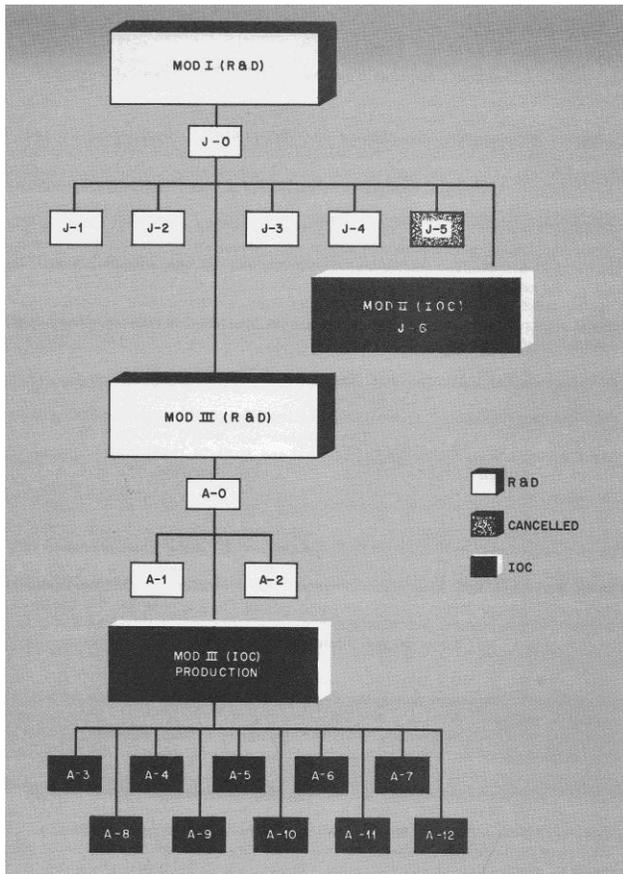
The Burroughs Atlas computers have never experienced an on-line failure during missile flights or in simulation and integration tests for these flights, nor has a countdown or flight test ever been delayed because of a critical computer malfunction.

One example is the MOD II guidance computer that operated over 17 months, on a 24-hour-a-day basis,

at Vandenberg Air Force Base without a single critical failure.

Testimony of computer technician Airman Ron Nettle assigned to an Atlas missile squadron at Offutt Air Force Base, Nebraska in the early-1960s: "Throughout my year and a half in the shop, we had about 3 failures to repair. It's at this time that I asked myself that 'if I were to work for a computer company, I sure would like to work for one with the reliability of this Burroughs Computer!' Due to their reliability, I did a lot of sweeping of floors and general clean-up. Each morning, a PM (preventive maintenance) was performed on the computers at the missile sites, including a Guidance Simulation Exercise, loaded into the computer via punched mylar tape. If any part of the Guidance Simulation failed, the diagnostics were run, and the bad major component was found and replaced with a spare on site. This is where I came in. The failing major component was then returned to the base shop for repair. We would then run diagnostics using this 'package tester' unit that was the size of about 3 side-by-side refrigerators, with more switches than I could count. We would replace the bad component and return it to the missile site as a spare."

Model Evolution



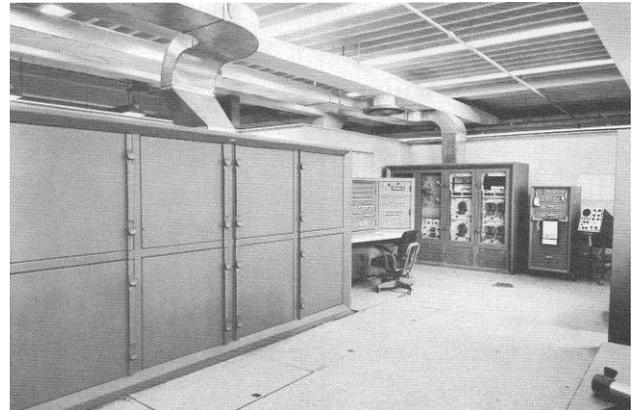
From the original design, the computer evolved into three models designated MOD I, MOD II, and MOD III (*diagram above*). There were two sub-designations of these models, R&D (research and development) and IOC (initial operational capability). R&D computers were to be used for research and development which not only involved research and development of the computer but also the Atlas. IOC computers were to be used for with operational Atlas missiles. At the time of contract award to Burroughs for the guidance computer, no working Atlas missile had yet been built.

