THIS REPORT HAS BEEN DELIMITED AND CLEARED FOR PUBLIC RELEASE UNDER DOD DIRECTIVE 5200.20 AND NO RESTRICTIONS ARE IMPOSED UPON ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

UNCLASSIFIED

AD 202249

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FOR MICRO-CARD CONTROL ONLY

1 OF 1

UNCLASSIFIED

BRL

REPORT NO. 1048

THE FREE FLIGHT AERODYNAMICS RANGE

WALTER F. BRAUN

DEPARTMENT OF THE ARMY PROJECT NO. 5803-03-001
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT NO. TB3-0108

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

REPORT NO. 1048

JULY 1958

THE FREE FLIGHT AERODYNAMICS RANGE

Walter F. Braun

Requests for additional copies of this report will be made direct to ASTIA.

Department of the Army Project No. 5B03-03-001
Ordnance Research and Development Project No. TB3-0108

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

REPORT NO. 1048

WFBraun/cr
Aberdeen Proving Ground, Md.
July 1958

THE FREE FLIGHT AERODYNAMICS RANGE

ABSTRACT

The Free Flight Aerodynamics Range, an instrument designed to produce data for the empirical determination of the aerodynamic coefficients of a missile in free flight, is described. The operating techniques and associated experimental procedures used in the range are given. Examples of air flow data obtained from the spark photograph are given. The capabilities, limitations and accuracy of the range are discussed.

TABLE OF CONTENTS

1. INTRODUCTION

The Free Flight Aerodynamics Range is an instrument for producing data from which the aerodynamic characteristics of a missile in free flight can be inferred. It is equipped with apparatus that launches a missile and records its position, yaw, and time of flight at many points along the trajectory.

The impetus for the development of the Aerodynamics Range stemmed from the inadequacies of the experimental procedures available for ballistic measurements in the late 1930's. Velocities and decelerations were measured by firing a magnetized projectile through solenoid coils placed at measured intervals along the trajectory and recording on a drum chronograph the time interval between the electric pulses generated by the missile passing through the coils. The experimental data for the analysis of projectile stability were obtained by firing through yaw cards placed at intervals along the trajectory and measuring the dimensions and orientation of the "key hole" that the yawing missile punched through the cards.

The technique of taking spark photographs of projectiles in free flight had been investigated by Cranz in Germany and Kent at Aberdeen. The problem of further developing the spark photography technique and of integrating this technique into a precision range adequate for the determination of aerodynamic coefficients was started in 1940 by Dr. A. C. Charters* at Aberdeen. In early 1943, six spark photography stations were in operation. Firing programs for the purpose of measuring the retardation of spheres and fragments demonstrated the superiority of this technique for the determination of the drag coefficient.[1,2]

The acquisition of additional experimental apparatus, the development of measuring and launching techniques, the application of ballistic theory to the data produced by the range and the development of procedures for reducing the range data to obtain other aerodynamic coefficients were

---

* Now at the Ames Aeronautical Laboratories, NACA, Moffett Field, California.

carried out under the direction of Dr. Charters. These efforts culminated in an experimental facility and method of analysis that determined, experimentally, ballistic data that was heretofore unattainable. To date, the over 5000 rounds that have been fired in the range have supplied a large amount of information useful in the design of missiles and the analysis of their performance.

2. THE RANGE

2.1 Description of the Facility and its Operation

The Free Flight Aerodynamics Range is an enclosed firing range instrumented to launch a missile in free flight and record its motion over 285 feet of the trajectory. The projectile flight is measured and the aerodynamic coefficients are determined from the retardation, the yawing motion, the swerve, and the rolling motion. Ballistic theory provides the link between the aerodynamic forces and moments acting in flight and the motion observed. The free flight range technique for obtaining the aerodynamic coefficients demands unusual accuracy in the measurement of time, distance, and angle. The required accuracy in distance and angle was developed from a photographic technique known as spark silhouette photography. This recording procedure gives distance accuracy to 0.001 foot and angular accuracy to 2 minutes of arc. The roll angle can be determined to an accuracy of less than 1 degree. Time interval measurements are obtained with the cycle counter chronograph to an accuracy of 1 microsecond.

The range area consists of the firing room containing the launching device, the blast chamber isolating the instrument area from the muzzle blast effects encountered in launching a missile, the range gallery containing the apparatus for recording the flight of the missile, and the control room from which range operations are conducted and where time measurements are recorded. A schematic drawing of the range area is illustrated in figure 1. Figure 2 shows the gun in firing position. Figure 3 shows the apparatus for recording the flight of the missile. Additional facilities and activities necessary to obtain ballistic data are the model shops, the physical measurements section, the data reduction section, and the program engineering section.

