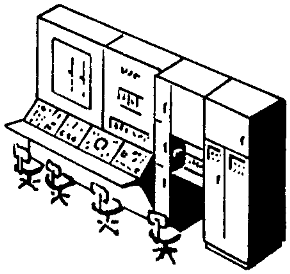

LESSON 7. NIKE HERCULES COMPUTER STEERING AND RECORDING

MMS Subcourse No 150	Nike Radars and Computer
Lesson Objective	To give you a general knowledge of the purpose, sequence of events during steering, and the basic functions of the horizontal and altitude plotting boards and the data recorder.
Credit Hours	Two

TEXT

SECTION I. COMPUTER STEERING PHASE.

1. **PURPOSE.** Computer-controlled flight starts approximately 7.3 seconds after the missile is fired and ends with missile burst. The two track radar systems supply continuous target and missile position information to the computer. From a comparison of differences between the missile and target information, the computer issues directional commands to the missile. The commands are designed to make the missile intercept the target by following the course that gives the quickest possible intercept. The quantities for solving the fire control problem are target and missile positions and velocities. From these quantities the computer determines the correct missile course and necessary guidance orders to bring the missile to this course. The missile course is correct as long as the target's course or speed does not change. If the target's course or speed changes, the required missile course also changes, and the computer issues new steering orders to the missile. During an engagement, the computer operates continuously to keep the missile as close as possible to the latest correct course.

2. **BLOCK DIAGRAM ANALYSIS.**

a. **Closing velocity solver** (fig 1).

(1) General. Five inputs are fed into the closing velocity solver: radar-to-radar parallax information, distance to the target from TTR, distance to the missile from MTR, time to intercept as determined by the "time-to-intercept" computer, and ballistics fall-in. With these inputs the closing velocity solver determines the rates at which the distance between the target and missile should diminish so that the missile may intercept the target in the predicted time to intercept (T).

(2) Radar-to-radar parallax. The displacement of the MTR from the TTR is known as radar-to-radar parallax. This parallax distance must be considered because target distances are measured from the TTR and missile distances are measured from MTR. The radar-to-radar parallax voltage allows the closing velocity solver to compensate for differences in TTR and MTR emplacement. The parallax information is handset into the computer by means of three variable resistors which allow the computer to see the MTR and TTR as if it were at the same location.

(3) Distance to target and missile. Since all distance inputs to the closing velocity solver are in rectangular earth coordinates, the velocity solver can easily determine the remaining distance the missile must travel by subtracting the missile distance and radar-to-radar parallax from the target distance. These distances

