1958

Fact Sheet

AN/FSQ-7
Computer

The SAGE/BOMARC Air Defense Weapons System

An illustrated explanation of What It Is and How It Works

IBM®

Military Products Division International Business Machines Corporation, 590 Madison Avenue, New York 22, N.Y.

NOTE TO EDITORS

This is the story of what happens when someone presses the "Fire" button on the Air Force's BOMARC air defense missile.

Because BOMARC is to be integrated into the SAGE system, it is also a story of what goes on in the IBM computer which functions as the control center of SAGE.

> For the purposes of illustration, this fact sheet recounts the remote firing of a BOMARC missile from a launch pad at Cape Canaveral by an IBM computer located 1,500 miles away in Kingston, N. Y.
>
> In normal operations, the firing station could be any of the BOMARC bases programmed by the Air Force. The IBM computer would be located in one of the adjoining SAGE centers. Ordinarily the distance between the missile launch pad and the computer would be several hundreds, rather than thousands, of miles.

The Air Force program for testing the compatibility of the BOMARC missile with the SAGE system has been conducted by the Military Products Division of IBM at its Kingston plant.

For further information, call:

IBM - Kingston (N. Y.)
Federal 8-5000 Ext. 223

IBM - New York City
Plaza 3-1900 Ext. 2782

Contents

I. ELEMENTS OF THE SAGE/BOMARC SYSTEM

The BOMARC weapons system is a surface-to-air missile system developed for air defense for the Air Force by Boeing.

When integrated with SAGE it becomes a fully automated system.

The target is tracked automatically.

The missile is launched automatically.

The missile is guided automatically to its target.

BOMARC is designed to operate with the air defense system. It shares that system with other air defense weapons. It functions as an integral part of the integrated air defense system.

Elements of the System

The SAGE/BOMARC system consists of the BOMARC missile itself and two additional elements which are part of the air defense ground environment.

These elements of the ground environment include:

1. Search and height-finding radar with a built-in data processor, and

2. A giant IBM/SAGE computer which functions as the control center of the whole air defense system.

Elements Of The SAGE/BOMARC System

A. THE BOMARC MISSILE

The BOMARC IM-99 is a supersonic rocket-launched ground-to-air missile which will permit the Air Defense Command to engage and destroy enemy aircraft far out from the intended target. Its range of over 200 miles permits defense of large areas.

Manufactured by Boeing Airplane Company, the BOMARC has a wing span of 18 feet, a length of 47 feet, and a diameter of 35 inches. It weighs about 15,000 pounds.

It combines the high thrust feature of its booster rocket with the fuel economy of its twin ramjet engines to achieve altitudes above 70,000 feet, speeds over Mach 2.5, and ranges in excess of 200 miles.

BOMARC employs the latest electronic guidance systems including the terminal guidance system in the missile itself. It is controlled remotely while in flight by an IBM/SAGE computer. It can carry a nuclear or conventional warhead.

The BOMARC is tied in with America's vast and complex air defense systems, which provide warning of an enemy air attack in seconds. The BOMARC has been fired on orders from a SAGE control center nearly 1,500 miles from the launching site, successfully intercepting drone targets. Both single and multiple targets have been successfully intercepted by the SAGE-BOMARC system. This versatile, integrated system can detect, track, intercept, and kill both subsonic and supersonic targets.

Newer models of the BOMARC will have increased range, and work is presently underway on a solid propellent propulsion system. Crew training was activated January 1, 1958. Units are expected to become operational soon.

The first four of fourteen BOMARC sites scheduled to become operational are located at or near Dow Air Force Base, Me.; McGuire Air Force Base, N.J.; Otis Air Force Base, Mass.; and Suffolk County Air Force Base, Long Island, N.Y.

B. THE RADAR DATA-PROCESSING SYSTEM

Long-range search radar is used to detect and report the target. Radar returns are converted by an on-site data processor into range and bearing. This positional information is relayed to the remote IBM/SAGE computer via leased lines.

Height-finding information is requested and processed automatically by the IBM computer.

For test purposes, an IBM/SAGE computer at Kingston, New York has been used to fire and control BOMARC missiles from Cape Canaveral — 1,500 miles away. When the SAGE/BOMARC systems become fully integrated, missiles will be controlled from the nearest SAGE installation.

Radar installations employed in these tests are located at the Patrick Air Force Base.

C. THE IBM/SAGE COMPUTER

SAGE is the name given the nation's vast new electronic air warning and interceptor control network. A number of air defense sectors already have SAGE systems in operation. When completed, the SAGE system will gird the U.S. air approaches and provide for an integrated system of air defense in depth.

Heart of the SAGE system is an IBM-built computer called the AN/FSQ-7.

This computer digests radar returns from all sources, plus ground observer reports, flight plans and weather information. It translates this information into an over-all picture of the air situation.

The computer automatically calculates for the air commander the most effective employment of such defensive weapons as guided missiles, anti-aircraft batteries and jet interceptors. In the case of intercepting jets, the aircraft are controlled by directions fed by radio directly from the computer to the automatic pilots in the planes.

First Automated System

The BOMARC is the first automated surface-to-air missile to be integrated into the SAGE system.

The SAGE computer locates the target; identifies it and tracks it.

From a point, hundreds of miles away, the missile is actuated and fired by the SAGE computer.

The computer controls the missile in flight and maneuvers it to the point where it dives on its target.

In the performance of these tasks, the computer responds to a "program" which is set up in advance in the machine. This "program" causes the computer to do specific things as certain events occur in rapid sequence. To control a single BOMARC firing, the computer must run through many thousands of individual steps in continuous sequence.