The initial and final steps in obtaining the aerodynamic coefficients of a missile are taken by these sections. These steps are planning of the program; design, construction, and measurement of the missiles; and finally, after the rounds are fired in the range, the measurement of the photographic plates and reduction and analysis of the range data. In planning a firing program cognizance must be taken of the capabilities and limitations of the range technique. To obtain data over the full range the missile must be launched with less than 1.7 mils dispersion. If the dispersion is greater, the missile is stopped within the range by armor plate protecting the apparatus. However, the data is obtained up to the point where the missile passes outside the field of the station.

To obtain the aerodynamic coefficients over a range of Mach numbers, firings must be conducted at several velocities. Since the loss in velocity is generally small over the 285-foot trajectory, the aerodynamic coefficients can be assumed to be constant and each round gives data at only one velocity, the mid-range velocity. For complete information on the missiles' characteristics, rounds are usually fired at a minimum of 7 different velocities: 3 supersonic, 2 transonic, and 2 subsonic.

There are practical limits to the size, weight, and velocity that can be satisfactorily tested in the range. Some exceptions to these limits can be made if somewhat less than complete range data is acceptable. The minimum size, a 1/8 inch sphere, is determined by the sensitivity of the apparatus. The minimum velocity, 600 feet per second, is determined by the shape of the parabolic trajectory due to gravity. The tests at lower velocities, however, can be conducted if only part of the range is used. At 200 feet per second, data can be obtained over 100 feet of the trajectory. The maximum size missile, approximately a 37-mm body diameter or a 2.7-inch fin span and a 10-inch length, is determined by the size of the station field. Missiles as long as 2 feet have been tested, with only part of the missile appearing on the photographic plates. Nevertheless satisfactory range data was obtained. The maximum weight and velocity are determined by the available launching devices and the ability of the blast chamber to withstand the muzzle blast. With conventional guns, missiles weighing 0.1 pound have been fired at 7000 feet per second. For heavier missiles the maximum velocity is lower, a typical example being 1.6 pounds at 3000 feet per second.

To obtain data on large missiles, small scale models are tested in the range. In the design of the model it is necessary to adhere to an exact scale duplication of the external shape. There is, however, a good deal of latitude in the design of the internal structure. The important factors that must be considered are: the location of the center of mass and the moments of inertia in order that the model will be stable; and, the strength of the model to withstand the high accelerating forces necessary to produce the required velocity.

After completion of design and manufacture of the missiles, their complete physical measurements are obtained. These consist of complete dimensions of the external shape, the location of the center of mass, the axial and transverse moments of inertia, and the weight. Procedures used in obtaining physical measurements are given in reference 3.

With a supply of missiles and an explicit firing program on hand the range is set up for the program.

The missile is launched from a gun mounted in the firing room with the muzzle in the blast chamber as illustrated in figure 2. The gun is positioned so that the trajectory traverses the field of the spark photography stations shown in figures 3 and 4. There are 45 stations in the range located in 5 groups of 9 stations covering 285 feet of the trajectory. Within each of these groups, the stations are 5 feet apart. The distance from the muzzle of the gun to the first station varies from 5 to 20 feet depending on the type of gun used.

The function of the stations is to provide the position data of the missile at 45 points along the 285 feet of the trajectory. This is achieved by a photographic technique. The station is essentially a specialized camera. To the right and below the trajectory the station supports two photographic plates. To the left of the trajectory is the point light source generated by a short duration spark gap. Above the trajectory a mirror is supported by the station frame.

When the round is fired the enclosed range gallery is dark. As the missile approaches each station it generates a voltage transient that triggers the point source of light. These diverging rays of light silhouette the image of the missile, its shock waves, and the fiducial marks of the station on the two photographic plates. Both plates are exposed from the same light source, the vertical plate directly and the horizontal plate from the light reflected by the mirror above the station (Fig. 5).

From twelve stations in the range an electric pulse, representing the time that the picture was taken, is fed to a twelve unit cycle counter chronograph. These counters indicate the time elapsed between the twelve pictures[4]. At the end of the range the missile is stopped by a sand butt.

After the round is fired the photographic plates are collected and processed in the photographic laboratory. The blue sensitive process type emulsion is developed eight minutes in D-19 developer, and then fixed and washed using standard photographic procedures.