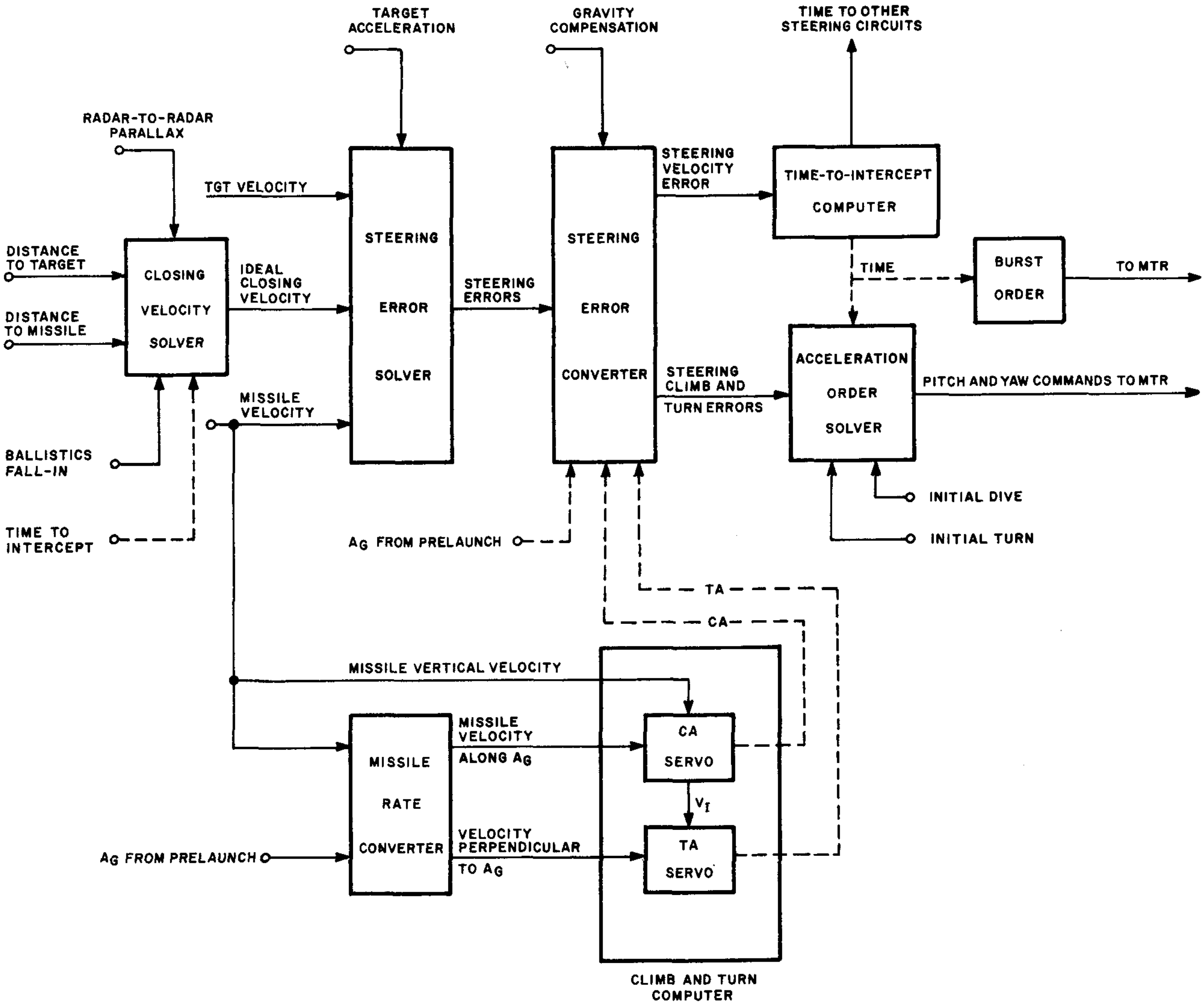

Figure 1. Steering block diagram.

are subtracted in each of the three coordinates (X, Y, and H).

(4) Ballistics fall-in. Ballistics fall-in is a factor applied to the closing velocity solver to guide the missile to a point in space above the intercept point. During the final 10 seconds of missile flight, it is removed from the steering solution by relay action of the computer and the missile is allowed to follow a ballistic descent onto the target. The ballistics fall-in factor is equal to the vertical distance the missile will fall due to gravity during the last 10 seconds of missile flight. Ballistics fall-in is one of the methods used by the computer to counteract the force of gravity on the missile and it compensates for the removal of glide bias during the last few seconds of missile flight. The other method, gravity compensation, will be discussed in the steering error converter.

(5) Time. The time input to the closing velocity solver is represented by a shaft position which is controlled by the "time-to-intercept" computer. In the closing velocity solver, the remaining distance to intercept is divided by this time to determine "ideal closing velocities." The calculation of "ideal closing velocity" is made in all three coordinates (X/T, Y/T, and H/T) and is computed by use of coarse time and fine time variable resistors. Near the end of the missile flight (T = 24 seconds), relays switch to the use of fine time resistors for the calculation of "ideal closing velocities." The "ideal closing velocities," applied to the steering error solver, represent the desired closing rates of the missile and target.

b. Steering error solver.

(1) General. In addition to the "ideal

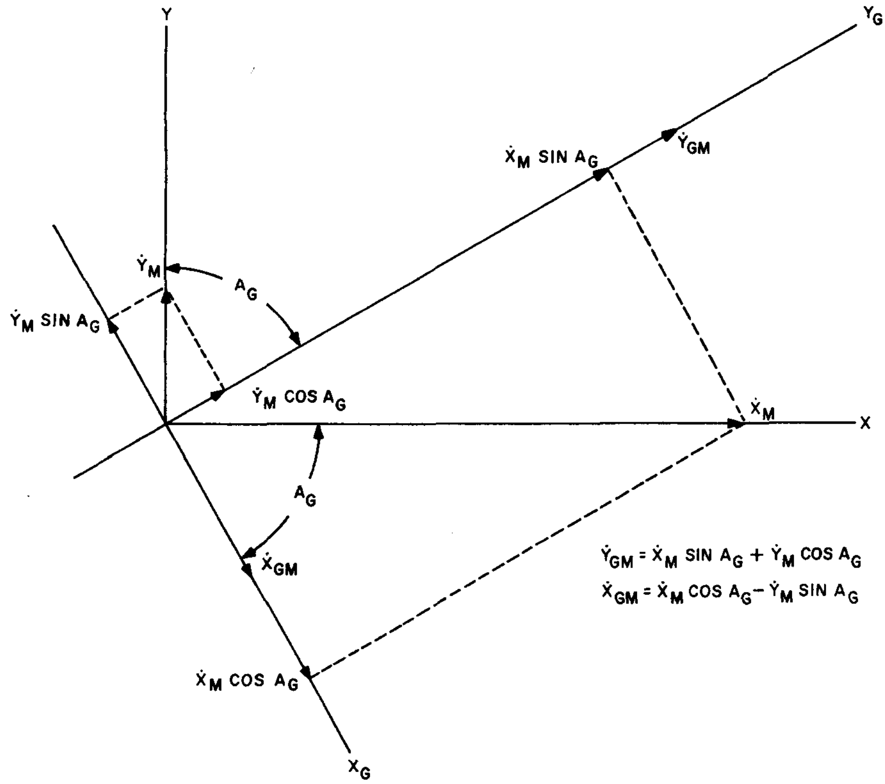

Figure 2. Conversion of the missile velocity from earth rectangular-to-gyro coordinates.

closing velocities," the steering error solver receives target and missile velocities and target acceleration from the steering differentiators. These differentiators perform the same function as those discussed in lesson 6.

(2) Target and missile velocity. The steering error solver computes steering errors in earth rectangular coordinates. This is accomplished by taking the difference in "actual closing velocities" (target and missile velocities) and "ideal closing velocities." The resulting steering errors represent errors in the closing rates of the missile and target and these errors lie along the X, Y, and H axes. The steering errors will be positive if time has been underestimated and negative if time has been overestimated. These errors will later be converted to orders which perform two functions. One causes the time-to-intercept computer to adjust the time solution; the other adjusts the missile flightpath.