SAGE stands for Semi-Automatic Ground Environment. The system was devised by the Massachusetts Institute of Technology Lincoln Laboratories. IBM/SAGE computers are built by the company's Military Products Division at its plant in Kingston, New York.

II. FIRING SEQUENCE

On August 7, 1958, the IBM/SAGE computer at Kingston undertook the first remote-controlled intercept of a drone target by a BOMARC missile. The BOMARC was fired from Cape Canaveral and the intercept was made at sea.

This was the first "live" compatibility test of the SAGE/BOMARC system.

Since then, there have been others.

On September 23, 1958, two BOMARC's were fired simultaneously against two drone targets. Both intercepts were successful.

Other tests conducted against conventional drone aircraft proved highly successful.

The SAGE/BOMARC system is designed so as to permit a single air defense sector to control a number of BOMARC missiles in simultaneous flight against a number of tracked targets.

Phases of the Sequence

What follows is an illustrated explanation of a single BOMARC firing sequence.

For the sake of convenience, this sequence is organized into four phases:

A. Target Detection and Reporting
B. Target Tracking
C. Missile Firing Preparation
D. Missile Guidance and Intercept

A fifth drawing assembles the whole system into a single illustration to show the relationship of its several parts.

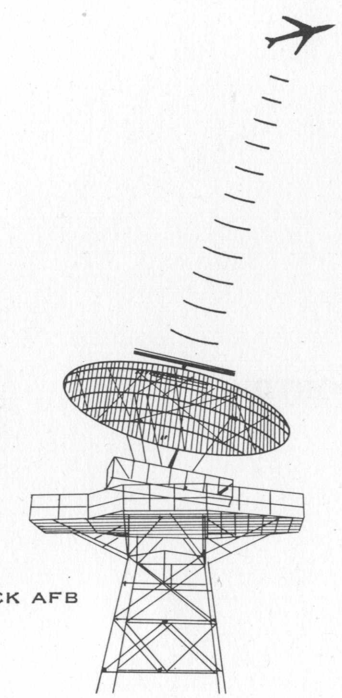
Appended to the firing sequence is a textual description in greater detail for further reference use.

First Phase

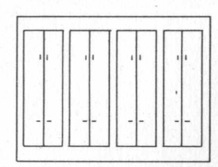
TARGET DETECTION AND REPORTING

FLORIDA

1 Radar system at Patrick AFB picks up signal which may indicate approach of a hostile aircraft.



2 Radar obtains positional data on this flying object. It passes the information on to a coordinate transmitter.

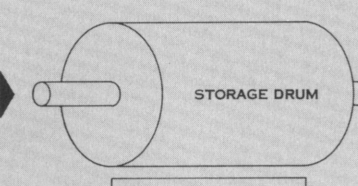


3 This coordinate transmitter converts the positional information given it by radar into data on the object's range and bearing.

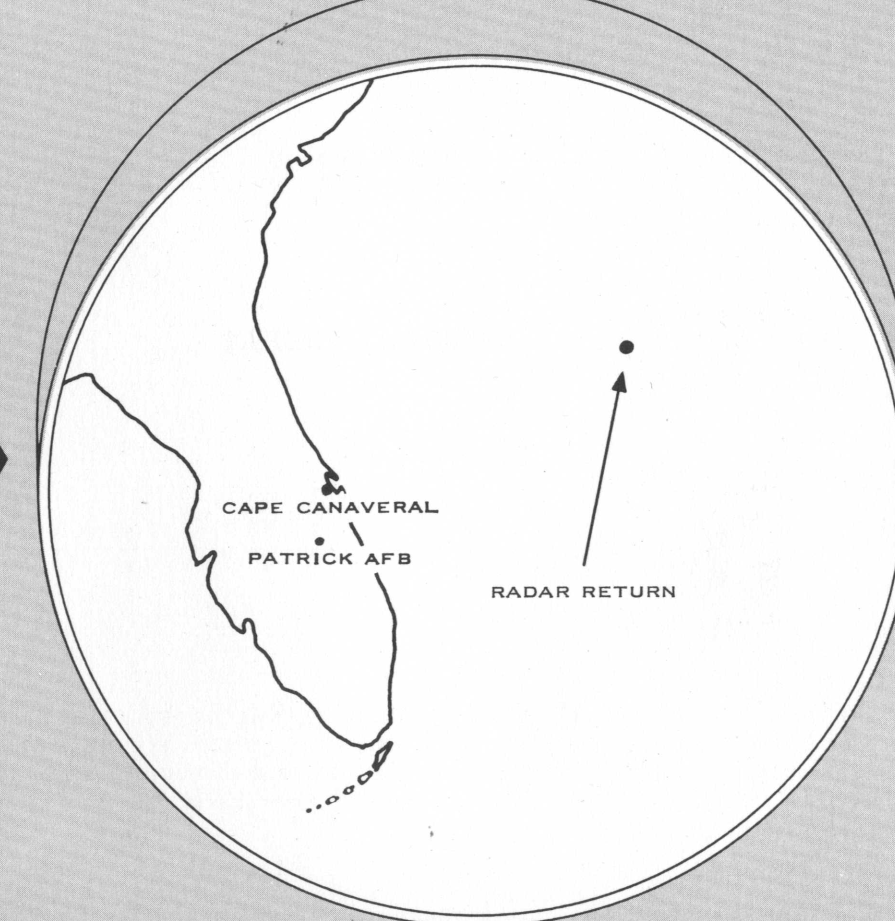
DATA LINK

4 Information on the object's range and bearing is transmitted 1,500 miles to the IBM computer at Kingston via leased lines.