MOD I

All MOD I computers held a “J” designation. Unconfirmed reporting indicates that the “J” designation derived from the original missile name which was to be Jupiter. The Army already having a missile named Jupiter resulted in a name change to Atlas. However, the die had been cast and the “J” designation remained.

There were to be 7 MOD I computers (*photo below*).

J-0 was an open frame working laboratory mockup that was used to determine final positioning of components. It was not a deliverable and is not counted in the total 17 computers eventually delivered to the Air Force. It remained in the Burroughs Great Valley Laboratory in Paoli, Pennsylvania.



Of the 6 deliverable computers (J-1 through J-6), only four (J-1 through J-4) were actually built. Parts for the remaining two were held in reserve with some components used as replacement stock.

J-1 was delivered to the Air Force Missile Test Center at Cape Canaveral in June 1957. This computer was at some point converted to J-1A to support guidance for the Atlas Able and Thor Able space launch vehicles. The J-1A suffix was presumably a designator for its new Able support mission. In the summer of 1961, J-1 was placed in in-place storage at Cape Canaveral. It was eventually donated to the Smithsonian Institution where it remains in inactive storage at this writing.

J-2 was delivered to San Salvador, British West Indies in September 1957 and used primarily as an impact predictor in support of Range Safety. It supported Atlas A, B, C, D, E, and F series flights and the Titan I. In the spring of 1961, it was placed in storage (location unknown).

J-3 was delivered to the Air Force Missile Test Center at Cape Canaveral in October 1957. It was removed in the spring of 1959 and shipped to the Burroughs facility in Radnor, Pennsylvania where it

was used for testing for a while, then dismantled and cannibalized for parts.

J-4 remained at the Burroughs Great Valley Laboratory as a working engineering model used for troubleshooting and to test design changes.

The major components of this J-4 computer were shipped to the Air Force Space Museum at Cape Canaveral the week of 17 May 1965 and placed on display (*photo below*) in Firing Room A of the blockhouse at Complex 26. It was in working

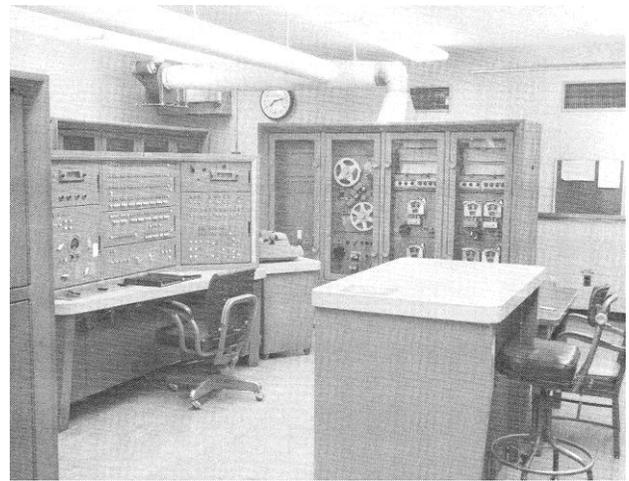


condition at the time of installation. During 1967 and 1968, a large stock of spare parts for the MOD I was transferred from Burroughs to the Air Force Space Museum.

J-5 was never built. Components were held in reserve and used as replacement stock.

MOD II

Due to an unprogrammed operational requirement at Vandenberg Air Force Base in 1958, components for the MOD I J-6 were assembled with some design improvements, including the addition of a command control (range safety) plotter console. Because of these modifications, the MOD I designation was dropped from J-6 and the



computer was given the MOD II (IOC) designation (*photo above*). It remained the only MOD II ever built. This was the first Burroughs guidance computer to support operational Atlas missiles for the Strategic Air Command.

MOD III

All MOD III computers were given an “A” designation, presumably in recognition of the Atlas ICBM’s operational name. There was a major change to the construction with the MOD III series. Instead of the exposed wiring of the MOD I and MOD II, the MOD III became highly modularized. The larger slide-in modules of the earlier models were reduced in size. Each slide-in module now consisted of smaller plug-in modules. These plug-in modules were manufactured and exhaustively tested under very tightly controlled clean-room conditions. Once manufactured, the modules could be handled and shipped under relatively normal conditions.