(3) Target acceleration. Target acceleration does not enter into the steering solution until the final 24 seconds of missile flight (T = 24). The steering solution is made more accurate by taking target acceleration and deceleration into account.

c. **Missile rate converter.** If the missile is to "understand" the steering orders calculated by the computer, the missile and computer must have a common reference. This reference is established by the gyro azimuth (A_G) which was calculated and locked during the prelaunch phase. Missile velocities in gyro coordinates must be known if the corrective steering orders are to be intelligible. These velocities are determined by the missile rate converter. The missile velocities in earth rectangular coordinates (X and Y) are applied to the missile rate converter. The missile X and Y velocities have components which lie along, and are perpendicular to, A_G. Figure 2 illustrates the determination of these component velocities.

d. **Climb and turn computer.**

(1) General. Since steering orders to the missile are sent in terms of climb and turn commands, it is necessary to calculate the present missile climb angle (CA) and turn angle (TA). The climb and turn computer determines these angles by using missile velocities in reference to the gyro plane.

(2) Missile orientation. In addition to establishing the A_G reference, the roll amount gyro establishes the reference axis for CA and TA and is part of a roll correction system. The origin for development of CA and TA (fig 3) is point 0 and represents the

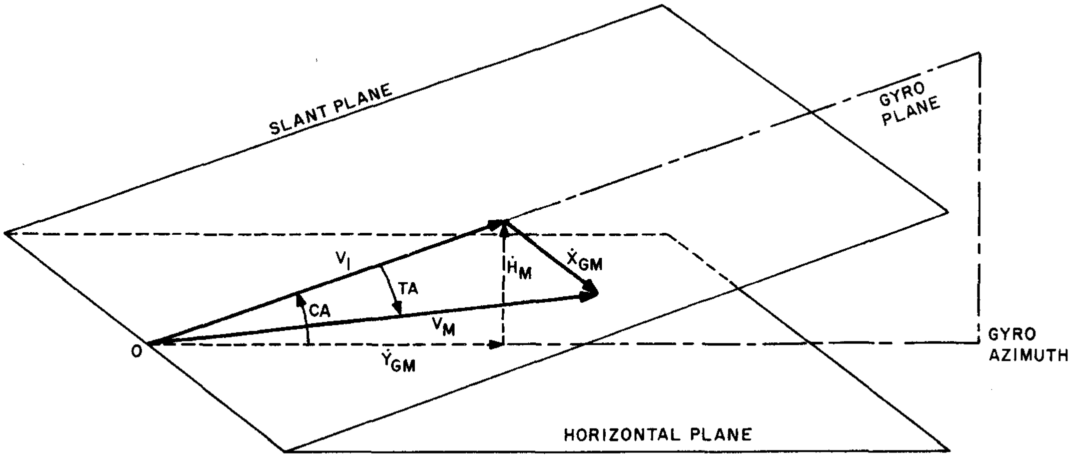

Figure 3. Missile velocity vector.

position of the roll amount gyro. The missile is held in a zero roll condition (no rotation around the gyro azimuth axis) by a roll correction system internal to the missile. This roll correction system is controlled by the roll amount gyro. Zero roll (belly down) is established at roll stabilization. Zero roll holds the missile elevons (control surfaces) in the normal position for executing climb and turn orders. If the missile is not in this zero roll condition, it might climb when it should turn. For example, if the roll angle were 90 degrees instead of zero, a climb order would result in a missile turn.

(3) Climb angle servo. The climb angle servo solves for the missile CA and velocity in the slant plane (V_I) by using the missile upward velocity ($\dot{H}_M$) which is the same in gyro and earth rectangular coordinates) and outward velocity ($\dot{Y}_{GM}$). This is accomplished in the same manner as solving for A_G. The resulting climb angle is a shaft position applied to the steering error converter. The resulting velocity vector (V_I) is a voltage applied to the turn angle servo.

(4) Turn angle servo. The turn angle servo solves for missile velocity (V_M) and TA by using V_I and rightward velocity ($\dot{X}_{GM}$). This calculation is also similar to that of A_G. The resulting TA is a shaft position applied to the steering error converter.

e. **Steering error converter**. The steering error converter translates steering errors into a form which the missile can "understand." The input steering errors are in earth rectangular coordinates which must be translated into steering errors referenced to the gyro coordinates (A_G). This process is the same as conversion of missile velocity - earth to gyro coordinates shown in figure 2. After the steering errors are determined in gyro coordinates, they are translated into errors in climb, turn, and velocity. This final translation of errors requires the CA and TA inputs from the climb and turn computer.