IBM COMPUTER/KINGSTON



5 Range and bearing information is relayed into the computer and stored in the computer's memory system.



6 Blip appears on the scope of the IBM computer at Kingston. It indicates an unknown flying object off the coast of Florida. This single radar signal is now stored in such a way that it can be associated with subsequent radar signals to determine whether the radar indeed may have picked up a hostile aircraft.

Second Phase

TARGET TRACKING

FLORIDA

DATA LINK

IBM COMPUTER/KINGSTON

7 At this point—a few seconds later—a second radar signal is picked up by the same radar in Florida. It, too, is converted into range and bearing and transmitted to Kingston in the same manner as the first.

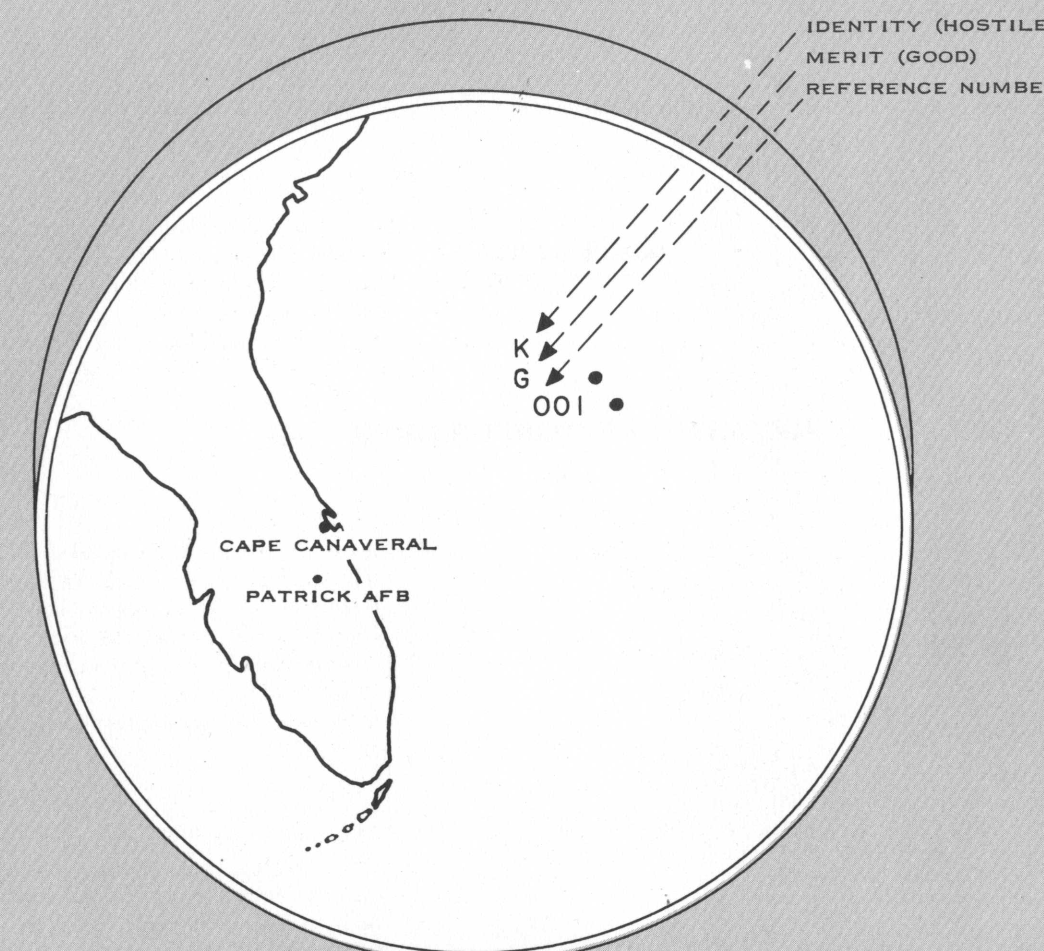
8 Information on the range and bearing of this second radar signal is stored in the IBM computer.

9 The computer automatically evaluates this second radar return. It relates it to the information already stored in its tracking system. It attempts to ascertain if this second return comes from the same flying object that produced the first—the unknown object which is now displayed on the scope.

10 If, on the basis of this second and subsequent returns, the computer establishes a correlation which indicates that an unknown object has penetrated the air defense sector, the computer sets up a target track. Now it will evaluate all subsequent radar returns to determine which ones are related to this flying object.

The tracking operator now identifies the track as hostile. The computer automatically requests information on the target's altitude from the height radar at Patrick AFB. This information is automatically transmitted to Kingston where it is stored in the IBM computer with other data on the hostile track.

However, if the computer does not establish a correlation among the first, second and subsequent returns, the computer stores those latter returns separately since they may indicate that the sector has been penetrated by some other object with a new range and bearing.



11 As subsequent radar returns are relayed to the IBM computer, they will confirm or dispute the "merit" of the track which has now been displayed on the scope. Symbols appear on the scope along with the track. "K" identifies it as a hostile track. "G" indicates that it is a track of reasonable validity. A reference number "001" is assigned the track to distinguish it from others in that sector.

