CHAPTER 11

GUNNERY

Section I. INTRODUCTION

79. (U) General

a. This chapter is a guide for the Redstone battalion commander and his staff on field artillery gunnery for the Redstone battalion. It prescribes procedures for fire direction, computation of firing data, and fire commands.

b. The primary characteristics of the Redstone are its long range and nuclear firepower capabilities. To be effective, this fire must hit the target at the *right time*. Field artillery doctrine demands delivery of accurate fire within time limits imposed by the tactical situation. Procedures must insure maximum reliability, flexibility, and timeliness in the execution of nuclear fire missions.

80. (CMHA) Trajectory

a. Phase I From Liftoff to Cutoff. The missile is fired vertically from point A_0 (fig. 15). The missile ascends initially at a relatively low speed. Because of this low speed, little or no control is provided by the rudders. Carbon vanes, located in the jet exhaust of the pro-

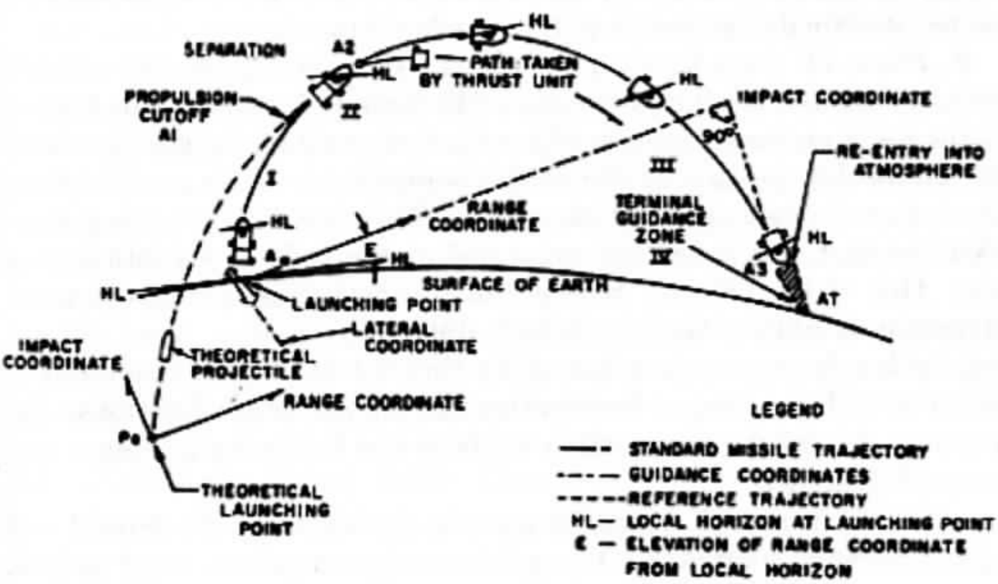

Figure 15. (U) *Redstone standard trajectory.*

pulsion unit, direct the expulsion of the hot gases and provide control and stability during the initial stage of this phase of the flight. Also, during this period lateral deviations are detected by the lateral accelerometer and correction commands are sent to the control surface by the guidance system. Although range guidance as such is not in effect at this time, deviations in velocity and displacement are utilized in the cutoff computer which determines cutoff when preset conditions are satisfied. The deviations that exist in range for the entire trajectory and laterally after cutoff are accumulated in the range and lateral computers and are fed to the control computer after reentry.

b. Phase II from Cutoff to Separation. At point A_1 (fig. 15), conditions permit the cutoff equation to be satisfied, and the propulsion unit is cut off. Cutoff is chosen so that the missile is traveling at a certain velocity at a certain point in space so as to follow a predetermined ballistic trajectory to the target. Between cutoff and separation of the thrust unit from the body, there is a delay of some 10 to 30 seconds. Up to point A_1, the missile has been under a constantly increasing acceleration. As a result, time must be provided for the acceleration to fall to zero and the velocity to stabilize. This is called thrust decay. The time between cutoff and separation has been delayed in order to prevent the thrust unit from colliding with the missile body during thrust decay. At point A_2, separation is completed, and the thrust unit follows closely behind the body. Because of little atmospheric density at this altitude (appro. 175,000 to 275,000 feet), the air vanes on the body are ineffective, and jet nozzles provide attitude control.

c. Phase III from Separation to Reentry. During phase III, the body follows a ballistic trajectory controlled in attitude by air jets. From separation to reentry, the range and lateral computers continue to accumulate deviations from the standard trajectory.