f. **Gravity compensation**. There are two basic methods of counteracting the effect of gravity on the Hercules missile. One method is to issue additional orders to the missile to cause it to climb an amount equal to the distance gravity causes it to fall. For example, if a glide (lift) bias were applied to the missile control elevons to produce a steady upward acceleration equal to 1 G (G = acceleration due to gravity), it would be possible to compensate completely for the effects of gravity. The other method is to use the principle used in aiming conventional guns. This method requires that the missile be aimed at a point directly above the predicted intercept point, so that the vertical distance between the aiming point and the predicted intercept point is equal to the distance that the missile drops due to gravity. This vertical distance between aiming point and predicted intercept point is called the superelevation (SE) distance and is equal to $1/2GT^2$. In this equation, T equals the remaining time of flight. Since SE is a function of the remaining time of flight, the distance decreases as the missile approaches the target. When the missile reaches intercept, SE = 0. The gravity compensation factor applied to the steering error converter is a combination of both methods and counteracts the effect of gravity on the missile. A glide bias of less than 0.8G is applied to the missile; the remaining correction is supplied by superelevation. A combination of glide bias and superelevation is used to retain flexibility of control in the vertical plane. If glide bias were exclusively used, the missile guidance capabilities in the vertical plane would be reduced by 1G. At high altitudes, this would mean that the missile would be incapable of executing the necessary climb command. The glide bias is removed at

(T = 10 sec) to allow execution of full climb and turn commands. Ballistic fall-in, 1b(1)(d), compensates for the removal of glide bias.

g. **Time-to-intercept computer.** Brushes on the time card variable resistors are positioned in accordance with the time solution (T). Since it is impossible to control the speed of the missile so that it will reach a designated point at a desired time, the time solution must be continuously revised so that the missile will arrive at intercept when T = 0. The input to the time-to-intercept computer is a time correction signal (steering velocity error) from the steering error converter. Internal circuits in the time-to-intercept computer regulate the rundown of the time solution. These internal circuits cause time to run down at a second-per-second rate and the steering velocity error input is used to correct this rundown rate. If the steering velocity error is positive, time has been underestimated and the missile must go faster to intercept the target, or time must run down slower. Similarly, if the steering error is negative, time has been overestimated and time must run down faster. The outputs of the time-to-intercept computer are voltages and shaft positions representing time (T).

h. **Acceleration order solver.** The steering errors (climb and turn) are developed as velocity terms and must be converted to acceleration orders before being transmitted to the missile. This is accomplished in the acceleration order solver by dividing the steering errors by time applied from the time-to-intercept computer. The orders to accelerate (change direction) must be rotated 45 degrees since the "belly down" position of the missile orients the missile elevons 45 degrees from the horizontal. Due to this orientation of the missile elevons, a "pure" climb or turn is executed by equal movement of both control surfaces. The acceleration orders are issued to the missile as pitch and yaw (G_P and G_Y) commands by way of the MTR. As the missile corrects its course, the error signals are reduced to zero.

i. **Burst order circuits.** The burst order must be issued before T = 0 to compensate for delays in generating and transmitting the order as well as placing the burst of the warhead at a position to obtain maximum target destruction. The time the burst order must be issued, prior to intercept, is known as burst time bias (BTB). The BTB varies with the missile and warhead used. The BTB is applied from handset variable resistors to the burst order circuits. When T = BTB, a burst order is issued to the missile by way of the missile tracking radar.

SECTION II. PLOTTING BOARDS AND DATA RECORDER.

3. **PURPOSE.** The automatic plotting boards and their associated circuits provide information essential for efficient tactical control of a Nike Hercules battery. The automatic plotting boards, consisting of a horizontal unit, an altitude unit, and their components are mounted on the battery control console in the battery control van. The automatic operation of these boards is made possible through servosystems. The computer output information applied to the plotting board servos is in rectangular coordinates and consists of the predicted intercept point, the target position, the missile position, and the time to intercept. The servos convert the input data into a continuous graphic "picture" of the engagement taking place. The horizontal plotting board displays information in the XY plane. The origin of the plots, i.e., TTR position, is located at the center of the board. The altitude plotting board displays information in the vertical plane and, again, each altitude-time plot is made with respect to the TTR position. All the input data is first transmitted to data selection circuits, then routed via switching circuits to the corresponding pens on each plotting board. A fire mark is produced at the time of fire and timing marks are made on both plotting boards at 10-second intervals. The plots can be placed over an area map and accurately located with respect to the battery position, for later analysis of tactical problems. Another important purpose of the plotting boards is to indicate restricted areas into which missiles may not be fired.

4. **HORIZONTAL PLOTTING BOARD.**

a. The improved Hercules system horizontal plotting board (A, fig 4) plots a continuous record of an engagement in the horizontal plane through use of unlined paper and two pens. Prior to missile away, one pen plots the predicted intercept point and the other pen plots the present target position. After missile away, the pen that was plotting the predicted intercept point is switched to plot the present missile position. The antitactical ballistic missile (ATBM) system horizontal plotting boards are the same as the improved system horizontal plotting boards.

NOTE: Figures 4 and 5 are not scale drawings.

b. The horizontal plotting board (A, fig 4) has a lucite plotting surface of 28.8 by 28.8 inches.