Third Phase

MISSILE FIRING PREPARATION

FLORIDA

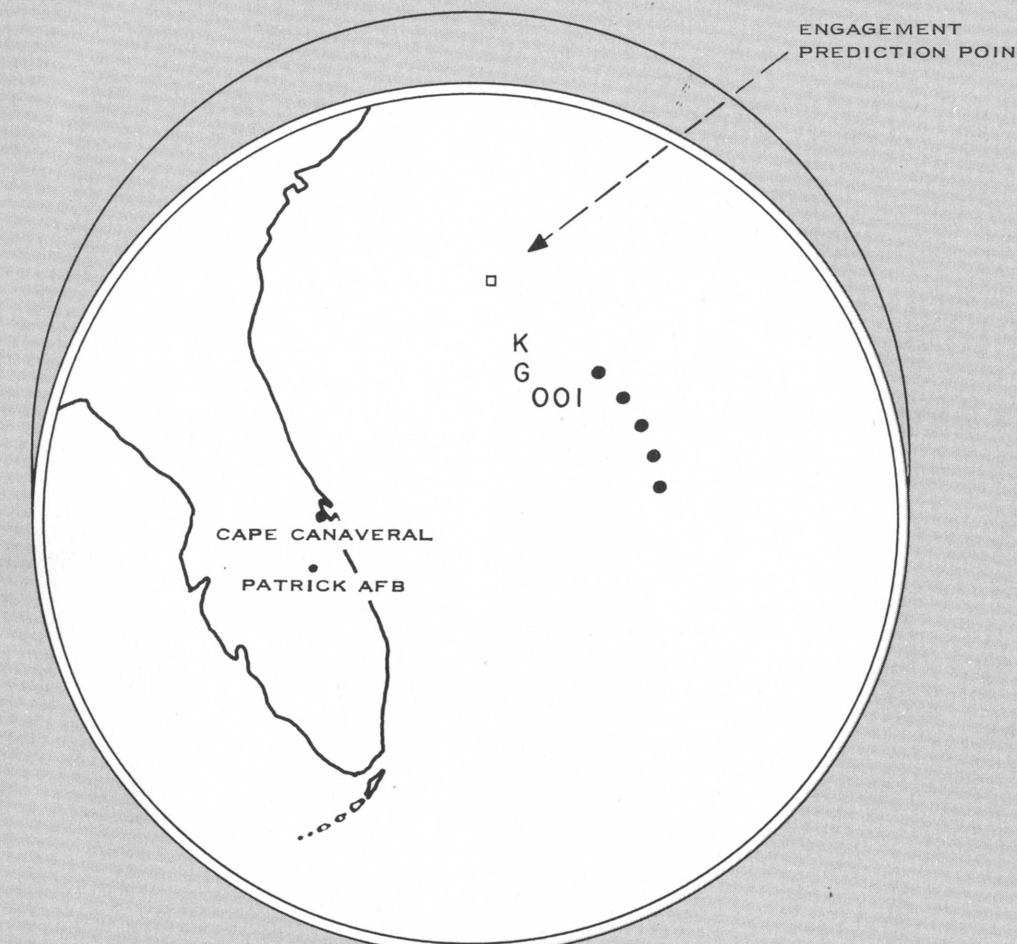
DATA LINK

IBM COMPUTER/KINGSTON

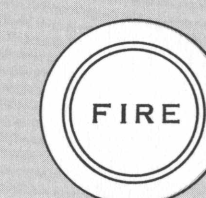
12 The target is now being tracked continuously by the computer as it maneuvers on its flight path into the sector. The computer performs complex calculations at split second intervals to predict the target's course and stay with its track.

13 A final check is made with Cape Canaveral to ascertain that a BOMARC missile is ready for firing on a signal from Kingston.

14 Cape Canaveral confirms that a BOMARC missile is in "standby" status and is ready for firing. This information appears on a digital display at the operator's console in Kingston.



15 The operator requests an "engagement prediction point" from the IBM computer. On the basis of the target's range, heading and altitude, the speed and flight characteristics of the BOMARC missile, and on the basis of atmospheric conditions, the computer predicts that point at which the intercept would take place if the missile were to be fired at this time. This "engagement prediction point" appears on the scope in the form of a small square.