The plates are measured on a 20 line to the inch, ruled grid set in a light box. From the measurements of the images of the two orthogonal plates, the co-ordinates and the orientation of the missile are determined with respect to the local co-ordinate system of the station to an accuracy of 0.01 inch and 2 minutes of arc respectively (Fig. 6). From the location of the local system with respect to a master co-ordinate system, as described in the survey of the range, the trajectory and yawing motion are obtained.

Another important type of aerodynamic data that can be obtained from spark photographs is the determination of the spin of missiles. Two or more spin pins are placed in the base of the missile (Fig. 7). One pin is pointed to provide identification. The distance between the pins is measured. Figure 8 shows how these pins appear in the spark photograph. The location of the pins in space may be computed as given in references 5 and 6. The roll angle at each station is obtained from the orientation of the vector between the pins.

It is necessary for the analysis of the range data to know the velocity of sound and the density of the air in the range at the time the round is fired. The range is air conditioned to keep these factors reasonably constant. Immediately after each round is fired the temperature is measured at three stations in the range, the air pressure is obtained from a standard mercury barometer, and the relative humidity is obtained from readings on a sling psychrometer.

The procedure for measuring the plates, and for the reduction and analysis of the range data is given in reference 5.

2.2 The Spark Photography Station

Each data position in the range is occupied by a spark photography station as shown in figures 3 and 4. The station is essentially a silhouette type camera. It contains a rigid, adjustable holder for the two photographic plates, the reference bar defining the local co-ordinate system, the spark light source and the electronic circuits for triggering the light source.

The size of the field of the station camera is determined by the dimensions of the photographic plates and the location of the point source of light. The area of this field normal to the trajectory is approximately 13 inches square. The length of the field parallel to the trajectory is 10 inches.

The top frame of the station consists of two flat, metal, photographic plate holders mounted at right angles with a reference bar fastened at the junction of the two surfaces. Attached to the top of the vertical plate holder is the mirror frame which supports the mirror at a fixed height but with angular adjustment. The base of the station, which is securely mounted to the track in the range, has three leveling screws which support the top frame. Adjustments are provided so that the top frame containing the local co-ordinate system can be oriented parallel to and positioned a predetermined distance from a master co-ordinate system for the range.

The spark light source which is built into a cylindrical can is supported by an adjustable stand located at the left of the trajectory as shown in figure 4.

The origin of the local co-ordinate system which is determined by the intersection of three perpendicular planes is located from the reference bar as shown in figure 6. The XZ plane, coincident with the emulsion surface of the horizontal photographic plate, is parallel to and 1.656 inches below the horizontal surface of the reference bar. This dimension is determined by the thickness of the reference bar, 1.750 inches, minus the thickness of the photographic plate. The YZ plane coincident with the emulsion surface of the vertical photographic plate is parallel to and 1.656 inches from the vertical surface of the reference bar. The XY plane is located by a Z fiducial notch which is machined in the center of the bar.

Two recesses cut into the top and side of the bar permit the photographic plates to be placed so that the edges of the bar and the Z fiducial notch are silhouetted on the plates when the spark photographs are taken. Figure 5 (a vertical plate) shows a missile in free flight and the image of the reference bar. The distance from the center of mass of the missile to the reference bar plus the reference bar constant (1.656 inches) is the Y ordinate of the missile image. The Z ordinate is obtained from measurements to the Z fiducial notch. The slope of the axis of the missile with respect to the reference bar edge is the vertical component of the orientation of the missile at the station. Similar measurements are obtained from the horizontal plate.

Since the photographic images are produced by diverging light from a point source the co-ordinates and orientation of the missile with respect to the local origin are obtained from the geometrical relationship of the vertical and horizontal plate co-ordinates, the co-ordinates of the point source of light and of its virtual image. Actually the center of mass of the missile is not seen on the plate, but two convenient points on the missile surface, whose average is a point on the axis a known distance from the center of mass, are used for measurements.

3. METHODS OF LAUNCHING A MISSILE

The range is capable of giving experimental data on any aerodynamic shape that can be successfully launched in free flight over the field of the spark photography stations. The minimum requirements for a successful round are: the dispersion from a predicted trajectory should be less than 1.7 mils; the round should have from 2 to 6 degrees maximum yaw in the range; and, the missile must be strong enough to withstand the forces necessary to accelerate it to the required velocity.