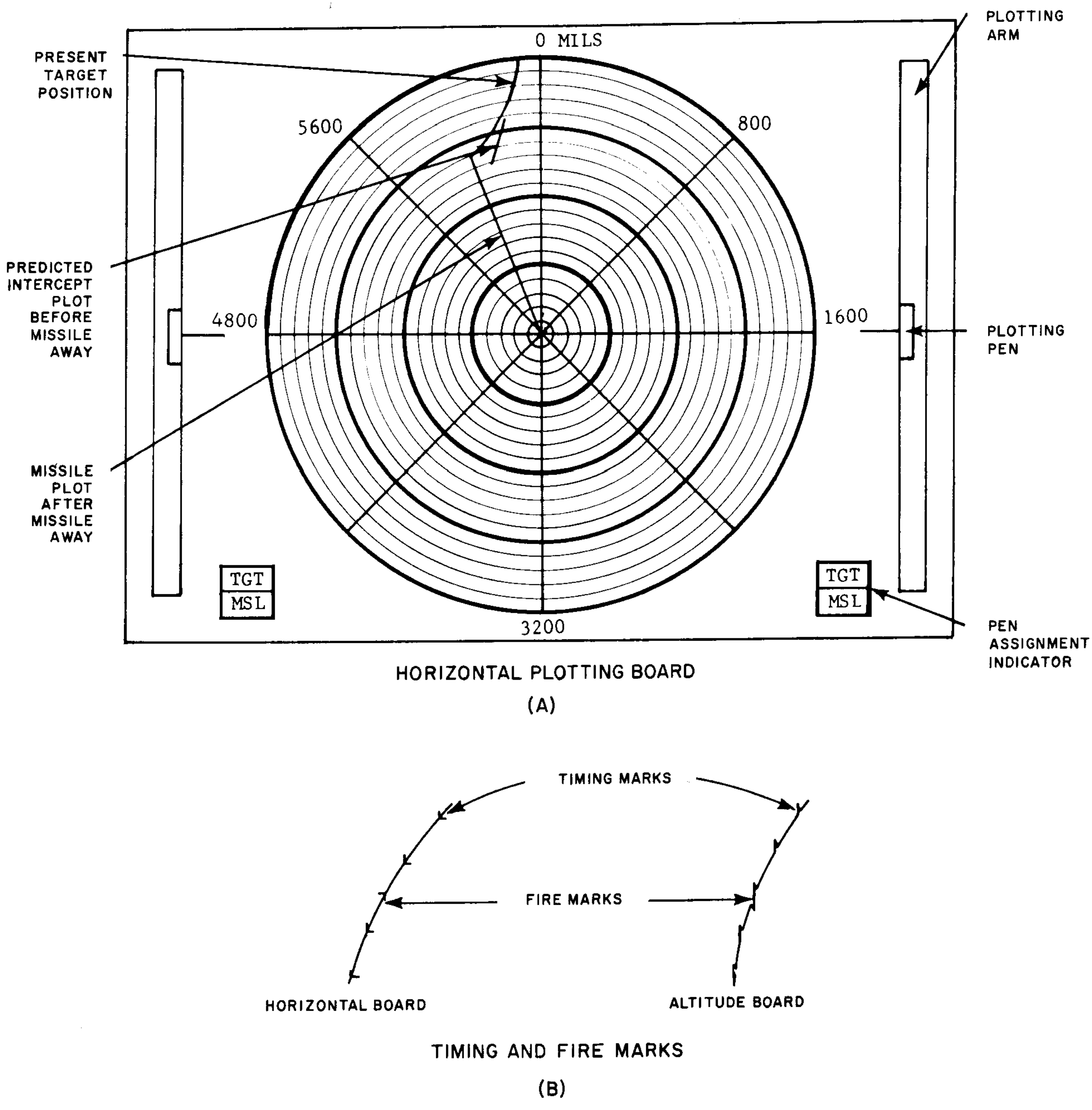

Figure 4. Horizontal plotting board and marks.

Inscribed on the face of the board are a series of concentric range circles and radial azimuth lines. The origin of the lines corresponds to the position of the TTR. Plotting paper is placed over this board for recording an engagement. The board is illuminated by rows of lights placed behind the lucite surface. These lights are powered by a 120-volt, 400-hertz source and may be varied in intensity by adjusting the PLOTTING LIGHTS-HORIZONTAL control on the tactical control indicator.

c. The two pens that plot the engagement are accessible from the front by a swingaway plexiglass window hinged at the left. Each pen is mounted on a carriage that may be driven up or down a vertical plotting arm. The plotting arms may be driven left or right across the plotting board. The pen carriages describe the Y motion, and the plotting arms describe the X motion. Two low-power servomotors, using flexible cables, move the two pen carriages vertically. Two other servomotors move the plotting arms horizontally.

d. During operation, each pen is assigned to plot a definite function. However, if the pens or plotting arms touch while attempting to maintain their respective