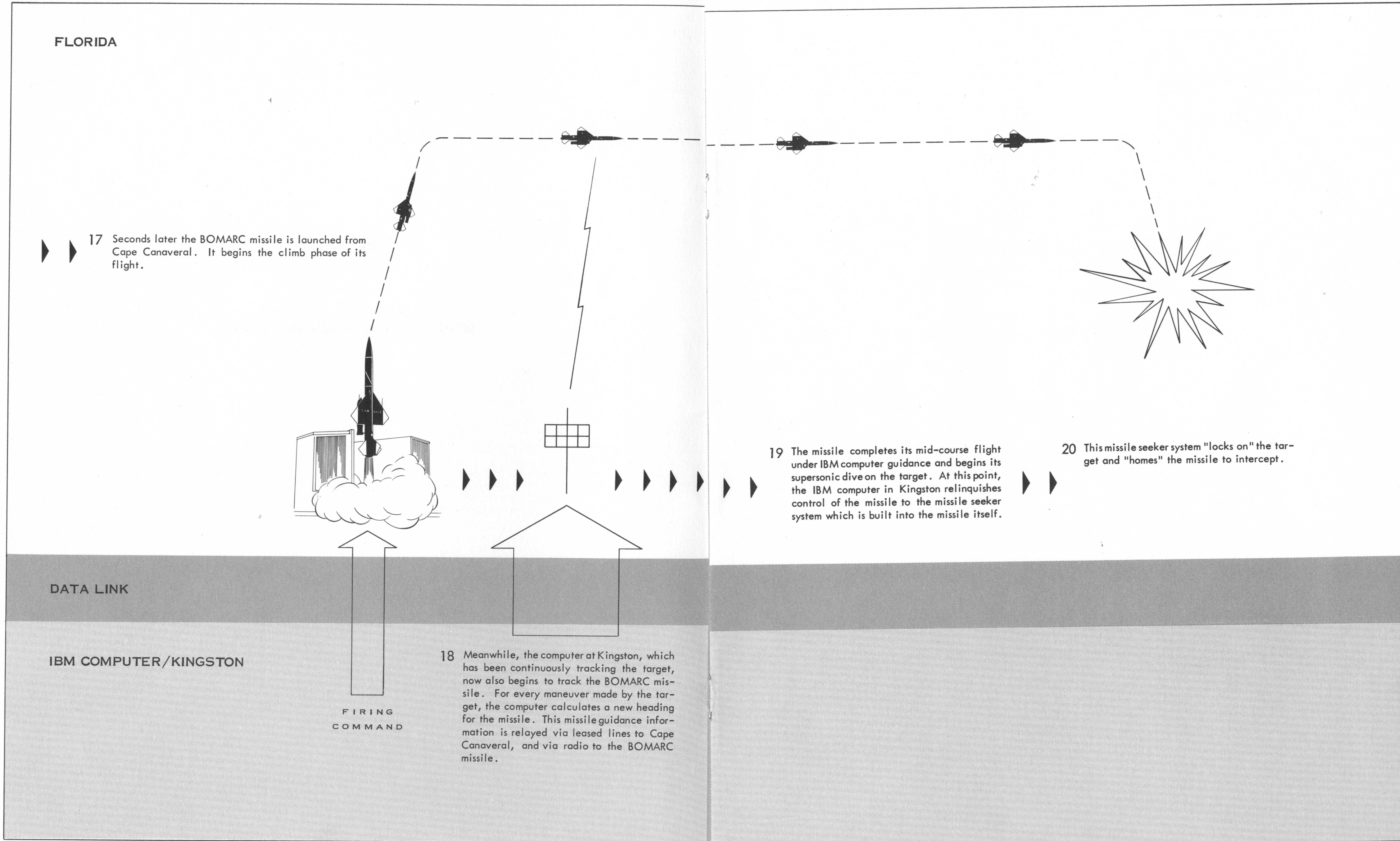


16 The operator at Kingston presses a "Fire" button on his console. This causes the computer to send commands to the missile at Cape Canaveral for initiation of the "fire-up" stage preparatory to launch.

Fourth Phase

MISSILE GUIDANCE AND INTERCEPT

Fourth Phase: MISSILE GUIDANCE AND INTERCEPT



17 Seconds later the BOMARC missile is launched from Cape Canaveral. It begins the climb phase of its flight.

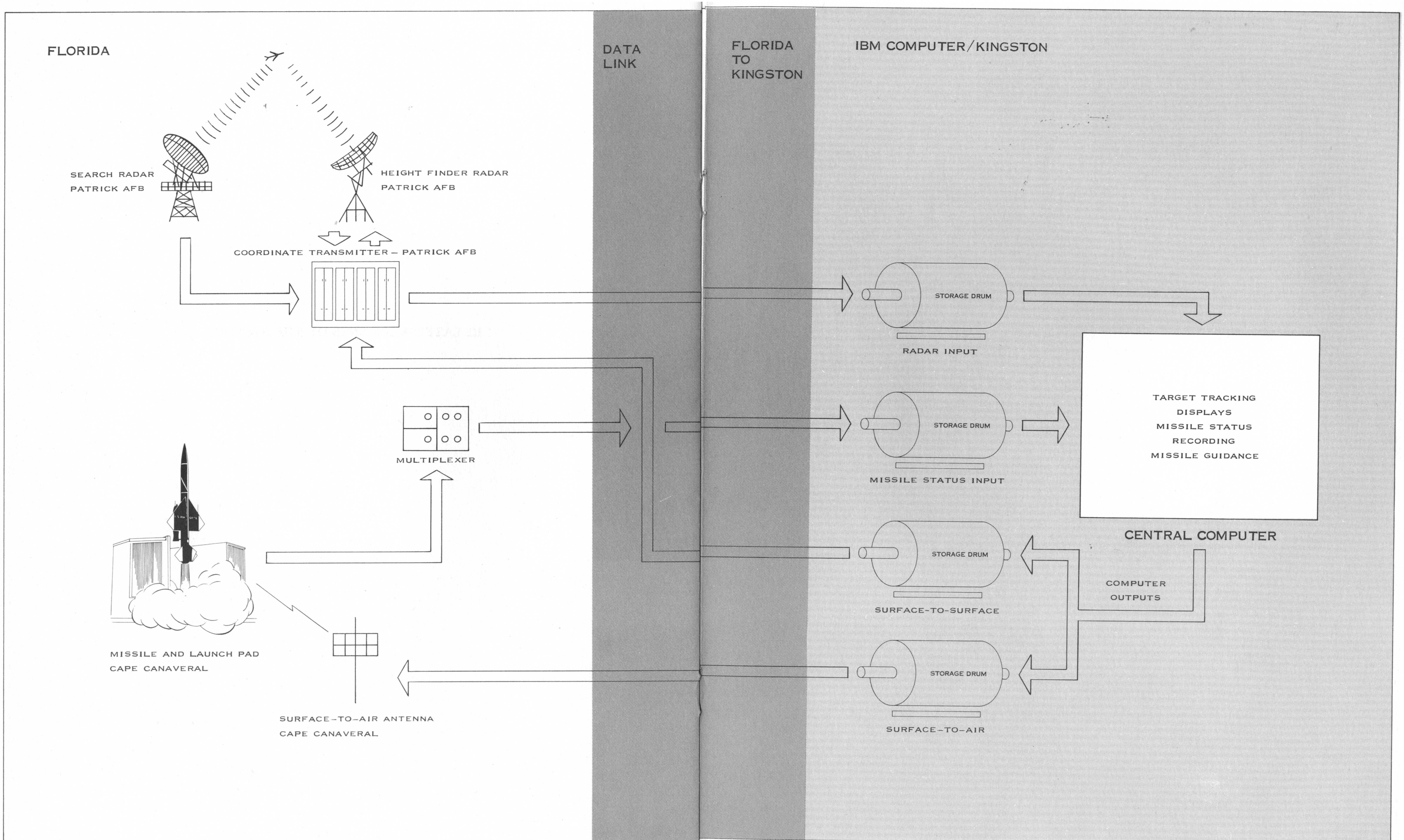
18 Meanwhile, the computer at Kingston, which has been continuously tracking the target, now also begins to track the BOMARC missile. For every maneuver made by the target, the computer calculates a new heading for the missile. This missile guidance information is relayed via leased lines to Cape Canaveral, and via radio to the BOMARC missile.