Practically all missiles that have been tested to date have been fired from conventional gun tubes. Since the range has been in operation a substantial arsenal of guns has been obtained for the test facility. These guns include both standard and special gun tubes, ranging in size from the .22 caliber rifle to the 57-mm cannon. A complete list of the available gun tubes is given in Appendix C. The majority of spin stabilized missiles are fired from 20-mm guns which are available in thirteen different twists of rifling. Fin stabilized missiles are generally fired from smooth-bore guns or from the railed gun. The railed gun has a bore with a cruciform shape. This is essentially a 20-mm smooth-bore with two slots .320 x 2.70 inches machined perpendicular to each other and symmetrical about the bore axis.

For high velocity tests the range has acquired a light gas smooth-bore gun (Fig. 9). The bore of the gun is 1 inch in diameter and 200 inches long. The chamber volume, which is 3 inches in diameter and 18 inches long, is sealed at the origin of the bore by a blow-out disk. The chamber will be charged with helium, hydrogen, and oxygen in proper proportions at pressures up to 25,000 pounds per square inch by means of the gas charger shown in figure 10. The hydrogen-oxygen mixture will be ignited by electric detonating caps. Installation of this gun is not completed to date, but it is expected that velocities over 10,000 feet per second will be obtained.

To facilitate handling a wide variety of gun tubes, a universal gun mount was designed to provide adjustments for aligning the tube and to provide for free axial recoil. Figure 2 shows the 20-mm railed gun mounted in firing position in the range. On the table next to the gun are the fin stabilized model, the sabot, the obturating wafers, the cartridge case, the powder chamber, and the breech mechanism. Cylindrical tube holders are available for mounting all gun tubes axial to the tube holder. The cylindrical holder and gun tube recoil freely on four roller bearings until the missile leaves the gun. Then a pair of hydraulic and spring action recoil cylinders absorb the recoil forces. The universal gun mount will adjust the gun axis in height and lateral position and permit adjustments for the proper angles of azimuth and elevation.

The bore of the gun is positioned with respect to the range co-ordinate system by the following procedure. The vacuum trajectory is computed for the required mid-range velocity and plotted on a graph of the station co-ordinates so that the allowable dispersion is a maximum. The line of departure is computed for this trajectory. A collimated light source is placed in the muzzle of the gun and a bull's-eye target is located on the line of departure at mid-range. The gun mount is adjusted to place the collimated light beam on the target. Measurements of the location of the muzzle of the gun with respect to the range co-ordinate system are taken.

An important problem in launching the missile is the control of the maximum yaw. Since some of the aerodynamic coefficients are obtained from the measurement of the damping of the magnitudes and of the rates of the nutational and precessional arms of the yawing motion of the missile, it is necessary that the missile have a measurable amount of yaw. To obtain effective data it is often necessary to induce some yaw when launching a missile.

The yaw producing forces and moments can be applied to the missile by attaching an asymmetrical fitting to the muzzle of the gun. The effect of this attachment, however, is not always predictable, quantitatively, and often increases the dispersion beyond the allowable limits of the range instrumentation.

Another method of inducing yaw is by means of the electromagnetic yaw inducer. A uniform magnetic field (maximum strength 20,000 gauss) is produced over an area 6 x 24 inches. The air gap of the field is adjustable from 3 to 6 inches deep. The yaw inducer is positioned so that the trajectory passes through the magnetic field. The missiles which are constructed of non-ferrous materials have an Alnico V bar magnet assembled within the body. When the missile passes through the magnetic field, it induces a magnetic moment to the bar magnet and thus a yawing couple to the model.

A third method of yaw induction can be used with some non-spinning small missiles. The sabot is designed so that the axis of the missile is not parallel to the axis of the sabot. Thus the missile is launched with a small amount of yaw.

The testing of standard projectiles is generally a straight-forward operation. The ability of the range to obtain data on aerodynamic shapes that are not normally fired from gun tubes led to the application of sabot techniques for the solution of the launching problem[7]. A sabot can be defined as any material that supports the model in the gun and is then discarded from the model by either centrifugal force, lift or relatively high drag force before the model reaches the first instrumentation point. One of the first attempts to put the sabot technique into use in the free flight range occurred in the testing of models of spinner rockets. These spin stabilized missiles had no rotating bands. For range testing, the spin was imparted to the model by a pre-engraved aluminum sabot that was keyed to the base of the missile. A 20-mm model of a spinner rocket with its drive key, pre-engraved sabot and gas seal is illustrated by figure 7. The separation of the sabot components from the free flight missile is shown by four spark photographs taken within ten feet of the muzzle of the gun (fig. 8).