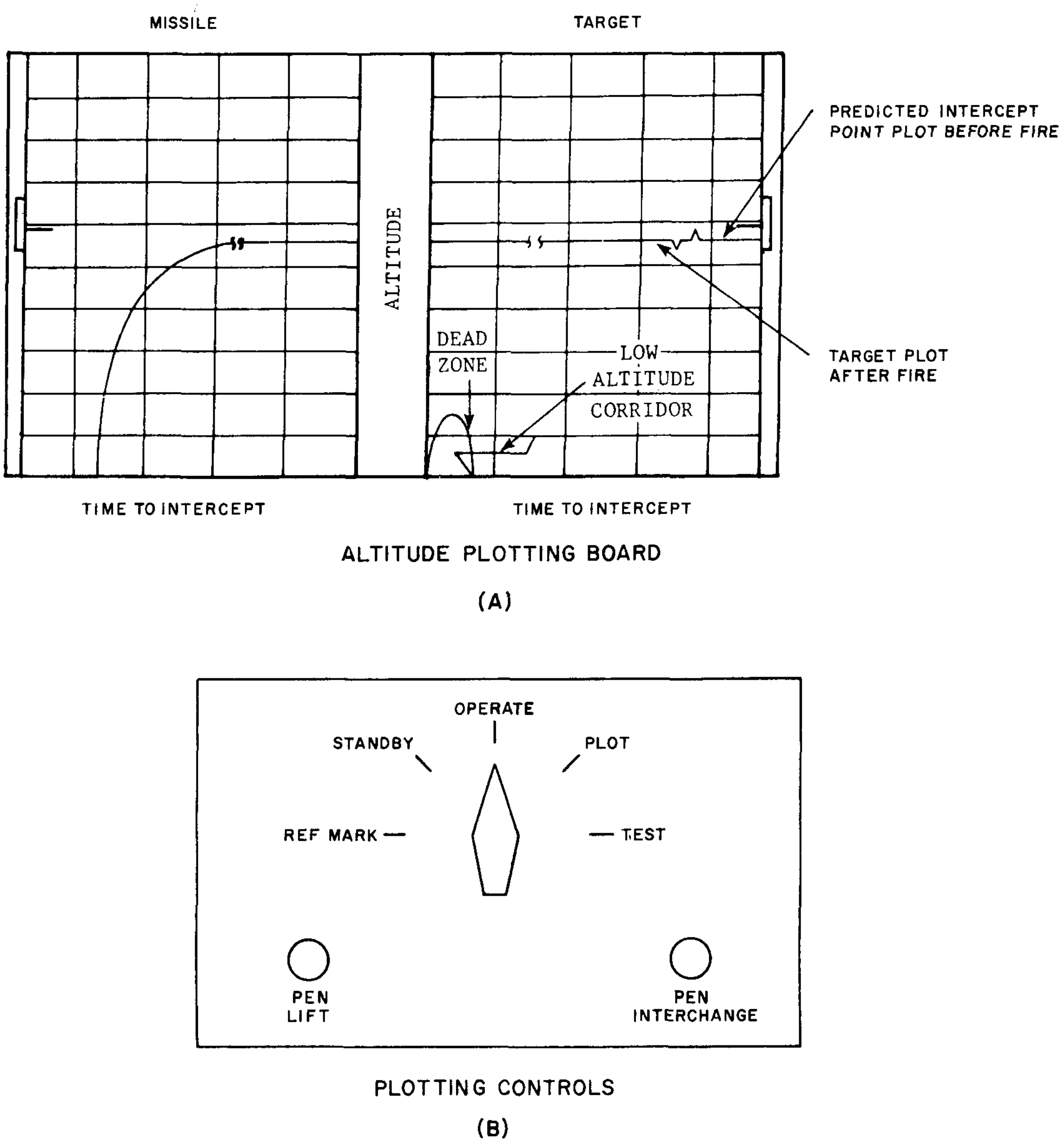

Figure 5. Altitude plotting board and controls.

plots, the pen interchange circuit switches the voltage inputs to the pen servos, and the functions of the two pens are interchanged. In this manner, the pens will not block each other when they come in contact. Pen assignment indicator lamps, located on the lower left and right corners of the board (A, fig 4), identify the pen's assigned function.

e. Timing marks (B, fig 4) are initiated by the mark circuit and appear at 10-second intervals throughout an engagement. The fire mark is inverted and in this way can be distinguished from the timing marks. Following an engagement, the complete plot can be removed. Since the paper is in a roll, removal of the used portion automatically pulls a new piece into place.

5. ALTITUDE PLOTTING BOARD.

a. The improved Hercules system altitude plotting board (A, fig 5), plots a continuous record of target and missile altitudes versus time to intercept. During prelaunch, the right pen plots the altitude of the predicted intercept point versus time to intercept. At missile away, this pen is switched to plot target altitude versus time to intercept. The left pen plots only missile altitude versus time to intercept. The ATBM system altitude plotting board is similar, with two main exceptions. First, the ATBM system altitude scale is three times larger. Second, the left board plots the present target altitude versus time to intercept, while the right board plots the predicted intercept point before