Because of the major changes to the circuitry and construction of the computer, the MOD III was produced with two sub-designations, R&D and IOC. The major difference between the R&D and IOC designators was the operator’s console. The R&D units had a full diagnostic console similar to but somewhat more streamlined than that of the MOD I and MOD II. The IOC units contained a very small operator’s panel built into the main cabinet. The panel allowed for target input and presented very basic diagnostic indications. The IOC models were to support operational missiles and not to be used for research and development purposes, so the need for a full console was unnecessary.

MOD III (R&D)

There were three MOD III (R&D) computers (*photo below*) built (designated A-0 through A-2).

A-0 was the engineering mockup that was not a deliverable to the Air Force. It was shipped briefly to Vandenberg Air Force Base for human interface testing. Everything from major assembly placement to overhead lighting type to color of the cabinets was evaluated. It was mentioned in the final reports that the Air Force specifically requested a change in the color of the cabinet paint because it resembled too closely the paint color of another Air Force contractor's equipment. Burroughs complied with the request.



A-1 was shipped to the Air Force Eastern Test Range at Cape Canaveral in September 1958. Shortly after its arrival, the MOD I J-3 was removed and A-1 took its place. The A-1 continued to work with J-1 for about two years, when J-1 was deactivated. The A-1 continued to support launch operations until April 1978 and was removed shortly thereafter.

A-2 was retained at the Burroughs Great Valley Laboratory in Paoli, Pennsylvania. As with the J-4, it served as a working engineering model used for troubleshooting and to test design changes.

MOD III (IOC)

As an operational unit, the Burroughs computer gained a military equipment designation at this point in its life. It was known as the AN/GSQ-33, Digital Computing System.



Each MOD III (IOC) computer (*photo below*) was designed to handle a "Site" of 3 operational Atlas D missiles from above ground "coffin" launchers (*photo above*). Vandenberg Air Force Base also had fixed gantry-style launch pads. The concept of operation required that the computer be programmed with targeting information while the first Atlas was being fueled and prepared for launch. After launch, the computer would provide guidance services until ballistic warhead separation. At that point, the computer would be free to guide Atlas number two. Finally, it would be cycled to guide the third Atlas. It sounds incredibly slow and cumbersome by today's standards, but the Atlas was the United States' first ICBM. Before Atlas, there was no ballistic missile with intercontinental range in the U.S. inventory. It was a major leap forward.



A-3 was delivered to Keesler Air Force Base, Mississippi in the summer of 1959 as a fully operational maintenance training computer. Keesler did not have operational missiles, but it was

a major Air Force technical training center at the time.

The remaining MOD III (IOC) computers (A-4 through A-12) were delivered to operational bases between the summer of 1959 through the fall of 1960. Missile unit names were changed over time and original Atlas D missiles were upgraded to newer models, but this was the original deployment scheme.

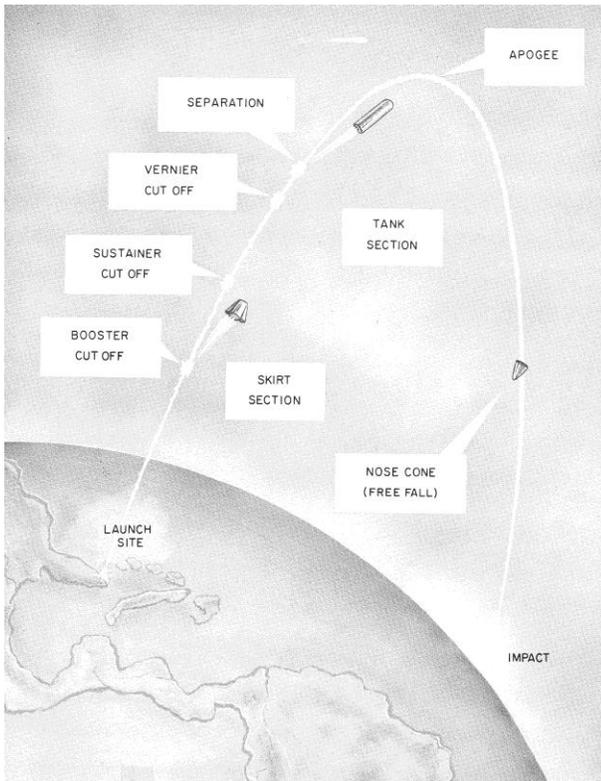
A-4 was delivered to Vandenberg Air Force Base in June 1959 to support the 576th Strategic Missile Squadron.