19 The missile completes its mid-course flight under IBM computer guidance and begins its supersonic dive on the target. At this point, the IBM computer in Kingston relinquishes control of the missile to the missile seeker system which is built into the missile itself.

20 This missile seeker system "locks on" the target and "homes" the missile to intercept.

RELATED ELEMENTS OF THE SYSTEM

IBM SAGE/BOMARC SURFACE-TO-AIR WEAPONS SYSTEM INTEGRATION



III. DETAILED TEXTUAL EXPLANATION

IBM Integration of the SAGE/BOMARC System

The following explanation, more detailed than that provided in the foregoing illustrations, is organized into the same four phases of a BOMARC firing. Each chapter can be related to the corresponding drawing of the illustrated sequence.

First Phase

A. TARGET DETECTION AND REPORTING

The IBM integrated SAGE/BOMARC firing sequence begins when an AN/FPS-20 long-range search radar at Patrick Air Force Base, fifteen miles southwest of Cape Canaveral, detects what may be a flying object off the coast of Florida in the sector screened by that radar.

This return is passed along to an AN/FST-2 coordinate data transmitter located on the radar site. The data transmitter converts the radar return to polar coordinates — range and azimuth — for transmission in digital form over 1,500 miles of leased lines to the IBM/SAGE AN/FSQ-7 computer in the Military Products Division plant of IBM at Kingston, New York.

Role of the "Program"

Digital information on the object's range and azimuth is stored in what are called the "Long Range Input" magnetic drums of the IBM computer. There the information is read by a "program" previously stored in the computer. And there the radar return is converted into "Cartesian coordinates."

The "program" consists of detailed instructions which are fed into the computer by punched cards and by magnetic tapes. They describe the sequence of operations which will cause the computer to perform the tracking, firing, and guidance tasks assigned it. Instructions for a BOMARC firing entail a sequence of many thousands of individual steps which are continuously repeated.

The "Cartesian coordinates" supplant the range and azimuth which had been relayed to Kingston. The latter had been calculated from the fixed point of the radar set at Patrick Air Force Base. When converted into Cartesian coordinates, this information is referenced to the launch pad of the BOMARC missile at Cape Canaveral. Thus when the missile is launched, track information on the target and guidance information on the BOMARC will be referenced to the same fixed point.

Establishing the Track

At this stage, the return is examined by the track correlation program of the IBM computer. The purpose here is to determine whether this "new track" can be associated with any other already in the system.

For the time being, the single radar return can signify one of three things:

1. It may be part of a previous track

2. It may represent "noise" — some form of electronic or atmospheric interference

3. Or it may, indeed, indicate a penetration of the sector by an unknown flying object.

If the return does not fall within a few miles of some previous track, and, therefore, is presumed not to be a part of another, the signal is stored in the IBM computer as a new, or "initial" pickup.

For the purposes of this firing, barring interference, we can assume that we may have detected a target.

At any rate, a blip has now appeared on the tracking scope of the IBM computer.

Second Phase

B. TARGET TRACKING

The whole TARGET DETECTION AND REPORTING sequence is being repeated continuously as new radar returns come in from the radar at Patrick Air Force Base to the IBM computer at Kingston.

The computer first stores and then evaluates these subsequent returns. It attempts to establish a correlation between them and the initial return to ascertain if there is evidence enough to justify the setting up of a new track on the computer's display scope.

If the tactical situation is such that the operator does not wish to await this evidence, he can initiate a new track manually on the tracking console. This he can do, first, by inserting into the computer the approximate speed and heading of the new object; thereafter, by hitting the target blip on his scope with the beam from a "light gun." This action will set up the track as "established." The track will be given a "fair" rating on creditability.

Correlation Process

On the other hand, if the operator does not initiate the track manually immediately after it has been set up as an "initial pickup," the program causes the computer to check subsequent returns at five second intervals to determine if they correlate with the initial pickup. If this correlation is established, the IBM computer automatically classifies the initial pickup as a "tentative" track, and gives it speed and heading. Another return with the same correlation — and the "tentative" track becomes "established."

For the moment, the track has only range and heading; its altitude is as yet unknown. The estimated height of the track may be inserted into the data tables of the computer by the operator at the console. Or, the procedure will be accomplished automatically.

Finding the Altitude

When the sequence remains automatic, the program transmits the "Cartesian coordinates" of the target for which height is requested to the output buffer drums of the IBM computer. The request is then transmitted via telephone lines to an AN/FPS-6 height finder radar on the search radar site at Patrick. When the target is located and its height determined, this information is sent to Kingston by way of the AN/FST-2 data transmitter in the same manner as a search radar return. The electronic message is labeled a height reply. This height information is then automatically inserted into the IBM computer along with other information on the track.

In a combat situation, the new track would already have been correlated, not only with other unknown tracks in that sector, but with all other flight information in the SAGE system to determine whether it is "hostile" or "friendly." Presumably, for test purposes, this finding has been made. The unknown object is labeled "hostile;" it will be intercepted.