Models of bombs and fin stabilized missiles are usually encased in a sabot so that they can be fired from smooth-bore gun tubes. A typical example is the half inch diameter model with its sabot (fig. 11). The two fingers that support the model axially in the gun are undercut at their junction with the sabot base to form a weakened area that fails in shear from set back when the gun is fired. When the sabot is free of the gun, the air drag lifts the fingers away from the model as shown in figure 12.

4. THE SPARK PHOTOGRAPH

The principle objective of the range is to obtain position, time and yaw data on missiles in free flight. In addition, the spark photograph yields information about the air flow around the missile body.

A missile moving through the air at a velocity greater than that of sound causes the air to pile up in front with a sharply defined boundary. This is the shock wave, a thin compression wave extending back from the nose of the missile. The shock wave is the boundary between the air in front, which has normal density, temperature, and pressure, and the air behind the shock wave in which the density, temperature and pressure are greatly increased. It is the refraction of light at this discontinuity in the air density, and thus the index of refraction, that produces the image of the shock front on the spark photograph. The light rays tangent to the shock envelope are bent towards the denser medium producing an unexposed line adjacent to an overexposed line on the photographic negative. Figure 13, a positive print from a typical negative, shows a complex array of shock waves, expansion waves and turbulent flow produced by the various discontinuities in the missile's configuration.

Figures 14 and 15 are spark photographs of 2 conical missiles, semi-cone angle 10°, base diameter 1.307 inches, velocity 2000 feet per second. Examination of the flow over the cone surface clearly illustrates the ability of the spark photograph to differentiate between laminar and turbulent flow over the missile surface.

Occasionally the drag of two missiles with identical shapes will be different due to different characteristics of the air flow. Figures 16 and 17 illustrate two rounds, one with high drag flow and the other with low drag flow.

Figure 18 shows the comparison of flow over a 20-mm model and a 105-mm projectile at transonic velocity. The existence and location of the shock and expansion waves due to local supersonic flow are illustrated.

The silhouette image of the missile shows the physical condition of the missile in free flight. Any structural failure of the missile can readily be detected.

Walter F. Braun

WALTER F. BRAUN

5. REFERENCES

1. Charters, A. C., and Thomas, R. N. The Aerodynamic Performance of Small Spheres from Subsonic to High Supersonic Velocities. Jour. Aero. Sci., 12: No. 4, p. 468, Oct 1945.

2. Charters, A. C. Some Ballistic Contributions to Aerodynamics. Jour. Aero. Sci., 14: No. 3, p. 155, March 1947.

3. Dickinson, E. R. Physical Measurements of Projectiles. Aberdeen Proving Ground: BRL TN-874, Feb 1954.

4. Karpov, B. G. The Accuracy of Drag Measurements as a Function of Number and Distribution of Timing Stations. Aberdeen Proving Ground: BRL R-658, 1948.

5. Murphy, C. H. Data Reduction for the Free Flight Spark Ranges. Aberdeen Proving Ground: BRL R-900, Feb 1956.

6. Boltz, R., and Nicolaides, J. D. A Method of Determining Some Aerodynamic Coefficients from Supersonic Free Flight Tests of a Rolling Missile. Aberdeen Proving Ground: BRL R-711, 1949.

7. MacAllister, L. C. On the Use of Plastic Sabots for Free Flight Testing. Aberdeen Proving Ground: BRL M-792, May 1954.

8. Kovasznay, L. S. G. High Power Short Duration Spark Discharge. Rev. Sci. Instr., 20: p. 696, 1949.

APPENDICES

A. Electronic Equipment

B. Survey of the Range Stations

C. List of Available Gun Tubes

D. Figures

APPENDIX A

Electronic Equipment

APPENDIX A

Electronic Equipment

The function of the electronic equipment in the range is to detect the approach of the missile to the station, to trigger the spark light source when the missile is in the field of the spark camera and to measure the time interval between successive pictures.

The range currently uses two different methods of detecting the missile or developing a voltage transient that defines the position of the missile along the trajectory. Figure 3 shows 45 stations in the range set up for electrostatic triggering. Since that picture was taken about half of these units have been replaced by photo-electric trigger systems as shown in figure 4.

In the photo-electric trigger system a voltage transient is developed when the missile interrupts a thin sheet of light that is normal to the trajectory. The rectangular black box on the track contains two collimated, 4 x 1/8 inch light beams which are produced by a pair of 8 volt, single filament projection lamps operated with direct current. These two light beams originating in the lower outside corners of the rectangular opening of the box are reflected across this area towards the center in four passes by mirrors placed in the upper and lower frame. At the center each light beam is focused on one of two 931A photo-multiplier tubes, which have a common anode circuit. Separate dynode voltage controls permit balancing the sensitivity of the two light areas. Normal operating total anode current is 50 microamperes; the unit operates satisfactorily, however, within a range of 20 to 100 microamperes.