d. Phase IV from Reentry to Impact. Reentry (appro. 300 seconds from liftoff for minimum range to 340 seconds for maximum range) is the point on the trajectory where the body unit of the missile comes back into that portion of the earth's atmosphere which is sufficiently dense to activate a deceleration switch. This is a critical period, since extreme heat and shock are generated as the body dives into denser air. One of the primary reasons for separation, is to improve aerodynamic stability of the missile body during this phase. Also, without separation, heavy construction of the thrust unit would be required in order to withstand rapid deceleration and maneuver accelerations. On reentry, the deceleration switch initiates the following guidance and control changes:

(1) The control computer accepts signals from the lateral and range computer. The guidance system gain is small at first, and then it gradually increases until the control servo loop

is operating at full gain. Possible destruction of the missile would occur if corrections were enforced too abruptly at this high velocity.

(2) The attitude error signals are attenuated so that primary consideration is given to guidance errors.

81. (CMHA) Standard Trajectories

a. The standard trajectories for the entire range of 93 to 324 kilometers are obtained by using one of two different tilting programs during the powered portion of the trajectory. These tilting programs are designated as short range and long range. The range covered by trajectories having the same tilting program is varied from maximum to minimum by cutting back the burning time. Thus, the powered portion of any trajectory in a family of related trajectories is identical except for time of cutoff.

b. Fourteen tapes representing standard trajectories are used in conjunction with the tilting programs. These tapes are carried in the test station. The correct tape is determined during the computation of the firing commands.

c. From firing until impact, the attitude of the missile in the pitch plane is controlled by the recorded program. This is done in order to insure proper pitch attitude of the missile throughout its trajectory.

Section II. THE GUNNERY PROBLEM

82. (CMHA) General

a. The Redstone missile gunnery problem is one of determining equipment settings which will cause the missile to deliver its warhead to the target. These equipment settings or presettings represent the fire commands which are sent to the firing position and placed in the missile prior to firing.

b. These presettings establish a precalculated standard trajectory in the missile guidance equipment. Missile performance is compared with this standard trajectory to determine any corrective maneuver necessary after reentry. Missile performance is measured by two gyro accelerometers which measure accelerations in the direction of their sensitive axes.

c. A knowledge of the guidance and control system is needed to understand the theory of the firing tables and the purpose of the presettings.

83. (CMHA) Firing Table Theory

a. The path or trajectory of the missile can be described by equations of motion which consider the forces affecting the missile throughout its trajectory. Since these forces are vector quantities, a reference or coordinate system is established. The basic trajectories for the Redstone missile are calculated with reference to a space-fixed Cartesian coordinate system (rectangular, three-dimensional). The reference of this system is the earth's center, with the Y axis going through the launcher location. The X and Y axes are in the plane of the trajectory, and the Z axis is perpendicular to the plane of the trajectory (fig. 16).

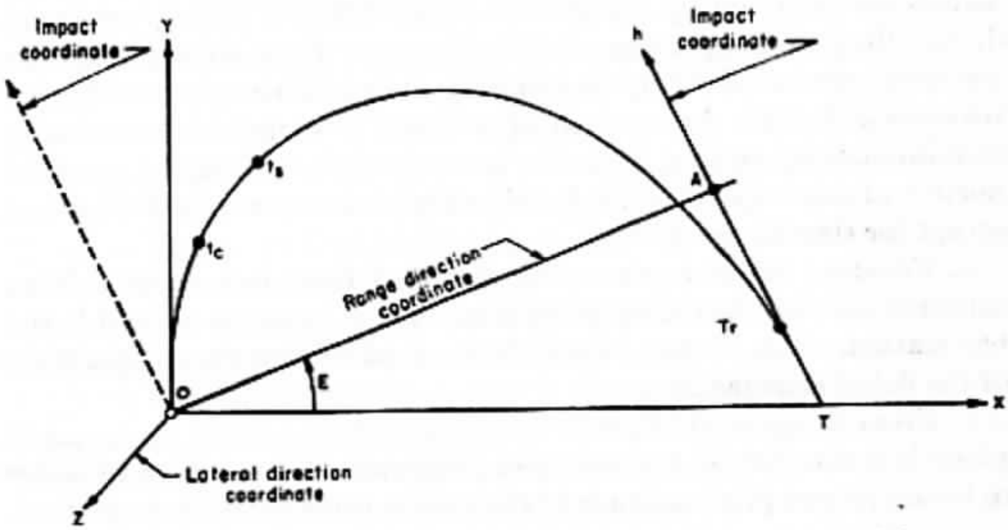

Figure 16. (U) Redstone standard trajectory, X, Y, and Z and guidance coordinates.