Blip is Labeled

Now the blip appears as an established track on the tracking console of the computer.

A "symbology" appears along with it. This symbology consists of three elements: (a) a reference number which is assigned the track to identify it; (b) a letter indicating the "merit" of the track; and (c) a letter indicating its identity, in this case — hostile.

The "merit" of each track is being constantly reviewed as all subsequent returns are correlated by the computer. Tracks are labeled "G" for good, "F" for fair, and "P" for poor. If the merit rating of a track declines, this would indicate to the operator that radar returns are not coming in with the same frequency. A manual adjustment may be needed on position and bearing to keep the track in sight. Or the track may disappear — indicating that it may have been caused only by atmospheric interference.

Assuming, however, that the track is real, that it is hostile, and that it has penetrated the sector, we shall now have to call on BOMARC to intercept it.

Third Phase

C. MISSILE FIRING PREPARATION

The airborne target off the coast of Florida is now being tracked continuously by the IBM computer in Kingston as it maneuvers on its flight path.

Once the track becomes "established," the computer predicts that position at which the target can expect to be found on the next radar return. This prediction is based on the target's last known heading and speed. The computer then looks for the target at, or near, that predicted position.

"Smoothing" the Track

However, it is quite possible that the next radar return may not show up at that precise prediction point. For one thing, the target may be in a turn; it may have changed its heading. For another, the radar may be exhibiting some of the inaccuracies common to any radar system.

The tracking program of the IBM computer will automatically compensate for these variances by "smoothing" the heading, speed and position of the target. By applying formulae already programmed into the machine, the computer will show a compromise point somewhere between the predicted position and the actual radar return. This "smoothing" technique enables the computer to follow the target no matter how evasive its maneuvers may be.

Firing Preparation

Meanwhile, the computer begins to prepare for the firing.

It automatically requests information from Cape Canaveral on the readiness status of the BOMARC missiles. This information is sent from a device called the "launcher status multiplexer," close by the launch pad. It goes via telephone lines into a crosstell drum of the IBM computer at Kingston and appears as a digital display at the weapons console.

The BOMARC missiles will be in any of the following stages: (a) Ready Storage, (b) Warm-up, (c) Standby, (d) Fire-up, (e) Launch, or (f) Malfunction.

Missiles ready for firing will show up on the console in "Standby" status.

Engagement Prediction Point

The operator at the Kingston console now requests an "engagement prediction point." This is the point at which the intercept would be made if the BOMARC missile were to be fired at this time.

Again, the computer refers to its program. In a split second, it performs the intricate computations necessary to relate the range, speed, heading and altitude of the target with the complex performance characteristics of the BOMARC missile.

The "engagement prediction point" appears on the IBM scope in the form of a small square. Once the target has been fired upon, a bracket will be displayed around this predicted engagement point. When the BOMARC is airborne, the engagement prediction point is replaced by an "X" to mark the computed intercept point.

The stage is now set for firing.

The operator in Kingston presses a FIRE button. This signal is relayed by telephone lines to the Cape. The "standby" missile now enters its "fire-up" stage preparatory to launch.

Meanwhile the IBM computer in Kingston continues to follow the target track.

Fourth Phase

D. MISSILE GUIDANCE AND INTERCEPT

At the instant the FIRE button is pressed at the weapons console in Kingston, pre-launch computations are initiated and transmitted to the guidance unit in the BOMARC missile.

These commands are fed directly to the missile during the brief period between flight initiation and take-off. They continue to go to the missile in flight via radio. They go by land-line to a transmitter at Cape Canaveral and from there by radio to the missile.

A few seconds after the fire button has been pressed, the BOMARC is boosted in a vertical climb by its rocket motor. The missile's ramjets cut in with a roar as soon as ignition speed has been achieved.

Within seconds, the 15,000 pound missile completes its climb to altitude and levels off for the midcourse phase.

Midcourse Flight

Midcourse commands are now calculated and transmitted to the missile as required to maintain an intercept course. These commands concern missile azimuth, time remaining until dive, dive angle, and the pointing angle of the homing device which is built into the missile. They take into account not only the performance characteristics of the missile itself, but a host of other factors relating to intercept conditions. All these computations are programmed in the computer in such a way that the same program can be employed in firing other missiles of varying characteristics.

At each calculation during this midcourse flight of the missile, a comparison is made between old and new missile headings. Any change in heading is noted by the computer and this information is used by the tracking program to "command track" the missile on its maneuver.

Missile Identification

Radar returns on the missile differ from non-missile returns. A built-in feature enables the radar-site AN/FST-2 data transmitter to distinguish between radar returns from the missile and target, and to distinguish each missile return from another. The flight path of the target appears on the scope at Kingston as a line of tiny crosses. The flight path of the missile appears as a succession of slants or slashes.

When the missile is guided to within striking distance of the target, the IBM computer tips it into a steep dive.

Homing Dive

Soon after the dive begins, the computer cuts out. The missile track is dropped by the computer program and the missile is now on its own.

The missile's seeker then "locks on" the target. The missile "homes" to the target and makes the intercept.

IV. SIMULATION

In the development of a weapons guidance and tracking system as complex and automated as this, it was necessary that we have some less costly but wholly reliable method of proving the computer's capability in advance of actual missile flights.

In developing the enormously detailed "program" which is required to make the computer work, and in testing the several elements of the system for compatibility, IBM employed a technique which is especially adaptable to systems in which digital computers are used.

All Elements Simulated

All elements of the system, including missiles, targets and radar equipment, were simulated in the computer.