A-5 and A-6 were delivered to Warren Air Force Base, Wyoming in September 1959 and October 1959 respectively to support the 564th Strategic Missile Squadron. Computers A-5 and A-6 were installed in the same room.

A-7 through A-9 were delivered to Offutt Air Force Base, Nebraska in February and March 1960 to support the 566th Strategic Missile Squadron.

A10 through A-12 were delivered to Warren Air Force Base, Wyoming in May through July 1960 to support the 565th Strategic Missile Squadron.

Closed-Loop Guidance

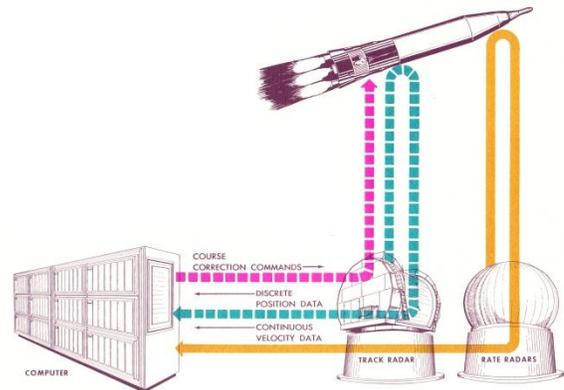


The primary function of the computer system is to participate in automatic, closed-loop control of the Atlas missile throughout the major portion of its powered flight (*diagram above*) and to effect power cutoff and release of the payload once the proper position and velocity are attained. Secondary functions of the R&D computer models were the performance of range safety calculations and the display and recording of the behavior and path of the missile during flight.

Until technology advances allowed guidance computers to be miniaturized enough to be installed inside the missile, the ground based guidance computer was a necessary part of the missile system.

The major guidance elements of the Atlas Weapon System are the rate radars, the track radars, and the guidance computer. The radars determine missile range, azimuth, elevation, range rate, and lateral rates. A radar beacon in the missile retransmits, in modified form, the signals received from the radars. During the sustainer and vernier stages of the missile flight, the rate radars provide the computer

with continuous velocity data, while the track radars provide discrete position data.



The specific task (*above*) of the guidance computer system is (1) to receive missile position and velocity data from the track and rate radars, (2) perform the guidance equations calculations, and (3) generate the missile guidance and discrete commands necessary to place the nose cone on the proper ballistic trajectory at the end of powered flight. In satellite guidance assignments the computer may be required to control such functions as orbital trip, injection into orbit, transfer between orbits and manned recovery.

MOD I System Components



The MOD I guidance computer consists of several major assemblies. A mockup of the suggested MOD I installation arrangement is above. Only the assemblies included in the Museum display are discussed. Other assemblies were either not included with the computer donated to the Museum or were used only on other models of the Burroughs guidance computer series.

Published specifications for the MOD I computer:

FUNCTION: Real-time missile guidance and control

TYPE: Parallel, fractional, synchronous, binary, single address

OPERATIONS: 38 orders

OPERATION TIMES: Add – 47.6 millionths of a second; Multiply – 552 millionths of a seconds; Divide – 990 millionths of a second

BASIC CLOCK SPEED: 210,000 pulses per second

WORD CONFIGURATION: 23 data bits with sign; 17 instruction bits

MEMORY: Instructions: 1536 18-bit, wired instructions; Data: 256 24-bit numbers, variable; Constants: 128 24-bit numbers, fixed wired; Switch: 10 12-bit switch settings

INPUT: Missile position and velocity data from radars (analog and digital signals) or from missile guidance simulator (seven-level perforated tape reader)

OUTPUT: Steering discrete commands to radar and to simulator (via seven-level perforated tape punch); selected flight data to two X-Y plotters

COMPONENT COUNT: Approximately 30,000

POWER: 208/120 V +5%; 60 cycle; 3 phase, 20 KVA max; 0.80 PF

Each MOD I guidance system was delivered to its site complete with an independent air conditioning system and suite of test equipment.