b. The missile guidance coordinate system establishes the measuring axes as the range direction coordinate and lateral direction coordinate. The values for missile presettings are determined along these two measuring axes (fig. 16).

c. With the Redstone system, the standard and reference trajectories must coincide at cutoff. Coincidence is accomplished by selecting a program tape and appropriate missile guidance coordinate directions. The tape is selected based on the computed range and provides coarse range control. The guidance coordinate directions were selected to provide optimum accuracy and simplicity in fabrication of guidance equipment. The selections of the coordinate direction and tape minimize errors due to time of flight variations and result in a free flight path after cutoff.

d. The range control generated by the tape causes the missile to follow a path approximating the standard trajectory with minimum angle of attack. When the guidance system is influenced by the presettings, this path will theoretically coincide with the standard trajectory at cutoff.

e. The guidance coordinates are referred to as range, lateral, and impact. No measurements are made in the impact coordinate direction since deviations in the impact direction result in only second-order errors, which are negligible. The impact coordinate is a line drawn tangent to the standard trajectory at a point determined by scientific computation involving the force of gravity and time of flight variations. This point, for purposes of discussion, can be considered to be at reentry. The range coordinate is a line drawn perpendicular to the impact coordinate passing through the launcher, and determines the direction of measurement for the range accelerometer. The lateral coordinate direction is perpendicular to the plane described by the range and impact coordinates or is perpendicular to the plane of the trajectory. The lateral accelerometer measures acceleration of the missile with respect to this plane.

84. (CMHA) Firing Tables

The firing tables contain tabulated data based on the performance of a standard missile following standard trajectories under standard conditions. The tabulated data are actually coefficients for the equations used in computing the missile presettings. The tables will also contain values to compensate for altitude variations and other deviations from standard conditions.

85. (CMHA) Functions of the Missile Presettings

a. General.

(1) These presettings are placed in the missile or launcher prior to firing. They provide the reference values for detecting deviations of the missile from its precalculated standard trajectory.

(*a*) K—aiming azimuth.

(*b*) T—cutoff constant (set in by L).

(*c*) N—cutoff constant (set in by M).

(*d*) E—elevation angle for range accelerometer (set in by P).

(*e*) Q—velocity setting (set in by I).

(*f*) S—displacement setting (set in by J).

(2) The presettings serve as the intelligence for the missile guidance and control systems. As the missile travels along the trajectory, its position is determined relative to these preset values. Variations in velocity and displacement are determined by the range and lateral gyro accelerometers along the respective measuring axes. The purpose of the range and lateral components of the guidance system is to guide the missile so at the completion of terminal guidance the trajectory passes through the target.

(3) The gyro accelerometer is constructed so that the output presents a first integration value of acceleration with time. This determines a value of velocity in meters per second. This

velocity is transmitted to a separate guidance component which performs the second integration with time. This determines a value of displacement.

(4) The values for velocity, displacement, two cutoff equation constants, and the elevation angle E are determined so that all computer outputs are zero or close to zero at the start of terminal guidance. Terminal guidance is initiated by a deceleration switch which measures the deceleration in the direction of the longitudinal missile axis. At this time, if computer outputs are not zero, the remaining values are cleared out and sent to the rudder servo system.

b. Explanation of Laying Azimuth K.

(1) Prior to the determination of the values of velocity, displacement, two cutoff equation constants, and the elevation angle E, it is necessary to determine a value for the laying, or aiming azimuth K. In discussing the laying azimuth, it is necessary to consider the relationship between the target and launcher as the earth rotates.

(2) The relationship of the launcher location and the target with the effect of the earth's rotation on these points is shown in figure 17. This illustration indicates a northwest firing direction showing the earth's velocity vector V_L for the full time of flight applied at the firing location (FP_1). The length of this vector represents the distance FP_1 will move (referenced to space) during the time from launch until impact, i.e., to FP_2. If the azimuth (K_T) from FP_1 to T_1 (Target Location at time of Launch) were used as the aiming azimuth the missile would impact at point D. However, T_1 traveling at a lower velocity has only moved to T_2 during the elapsed time causing a miss distance equivalent to the distance between T_2 and Point D. To determine the proper aiming azimuth the velocity vector V_L is applied opposite the earth's rotation at the predicted target (T_2) and a correction is applied to K_T producing aiming azimuth (K). Rotational effects and latitude differences also influence range computations. These factors are reflected in the cutoff equation and in the range computations.