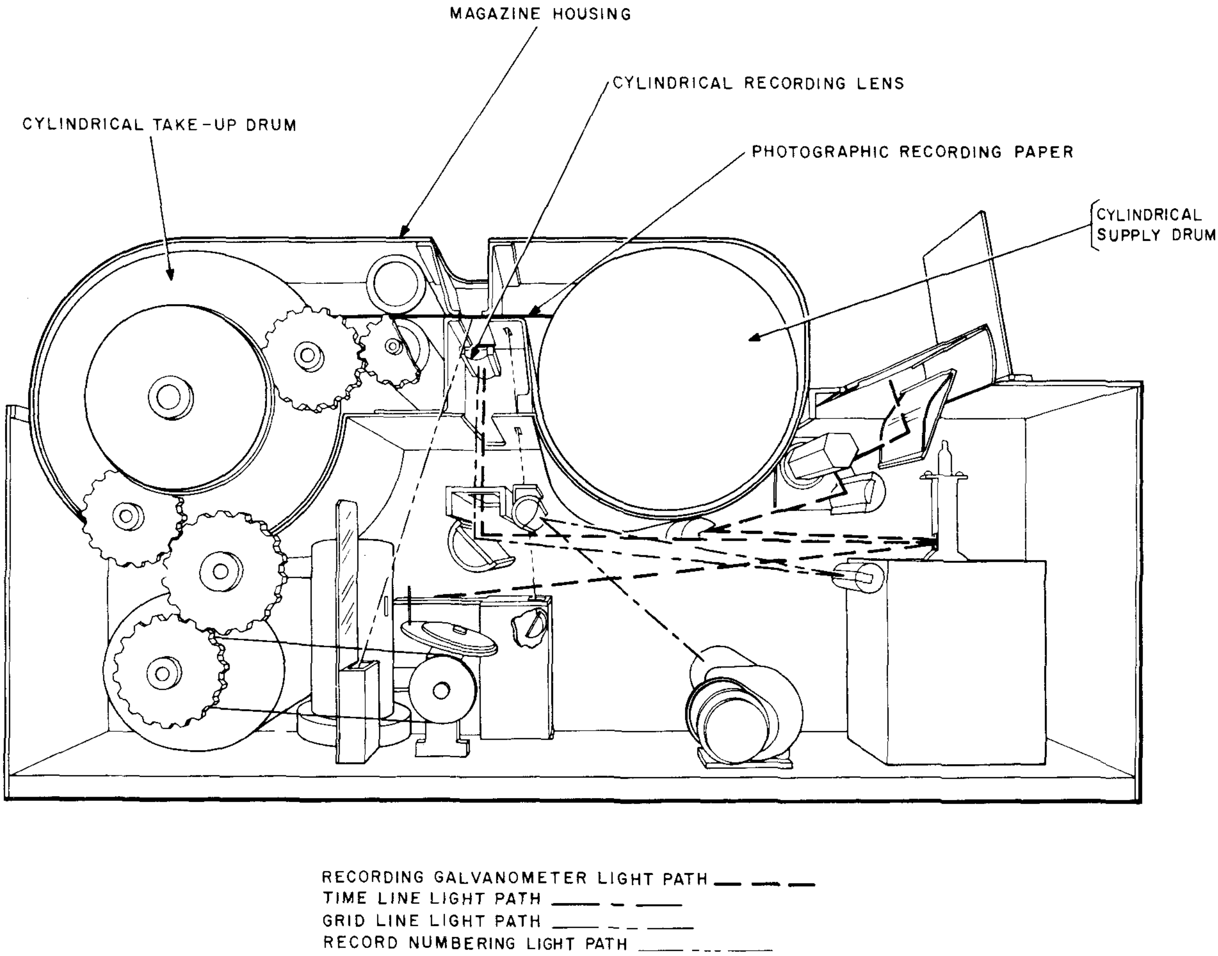

Figure 6. Multichannel data recorder - pictorial diagram.

fire and after fire; it plots missile altitude versus time to intercept.

b. The altitude plotting board has a lucite plotting surface of 9 by 15 inches and is subdivided into two distinct plotting surfaces. The face of the plotting surface (A, fig 5) is inscribed with horizontal and vertical lines representing altitude and time to intercept respectively. The right half of the board is the target portion and is inscribed with the dead zone and low altitude corridor. The left half of the board is the missile portion. This board is illuminated in the same manner as the horizontal board, with a comparable control, PLOTTING LIGHTS-ALTITUDE, located on the tactical control-indicator.

c. The mechanical construction of the altitude plotting board is similar to that of the horizontal plotting board; however, the pen driving mechanism is different. The altitude plotting board requires only three servomotors - one drives the missile pen carriage; the second drives the target pen carriage; and the third, which is common to both pens, drives both vertical arms. The servomotors drive the pens by flexible cables, as in the horizontal board.

d. Pen interchange circuits are not required in the altitude plotting board, since each pen can only operate on its respective side of the board with zero time in the center. However, mechanical stops are provided to prevent the pens from touching and a protection circuit stops the pens should they ever be overdriven.

6. PLOTTING CONTROLS.

a. The various modes of plotting board operations are determined by the plotting controls. The controls (B, fig 5) consist of a rotary five-position switch, the PEN LIFT pushbutton, and the PEN INTERCHANGE pushbutton. With the plotting board condition switch set to STANDBY, the pens of both boards are resting close to the outer edges of the boards. The two pens of the horizontal board are on the 4,800- to 1,600-mil line, and the two pens on the altitude board are on the zero altitude lines. When the switch is placed in the OPERATE position, the pens move to the coordinates of the input data but remain lifted from the plotting surface. When in the PLOT position, the pens drop to the plotting surface and begin recording the desired data. In the TEST position, the pens will trace for test purposes. The PEN INTERCHANGE pushbutton provides manual interchange of the pens on the horizontal plotting board. The PEN LIFT pushbutton is used to lift all pens simultaneously.

b. When the five-position switch is switched from the STANDBY to the REFERENCE MARK position, the right pen of the horizontal board and both pens on the altitude board touch the plotting surface and draw traces of the outer edges of the boards to the origin of the coordinates. The right pen of the horizontal board draws along the 1,600-mil line to zero range and stops. Similarly, the pens of the altitude plotting board draw along the zero altitude line toward each other to their respective zero time positions and stop. Switching from REFERENCE MARK back to STANDBY causes all three pens to draw short vertical lines, lift, and return to their respective STANDBY positions. This operation is used for locating the center and to indicate orientation of the plot before it is removed for evaluation. The OPERATE position is used at the start of an engagement. This position prevents extraneous traces from being plotted while the pens move from the edges of the board (STANDBY) to the current data points (PLOT). Pushing the pen lift button leaves a break in the plot and can be used to reference an occurrence of interest for later analysis.