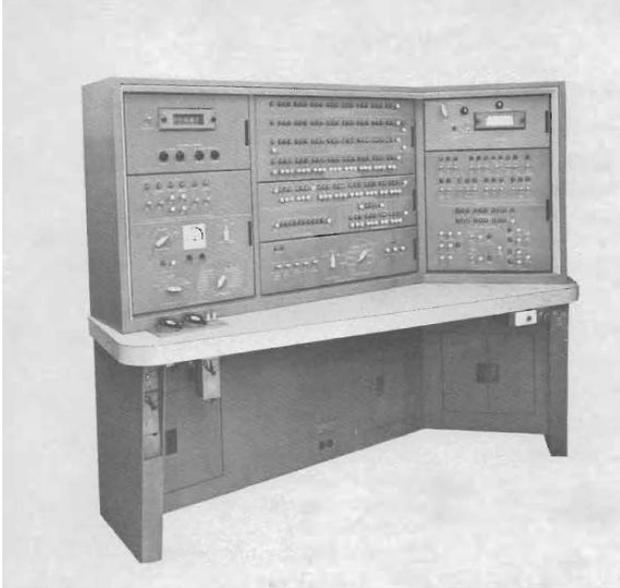
Digital Computer



The digital computer accepts azimuth, elevation, range, range rate and lateral rate information in binary form from the rate and tracking radars. This input information is sampled by the computer and the necessary computations are performed to determine the guidance commands required by the missile on its trajectory.

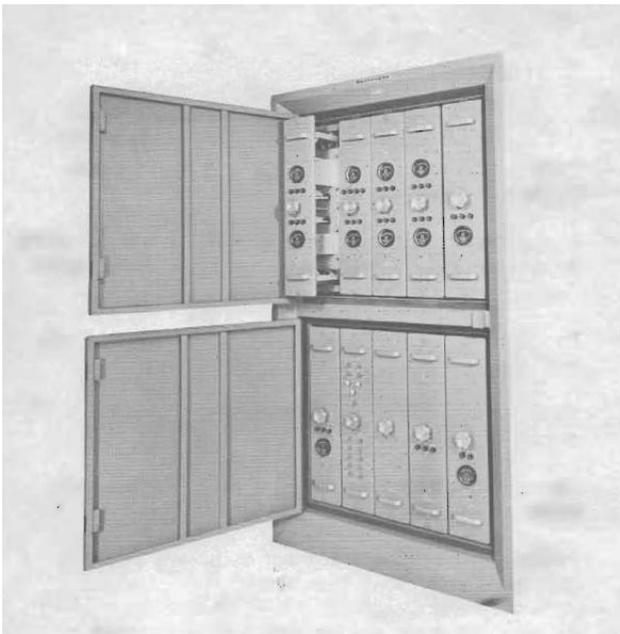
The computer is packaged as a single cabinet containing 55 plug-in packages plus a bank of manual switches which control the switch memory. Included in this cabinet are 34 direct-coupled transistor logic packages; 8 wired-core memory packages which contain program instructions, equations and launch point constants; 1 package containing a ferrite-core main memory which stores intermediate data and results of computations; and 4 packages which serve as sense amplifiers and inhibit drivers to the main memory.

Operating Console



The operating console is a single cabinet comprised of three panels with all controls and indicators arranged for optimum operator orientation. The operating console permits the exercise and test of the system as a whole, or of its major elements, either automatically, semi-automatically, or step-wise with visual indication of correct or erroneous operation.

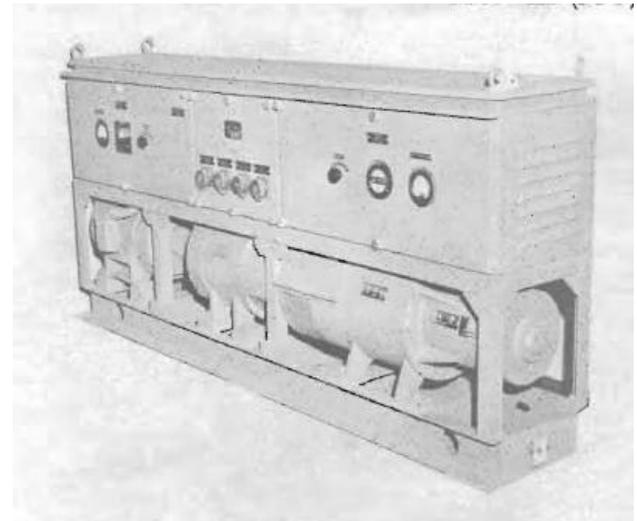
Power Supply Unit



The power supply for the computer is contained in a separate cabinet compatible with other units of the