c. Explanation of the Elevation Angle (E). At the launcher an angle is formed by the range coordinate and the horizontal reference of the stabilized platform. This angle is the elevation angle.

d. Explanation of the Presettings Velocity (Q) and Displacement (S). Q and S represent the velocity and displacement values the missile should experience, along its trajectory on the range axis, from launch until terminal guidance is initiated at reentry. They are calculated and set into the guidance system so that if the missile follows

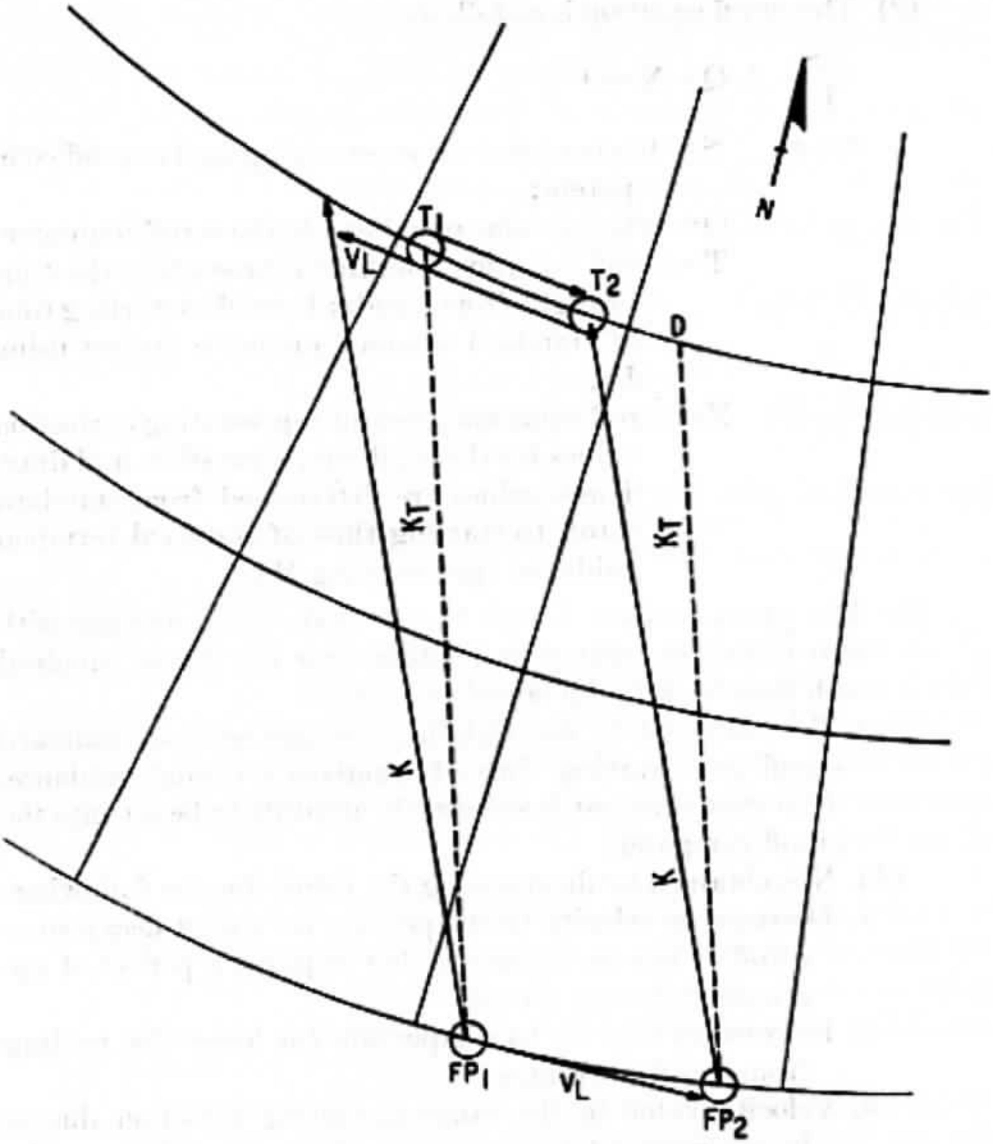

Figure 17. (CMHA) The effect of the earth's rotation.

the precomputed trajectory the measured values should have cancelled out the preset values at reentry. The characteristics of the guidance hardware are such that velocity is preset with a negative value and displacement is preset with a positive value.

e. Explanation of Presettings T and N (Two Constants in the Cutoff Equation Preset Through L and M).