7. DATA RECORDER.

a. The multichannel data recorder (fig 6), a precision instrument capable of great accuracy, is basically an electromagnetic photograph oscillograph which provides an automatic record of battery activity and equipment performance during an engagement. It also records system testing and training engagement. The permanent record of information provided by the multichannel data recorder may be used to indicate human error, equipment malfunction, or both. The recorded information is useful in evaluating the combat effectiveness and improving the tactical use of improved Nike Hercules systems.

b. Two hundred feet of photosensitive recording paper may be loaded in the multichannel data recorder to provide a continuous recording period of 3 hours and 20 minutes. The recording paper is 12 inches wide and is driven at a rate of 0.2 inch per second. Sixteen signal traces, representing information from various parts of the Nike Hercules system, are recorded on the moving paper. Each engagement is numbered for future identification, and reference grid and time lines are superimposed on the record. The grid lines are 0.1 inch apart on a horizontal scale. The time lines are 0.2 inch apart on a vertical scale, and each space represents 1 second. A photographic processing machine is used in conjunction with the multichannel data recorder for developing the recording paper.

c. The multichannel data recorder, in conjunction with a meter and channel control indicator, a signal and channel relay assembly, and a data switching panel, routes and combines a total of 31 signals into 16 recording channels. The 31 signals are either quantitative or step-type signals. Quantitative signals are those which are always present but have levels which vary with time. Step-type signals are those which have constant levels and which may or may not be present. These signals are plotted on light-sensitive photographic linagraph paper by the following sequence of events: Input signals from the computer are applied to the galvanometers in the multichannel data recorder causing current to flow in the galvanometer coils. This results in a deflection of the corresponding galvanometer mirror. Light, which is present at the lens of the galvanometer, is reflected on a light-sensitive photographic recording paper by associated mirrors and lenses. As the current in the galvanometer coil varies in amplitude, the galvanometer mirror deflects accordingly. Thus, the light beam, which is reflected by the galvanometer mirror, produces a line on the recording paper.

EXERCISES FOR LESSON 7

1. How are the missile elevons orientated with respect to the horizontal plane for proper execution of climb and turn orders?

   A. 15 degrees
   B. 35 degrees
   C. 45 degrees
   D. 60 degrees

2. At what time does switching from coarse time to fine time occur?

   A. T = 0 seconds
   B. T = 10 seconds
   C. T = 24 seconds
   D. Roll stabilization

3. What unit in the computer converts steering errors into pitch and yaw commands?

   A. Acceleration order solver
   B. Steering error converter
   C. Climb and turn computer
   D. Steering error solver

4. At what time is glide bias removed from the steering error converter?

   A. Fire
   B. Liftoff
   C. T = 24 seconds
   D. T = 10 seconds

5. What is the location of the horizontal plotting board pens when the plotting board condition switch is at the STANDBY position?

   A. Both at zero mils
   B. 1,600 to 4,800 mils
   C. Zero and 3,200 mils
   D. Both 3,200 mils

6. Where is the pen interchange circuit used?

   A. All plotting boards
   B. Altitude plotting board
   C. Horizontal plotting board
   D. Early warning plotting board

7. Data applied to the plotting board servos is in which coordinate system?

   A. Gyro
   B. Rectangular
   C. Spherical
   D. Climb and turn

8. Where are the plotting boards located?

   A. Battery control console
   B. Radar control console
   C. Launching control console
   D. Missile control console

9. After missile away, what is plotted by the right pen on the altitude plotting board in an improved system?

   A. Predicted intercept point and target altitude
   B. Missile altitude and target altitude
   C. Missile altitude versus time to intercept
   D. Target altitude versus time to intercept

10. Acceleration (G_Y and G_P) orders transmitted to the missile cause it to perform which maneuver?

    A. Change direction of flight
    B. Change the A_G angle
    C. Increase speed
    D. Decrease speed

11. How does the computer determine the steering errors?

    A. Divides the remaining distance to the target by time
    B. Divides the climb and turn errors by time
    C. Subtracts MTR parallax distance from TTR position
    D. Takes the difference in actual and ideal closing velocities

12. How is the time-to-intercept rundown rate affected if time has been overestimated?

A. Increases
B. Decreases
C. Switches to second-per-second
D. Controlled by a positive steering error

13. Which unit in the computer determines the missile velocities in gyro coordinates?

A. Missile coordinate converter
B. Steering error solver
C. Climb and turn computer
D. Missile rate converter

14. Which angle affecting missile flight is measured from the horizontal to the slant plane?

A. A_M
B. CA
C. TA
D. A_G

15. In which positions should the plotting control switch be placed to mark the orientation of a plot?

A. Standby to reference to standby
B. Standby to plot to standby
C. Operate to plot to operate
D. Operate to test to standby