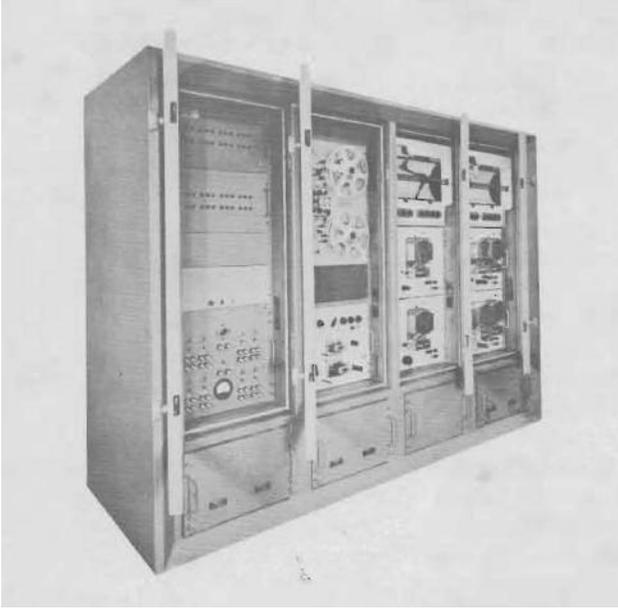
computer system. The power supply circuits consist of a simple transformer, rectifier, filter and associated protector and switching circuits. The power supply unit receives power from the 420-cycle generator in the motor-generator set and converts this voltage to d-c for use in the computer.

Motor-Generator Set



The motor-generator set is a regulated source of power for the guidance computer system. Each is a complete functional unit which incorporates controls and components. By converting the 60-cycle input power to a closely regulated output required for computer operation, the sets serve to isolate the computing system from input power transients. A control cabinet mounted above the rotating equipment contains starting switch gear, regulator-exciter, and protective devices. Each motor drives the generators with in-line shafts mechanically connected by flexible couplings. The generators are rigidly secured to a common intermediate base.

Terminal Equipment Unit



The terminal equipment consists of a single cabinet containing 15 removable packages. Included are two rectangular coordinate plotters, four recorder packages (two containing two tape punches), one package containing a high-speed tape reader, one package containing two tape readers (one a single, the other a dual tape device), seven circuit packages, a vacuum pump, and a tape storage bin.

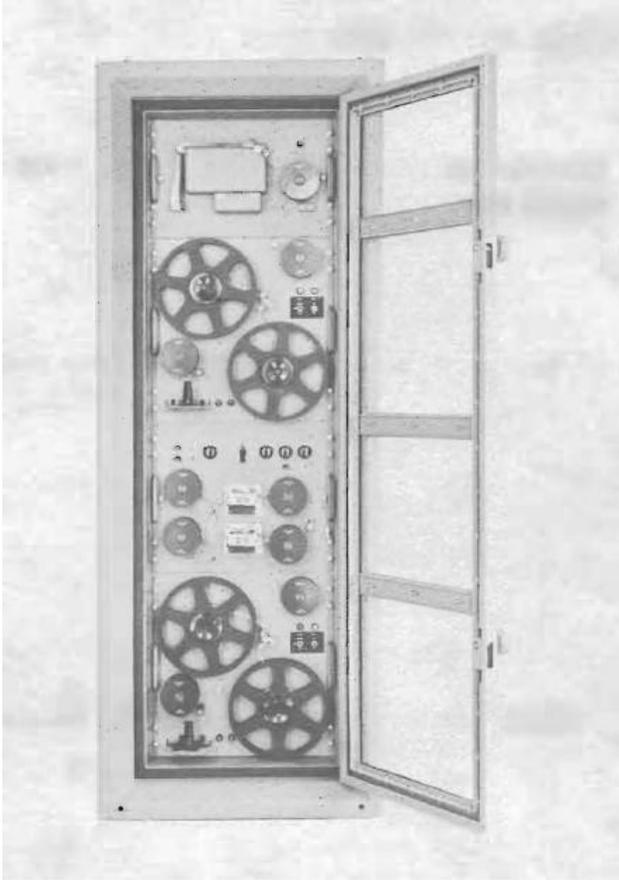
The unit automatically records computer intermediate results and output data on punched tape, and graphically plots actual or simulated missile trajectories resulting from computer output. During test and exercise operations the unit provides computer input data as read from punched tape which simulates the signals received from the radar tracking system during actual guidance. This unit is capable of checking the accuracy of the computer output information by comparing the output data with pre-punched master tapes containing the correct data for a particular simulated input.