(1) Before firing, both the anticipated points of terminal guidance and cutoff are only approximations since they are determined by the peculiarities of the particular trajectory. The exact point of cutoff is determined through solution of a cutoff equation in the cutoff computer. The cutoff computer is located in the range computer and is physically geared to operate from the same signal sources.

(2) The cutoff equation is as follows:

$$\frac{\Delta S}{T} + \Delta Q + N = O$$

where Δ S = displacement value remaining in the cutoff computers;

Δ Q = velocity value remaining in the cutoff computer;

T = cutoff equation constant representing the time of flight from standard cutoff to starting time of standard terminal guidance (preset using L).

N = cutoff equation constant representing correction values for thrust, decay, separation, and drag. These values are determined from standard cutoff to starting time of standard terminal guidance (preset using M).

(3) The present values T and N are obtained by starting with zero values at reentry and integrating the forces involved with time back to the launcher location.

(*a*) T is obtained by determining the time between standard cutoff and starting time of standard terminal guidance. This time constant is sufficiently accurate to be set into the cutoff computer.

(*b*) N is obtained by determining the values for the following:

1. Decrease in velocity to compensate for thrust decay since cutoff is not instantaneous but requires a period of approximately 0.38 second.

2. Increase in velocity to compensate for losses due to drag from cutoff to reentry.

3. Velocity value in the range-measuring direction due to forces involved in separating the body unit from the thrust unit.

(4) When standard conditions do not prevail, the cutoff equation attempts to make the value of the displacement integrator plus the displacement presetting equal to zero at terminal guidance. Any displacement value present at reentry is canceled by the maneuver during terminal guidance.

Section III. BATTALION FIRE DIRECTION

86. (U) General

a. The fire direction center is that element of the command post by which the commander exercises fire direction control. It consists of gunnery and communication personnel who assist the commander in the control and coordination of fires. The fire direction center personnel convert fire missions from higher headquarters into appropriate fire commands for the missile batteries. The fire direction center personnel control the execution of fire missions.

b. Accuracy, flexibility, and speed in executing fire missions depend on—

(1) Accurate and rapid preparation of firing data.

(2) Transmission of fire commands directly to the missile batteries as soon as determined.

(3) The efficient assignment and division of duties among fire direction personnel.

(4) The adherence to a standard technique.

(5) The efficient use of mechanical devices, such as the calculating machine.

(6) Fire direction personnel functioning as a team and operating in a definite sequence.

87. (U) Personnel

a. Personnel in the fire direction center include the S3, assistant S3, chief fire direction computer, six fire direction computers, and such other members of the operations and intelligence platoon as may be required. The S3 is the gunnery officer of the battalion. Other officers of the battalion staff should be trained to relieve the S3 when necessary.

b. General duties of personnel in the fire direction center are as follows:

(1) The S3 plans, coordinates, and supervises the activities of the fire direction center and is responsible for training the personnel. On receipt of a fire mission, he alerts the firing batteries. The assistant S3 is the chief assistant, relief, and replacement for the S3.

(2) The assistant S3 in charge of the fire direction center supervises and trains the fire direction computers and actively supervises the computation of fire mission data and its transmission to the firing battery.

(3) The fire direction center personnel prepares and maintains a fire capabilities chart.

(4) The chief fire direction computer supervises, checks, and reconciles the computations of the fire direction computers and supervises transmission of data to the firing batteries.

(5) Computers determine and read firing data based on information contained in the fire mission and basic data.

88. (U) Fire Capabilities Chart

The fire capabilities chart is a 1:250,000 or smaller scale map containing information similar to that on the fire capabilities chart and situation map in other field artillery units. The chart is designed to show the S3, at a glance, information necessary for fire orders and safety. This chart shows locations of targets, zones of fire, bomblines, and no-fire lines, as well as the tactical situations of both enemy and friendly forces. Standard artillery symbols and colors are used.

89. (U) Basic Data

a. Basic data for computations are received at the fire direction center from various sources. Computers record these data on the fire direction center basic data record (fig. 18) and the fire command sheet (fig. 19).

b. Survey personnel report survey data to the fire direction center as data become available. The survey data consist of the universal transverse mercator (UTM) grid zone on which the survey is based, the grid coordinates and/or geographic coordinates and the height (altitude) of each firing position, and the grid azimuth of orienting line.

90. (U) Status and Readiness Charts

At the completion of each major step of operation required in preparing a missile to be fired, the missile battery commander will render a report to fire direction center. This data will be recorded on an appropriate chart (fig. 20). Ths chart enables the S3 to determine the status of each firing battery in relation to each assigned mission. A prearranged code can be used in transmitting this data, but the code must be changed frequently enough to preclude compromise.