Simulated radar returns on targets were pre-stored on tape and read into programs for the computer. They were processed exactly as if they had been real returns from real targets. Even "noise" returns and the varying performance characteristics of radar were simulated.

To simulate the BOMARC missile, it became necessary to analyze its flight characteristics in tedious detail and to express those characteristics in numeric language for use by the computer.

Such missile properties as weight, speed and maneuver capability had to be represented to simulate an actual missile in flight. These complicated equations also reproduced such forces as thrust, drag, lift and gravity.

Program Functions in Same Way

Despite what appears to be a vast difference between simulated and "live" firings, the system functions in precisely the same way on one or the other. To conduct a simulated firing, the operator need only make a switch insertion at the computer console.

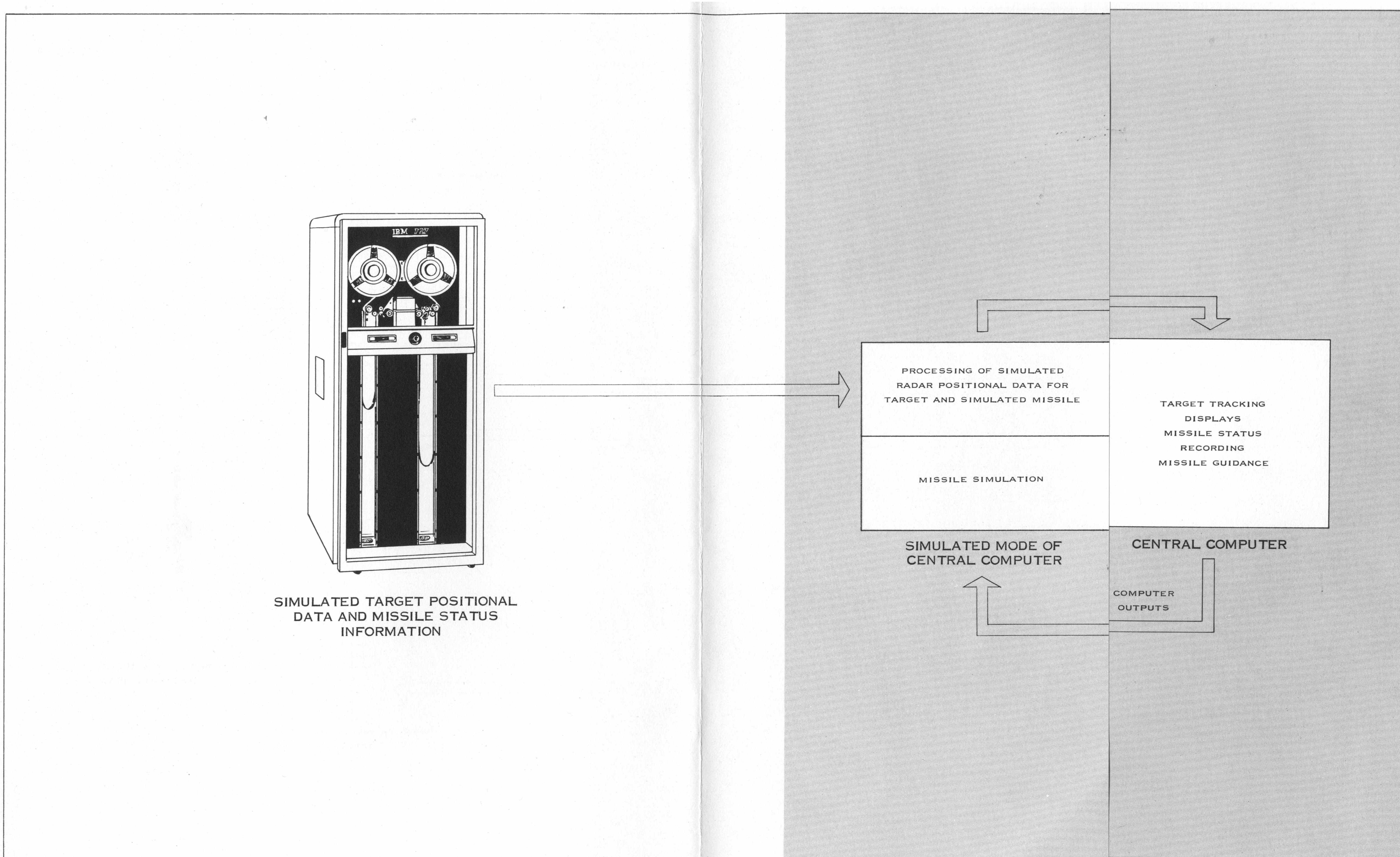
The simulation program will generate simulated radar and missile inputs, activate the simulated missile, and represent it in its flight to interception. Thereafter, the very same computer program which was used for this simulated test can be employed in the live firing.

Value of Simulation

Simulation has not only helped to reduce costs in the development of the weapons system, but it enables the system to be checked out with a dry-run preparatory to every "live" or operational firing. It is a technique which permits the weapons system to pre-test itself for reliability without any disruption of readiness.

The procedure has been employed in almost 2,000 simulated intercepts with a high degree of success.

SIMULATION TECHNIQUE


IBM 727
SIMULATED TARGET POSITIONAL DATA AND MISSILE STATUS INFORMATION
PROCESSING OF SIMULATED RADAR POSITIONAL DATA FOR TARGET AND SIMULATED MISSILE
MISSILE SIMULATION
SIMULATED MODE OF CENTRAL COMPUTER
TARGET TRACKING
DISPLAYS
MISSILE STATUS
RECORDING
MISSILE GUIDANCE
CENTRAL COMPUTER
COMPUTER OUTPUTS