Data Printer



The data printer is used with the terminal equipment unit, data processing unit or verifying reperforator and is a separate off-line unit which does not affect the operation of any other system element. This unit consists of a commercially available electric typewriter modified by Burroughs to incorporate an electro-mechanical translator.

Data Processing Unit

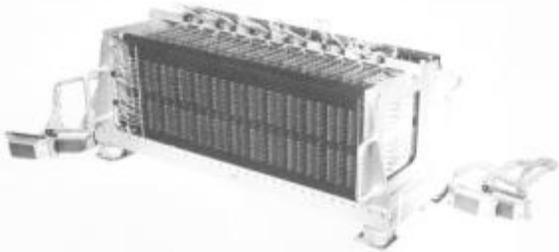


The data processing unit is used to compare or process information on punched tape. A single cabinet contains four removable packages: a data punch, a comparator package, and two tape supply reel units. Each package contains its own controls, fuses, and indicators, and the unit operates automatically in accordance with the appropriate control setting. The data processing unit performs a variety of tape processing functions. It compares two tapes which stop automatically to give visual indication of any discrepancy and merges the information contained on two separate tapes into a single tape.

Additional Talking Points

1. While the guidance computer itself is entirely transistorized (or solid state) the tape readers and punches in the Terminal Equipment Unit contain vacuum tube driver assemblies. The readers and punches were manufactured by the Teletype Corporation and had a proven record for absorbing the constant mechanical pounding they would endure while in operation. Burroughs simply repackaged the mountings to fit into the Terminal Equipment Unit cabinet without making any major modifications to the Teletype equipment.

2. While all modules of the computer are heavily marked with their functions, including their individual test ports, there is one large unmarked panel on the Digital Computer cabinet. It is behind this panel that the random access memory module



resides. It is a long box (*above*) containing 24 square frames stacked in a row. Each frame (*left*) is criss-crossed with fine wires in intersecting rows. At each intersection is a tiny ferrite (compressed powdered iron) donut, or core, threaded onto the wires.

By passing an electric current through the wires, corresponding cores can be magnetized, representing a binary “1”, or demagnetized, representing a binary “0”, binary being the basic language of all digital computers.

3. By combining all of the memory (program plus random access memory) and translating that into modern 64-bit architecture, the MOD I computer contains about 578 words (bytes) of memory.

4. The term “byte” had not come into being when this computer was built. The term in use at the time was “word”.

5. There is no input keyboard or video display in the sense of modern computer technology. The Operator Console contained all the switches and displays necessary for the operator to run, monitor and troubleshoot the computer.

6. The tape readers and punches in the Terminal Equipment Unit use paper tape, not magnetic tape. The higher quality paper tape was reinforced for added strength with a thin film of mylar plastic sandwiched inside two paper layers. These are 7-level reader/punches, meaning that each character on the tape consisted of a single row of seven holes. The code combination of seven holes and non-holes on each row corresponded to a number or alphabetic letter.

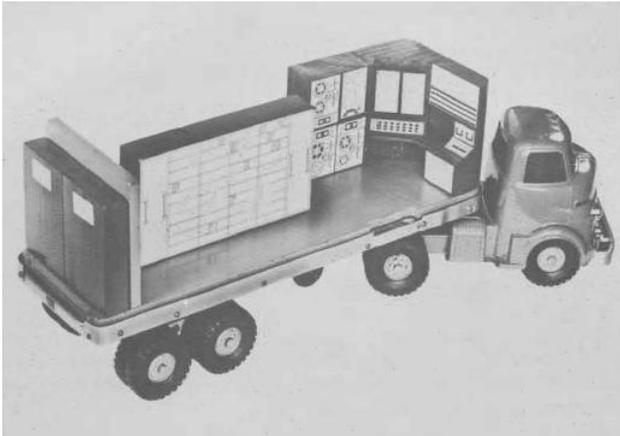
7. The glass doors on the Terminal Equipment Unit are mainly for soundproofing. The Teletype readers and punches made quite a clatter when they were running. Old movies showing the inside of a newspaper or television newsroom frequently include the very recognizable clatter of the ever-present Teletype machines from each of the major wire news services (AP, UPI, Reuters, etc.)