91. (U) Fire Mission

A separate fire mission for each missile to be fired is received from the army fire support coordination section. The fire mission should contain the following elements: Warning, identification, concentration number, date and time to fire (or time on target), type of warhead, height of burst, target location, altitude of target, and nature of target. Items in *a* through *i* below pertain to elements of the fire mission—

a. Warning—The army FSCS should send a warning order of an impending fire mission to the battalion as early as possible prior to the desired time to fire.

a. Identification—Designation of the higher artillery headquarters ordering the fire mission.

c. Concentration Number—Identification of mission by letter group and number system.

d. Date and Time to Fire—Greenwich civil time. The army artillery fire direction center must insure that the desired time to fire is

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FDC BASIC DATA RECORD

Received From ___Army FDC___ Date and Time ___060520E Apr___
Received By ___Sp Jones___

Fire Mission		Survey Data	
Identification	Hawk 3	Battery to Fire	A
Concentration Nr	AB 21	Firing Position	F
Date and Time to Fire	061630E Apr	Grid Azimuth of OL	116° 27′ 42″
Type Warhead	Y 1	Convergence (line 34, WSI)	∆ 2°22′49″
Type Burst	Air	Geodetic Azimuth of OL	114°04′53″

Missile Data

Missile Nr	2001	Liftoff Weight	61,884
Calibrated Thrust	78,000	Alcohol Temperature	−25°
Calibrated specific impulse	216.7		

Firing Position	*(1) GEOGRAPHIC COORDINATES (Code −1)	Target
(2)	Latitude	(4)
(3)	Longitude	(5)
(6)	Altitude	(7)

Firing Position	*(1) UTM COORDINATES (Code +1)		Target
(9) 346 309	Easting		(11) 653 368
(8) 6 646 963	Northing	(14) Spheroid	(10) 6 654 755
(6) 1235 M	Altitude		(7) 730 M
(12) 44	Zone		(13) 44

STATUS DATA

Mission Assigned to Battery ______________ Missile Nr ______________

Code, Date and Time Completed

M	A	J	K	N	L	Q	F	B	C	X	
Ø 6 Ø 9 3 Ø	Ø 6 1 Ø 4 5	Ø 6 1 1 2 Ø	Ø 6 1 2 3 Ø	Ø 6 1 4 1 Ø	Ø 6 1 3 3 5	Ø 6 1 5 Ø 2			Ø 6 1 4 2 Ø		

*Number in parentheses correspond to input code numbers for the missile firing data computer (Redstone)

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Figure 18. (CMHA) ***Example of fire direction center basic data record.***

within the capabilities of the battalion, considering the state of readiness.

e. Type of Warhead—Depends on tactical situation.

f. Type of Burst—Depends on tactical situation.

g. Target Location—Because of the range of the missile, the target location must be a complete reference, including the universal transverse mercator, grid zone designation, the 100,000 meter square identi-

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Worksheet 16

FIRE COMMAND SHEET

Battery A

Firing Position F

Concentration Nr AB 21

Type Warhead Y1

Missile Nr 2001

Date and Time to Fire 061630Z Apr

*Geodetic Azimuth of Orienting Line 114° 04' 53"

**Presettings:

15.	Tape Number (From Firing Table)	13
16.	K (From WS 5)	84° 51' 34.6"
17.	L (From WS 13)	702
18.	M (From WS 13)	576
19.	X (From WS 6)	478
20.	Y (From WS 6)	933
21.	Z (From WS 6)	750
22.	E (From WS 6)	38.2
23.	F (From WS 14)	118.711
24.	F + .01 (From WS 14)	118.685
25.	F - .01 (From WS 14)	118.737
26.	H (From WS 15)	0.416
27.	H + .01 (From WS 15)	0.587
28.	H - .01 (From WS 15)	0.245
29.	I (From WS 14)	364.516
30.	J (From WS 14)	234.442
31.	Q (From WS 11)	- 2210.839
32.	S (From WS 12)	166679
33.	P (From WS 6)	58
( ).	Alcohol Temperature	- 13.4

*Grid azimuth of orienting line plus or minus convergence (Line 34 WS 1).

**These numbers correspond to the output code numbers for the Missile firing data computer (Redstone).

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Figure 19. **(CMHA)** ***Example of fire command sheet.***

MISSILE NR	TIME TO FIRE	MISSILE DATA				STATUS		CODE										REMARKS
								H	Q	V	Z	A	F	Y	B	I	J	
		LIFTOFF WEIGHT	CALIBRATED THRUST	SPECIFIC IMPULSE	ALCOHOL TEMPERATURE	READY STORAGE	BATTERY	MATING COMPLETED	HORIZONTAL CHECKOUT	ERECTION COMPLETED	PROPELLANT LOADING			LAYING COMPLETED	VERTICAL CHECKOUT	START LOX REPLENISHING	AREA CLEAR	
											ALC	LOX	H_2O_2					
2001		61,884	78,000	216.7	-25°	A	A	0930 6 Apr	1045 6 Apr	1120 6 Apr	1230 6 Apr	1410 6 Apr	1425 6 Apr	1502 6 Apr		1410 6 Apr		Informed Bn of status 1500 hrs
2002		61,902	77,900	216.3	-25°													
2003		62,004	78,000	217														A Btry pick up at 1900 hrs 6 Apr
2004		61,900		217.1														

Figure 20. (U) *Example of status and readiness chart.*

fication, and the coordinates to the nearest meter. If the missile firing data computer, Redstone, is to be used to determine firing data, either UTM grid or geographic coordinates are acceptable.

h. Altitude of Target—Meters above mean sea level.

i. Nature of Target—This element of the fire mission is not mandatory but is highly desirable. Informing personnel of the general nature of the target of which they are firing is an important morale factor.

92. (U) Fire Control Procedures

A fire mission received from the army fire support coordination section is decoded, and personnel in the battalion fire direction center perform the following operations in the sequence listed:

a. Computers enter all firing data directly obtainable from the fire mission on the fire direction center basic data record (fig. 18) and the fire command sheet (fig. 19).

b. Simultaneously with action in *a* above, the target location is plotted on the fire capabilities chart.

c. The S3 determines which battery will fire by using the information contained on the status and readiness chart in conjunction with the battalion commander's policy. The S3 immediately alerts the missile battery(ies).

d. Computers determine firing data.

e. The S3 transmits firing data to the missile battery by messenger or other communication channels. At times, it may be necessary to encode certain fire commands by using a prearranged message code. All personnel should be trained so that the use of such a code does not delay the execution of a fire mission.

(1) If the missile programing data computer is used for determining firing data, all firing data is transmitted at once to the missile battery.

(2) If the firing data are computed by the longhand method, initial data may be transmitted to the missile battery in fragmentary form.

Section IV. DETERMINATION OF FIRING DATA

93. (CMHA) General

Firing data may be computed by using the missile programing data computer or by computers using the longhand computation method. The longhand method requires approximately 2 to 3 hours. Since the missile programing data computer requires approximately 10 minutes overall warmup, testing, and computation time, this method will be used whenever possible. During cold weather, warmup time might become considerable causing an increase in the 10 minute overall time. To overcome this the computer van could be stored in a heated shelter or a source of heat improvised in the van itself. Fire direction personnel must, however, be proficient in the use of the longhand method to provide for situations in which the missile programing data computer is inoperable or not available.

94. (U) Computation of Firing Data Using Missile Programing Data Computer

a. The missile programming data computer is a compact, transistorized, general purpose, digital computer, which has been programed to solve the Redstone gunnery problem and the convergence problem.

b. Operation.

(1) Using the keyboard on the control panel and the procedures set out in TM 9–1430–350–12/2 the operator enters the parameters of the particular problem to be solved in accordance with the format shown in figure 21.

(2) After all parameters have been entered, the computer starts computation of the problem. When the computer has completed the problem, it will print out the solution in accordance with the format shown in figure 21.

95. (U) Determination of Firing Data Using the Longhand Solution—General

a. Computers obtain elements of firing data from the firing mission, firing tables, and basic data. Two computer teams check their computations with each other at logical points. The chief fire direction computer checks and resolves differences in computations to eliminate errors as quickly as possible.

b. All personnel in the fire direction center must know the arrangement of the firing tables and how to use them. An explanation of the use of the firing tables, together with sample problems, is contained in the introduction to the firing tables. Fire direction personnel must also know how to use the calculating machine.

96. (U) Composition of Firing Data

Firing data is composed of—

a. Basic data.

b. Preliminary presettings.

c. Conversion of presettings to missile settings and calibration factors.

97. (U) Equipment

The following equipment is needed to compute firing data:

a. Trigonometric functions, seven-place (argument in decimals or degrees).