8. The plotters at the top of the right two Terminal Equipment Unit doors contain small ink pens that leave a line on the plotter paper as they move. The lines are a visual record of position or velocity of the flight. Special plotters were often installed in remote locations available to Range Safety from which the Range Safety Officers could instantaneously see the progress of a missile flight and make flight safety decisions based on the plotter readings.

9. While the Motor-Generator Set is on display at the Museum with the rest of the guidance computer, it would have been installed in another room at operational installations. When running, the Motor-Generator Set makes a tremendous amount of noise, sufficient to drown out any attempt at nearby conversation.

10. The original concept for the Burroughs guidance computer included a requirement for the

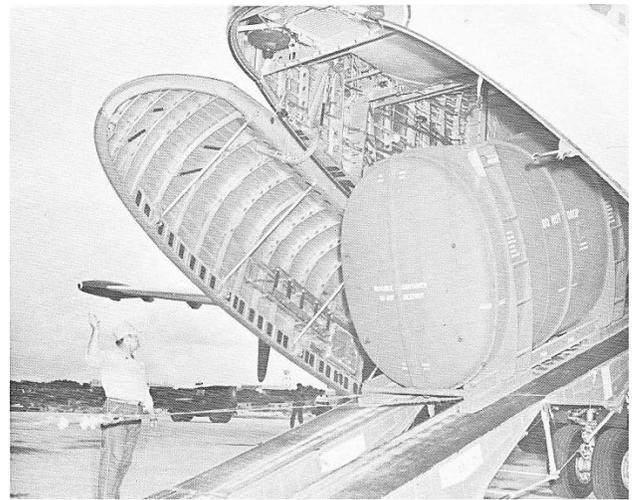
computer to be installed inside of a semi-trailer (model below) for mobile operation. The requirement was dropped before design began.



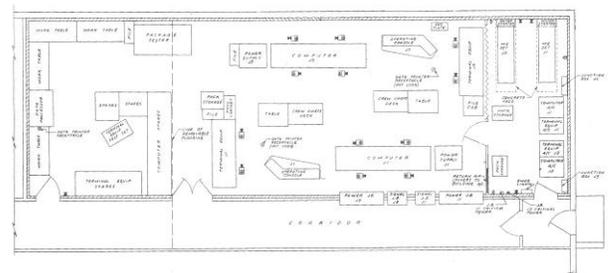
It is assumed that this mobile guidance computer would have been used in conjunction with the General Electric mobile guidance system on display in the rocket garden (below).



11. Elaborate metal shipping containers were built for the first few computer units shipped to Cape Canaveral and San Salvador. The containers received substantial damage during the air shipping process and were never used again. The computer units were packed in reinforced wooden crates and shipped by truck. No further damage was noted. There is no word on how the San Salvador computer was shipped out at the end of its life. The photo (below) shows an early shipping container being unloaded from a C-124 aircraft at the Cape Canaveral Air Force Station skid strip.



12. The Burroughs guidance computers at the Cape were installed in the General Electric (GE) Radio Guidance Center. This facility was later designated the Delta Support Facility. The building still exists and is located on the north side of Lighthouse road about halfway between Complex 26 and Phillips Parkway. When operational, the building stood at the center of a set of four tracking antennas that were in the form of a cross with the guidance center in the middle. The abandoned cable trench for one of the antennas passes directly through Complex 26 in a NW to SE direction immediately parallel to the crossover road nearest Pad 26B. The diagram (below) shows the arrangement of the original J-1 and J-3 installation, plus maintenance area in a single room at the Guidance Center.



Compiled for the Air Force Space and Missile Museum by Jim Hale, 16 September 2011, from museum accession records and Burroughs Corporation reports. Special thanks to John "Andy" Anderson for historical perspective on the operational installation at the Cape, John Hilliard for operational Atlas site information, and George Leiby, former Burroughs techrep.

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