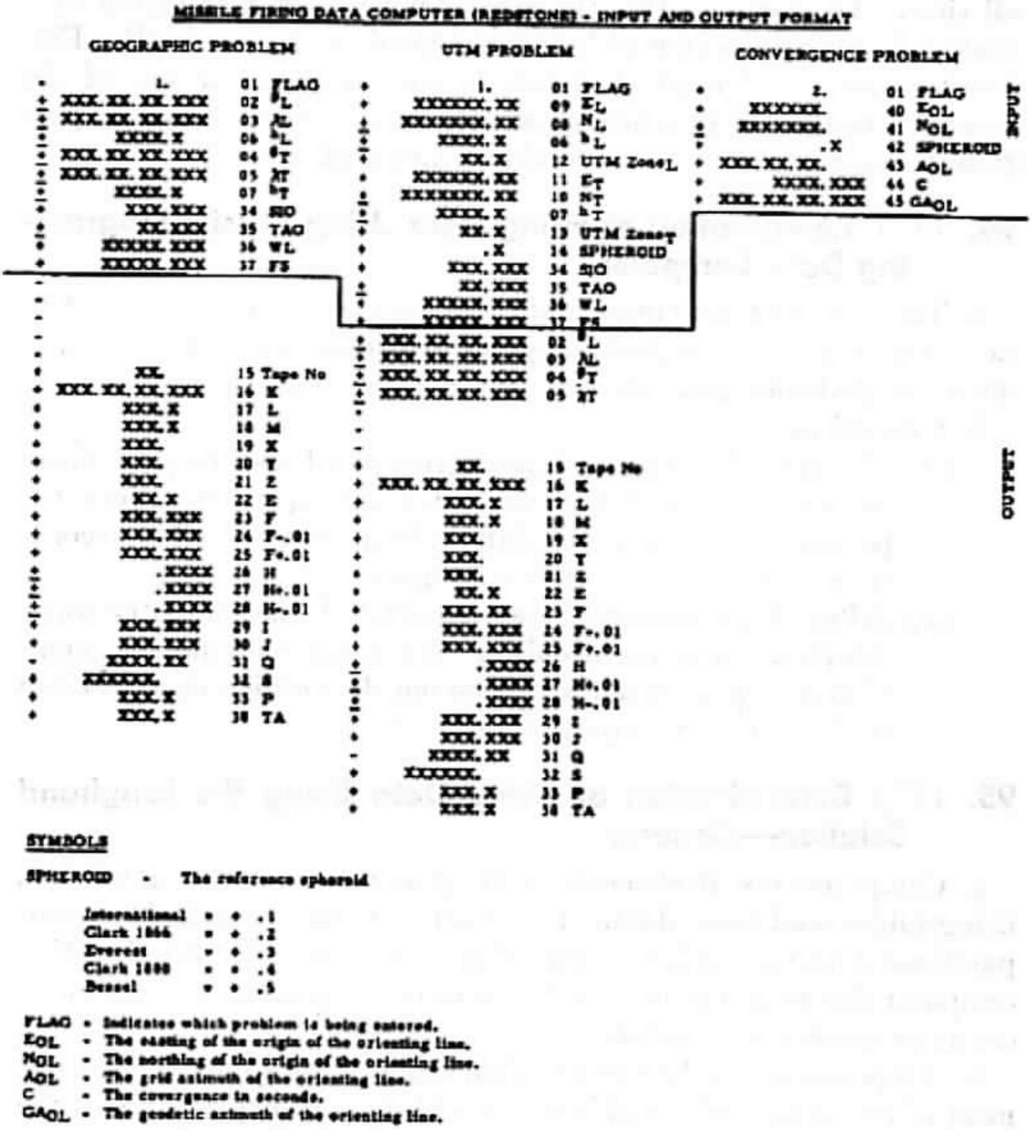

Figure 21. (CMHA) *Example of input format, missile firing data computer, Redstone.*

b. TM 5-241-2 (universal transverse mercator grid; zone to zone transformation tables).

c. Tables for transformation of coordinates from grid to geographic for the appropriate spheroid (TM 5-241-3/2, International; TM 5-241-4/2, Clark 1866; TM 5-241-5/2, Bessel; TM 5-241-6/2, Clark 1880; TM 5-241-7/2, Everest.

Note. The publications in *c* above are the new designations for the volumes II of Army Map Service Technical Manuals (AMSTM) 6, 7, 8, 9, and 11, respectively.

d. Tables for radii vector for the appropriate spheroid, see firing tables.

e. A calculating machine of at least 10 column capacity.

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