Since the light screen is close to the emulsion of the photographic plates there is some tendency towards fogging the plates from stray light even though the light beams are carefully baffled. Experience has shown that the light beam can be on for about 40 seconds without producing any noticeable fogging of the plates. An operating procedure was developed to limit the time that the lights are on. During the time that the photographic plates are being placed in the stations and the gun is being loaded, the lights in the photo-electric trigger circuits are off and a squelch circuit prevents the spark gap from being triggered. The lights are turned on 30 seconds before the gun is fired. After 20 seconds the light intensity and thus the anode current reaches a steady state condition and the squelch circuit is removed. The squelch is reactivated and the lights turned off 2 seconds after the round is fired. A clock type timer actuates a series of relays that perform, in the proper sequence, all the operations necessary to fire the round.

When the missile interrupts the light beam a voltage transient is developed at the anode of the photo-multiplier. This voltage is passed to the amplifier through a 120 cycle rejection filter. The amplifier has a gain of about 4000, with a pass band of 4 kilocycles to 150 kilocycles. The amplified voltage transient initiates a time delay circuit that is adjustable from 50 microseconds to 5000 microseconds. Since the plane of the light screen is 1 foot ahead of the center of the photographic plate, the proper delay must be interposed before the triggering of the spark gap, to give the missile time to reach the center of the photographic plate. The output of the time delay circuit initiates a trigger thyratron which pulses the primary of a step-up pulse transformer. Approximately 15,000 volts is developed at the secondary which is connected across the trigger electrode and ground of a tertiary spark gap.

The construction of the spark gap which provides the light to expose the plates is shown in figure 19. The short duration, high intensity, point source of light is obtained by discharging 2.16

watt-seconds of energy from a 0.12 microfarad capacitor, initially charged to 6000 volts, through a tertiary spark gap at atmospheric pressure. The main electrodes are constructed of aluminum. The light is projected on to the photographic plates from a 0.050 inch diameter aperture in the front electrode of the gap. The effective duration of the light flash is approximately 0.5 microsecond. Details of the gap design and the method of measuring the duration are given in reference 8.

The voltage transient, that is developed when the gap discharges, is attenuated and is used to determine the time that the spark photograph was taken. A twelve unit 1.6 megacycle counter chronograph is started when the gun is fired. The twelve counters are stopped respectively by the signals from the spark gaps of twelve selected stations in the range. The differences in the indicated times are the time intervals between successive pictures in the range. The accuracy of the time interval is about 1 microsecond.

The alternate method of detecting the missile, the electrostatic triggering system, depends on the phenomenon that a missile can be charged to a high potential which it retains in flight. Between the muzzle of the gun and the first station in the range, a steel comb, charged to 25 kilovolts, is placed close to the trajectory. As the missile passes the comb it is charged to a high negative potential. Each station has a single loop shielded antenna as shown in figure 3. When the missile passes through the antenna, the electrostatic field will generate a voltage transient which is amplified and shaped to initiate the time delay circuit. The time delay circuit, and spark gap used with electrostatic triggering are identical to those described in photoelectric triggering.

APPENDIX B

The Survey of the Range Stations

APPENDIX B

The Survey of the Range Stations

It has been shown how at each station in the range the position of the missile is located with respect to the local or station co-ordinate system. To consolidate the data obtained at the stations into a graph of the trajectory and a plot of the yawing motion it is necessary to locate the station co-ordinate systems with respect to a master co-ordinate system of the range. The stations are adjusted so that their co-ordinate systems are parallel to a master co-ordinate system. The difference between the two systems is thus only the location of their origins, where x_i, y_i, and z_i are the co-ordinates of the local origin of the ith station relative to the master origin as shown in figure 6. The procedure for placing and adjusting the stations and measuring their positions is the survey of the range.

To insure continued accuracy of the range data a survey is conducted approximately once a year. This usually takes about one month to perform; part of this time, however, is required for a general overhaul of the range equipment.

The survey procedure may be divided into five main steps: 1) checking the station co-ordinate system; 2) placing the stations within a master co-ordinate system; 3) measuring the co-ordinates of the local origin with respect to the master origin; 4) surveying the spark gap position; and 5) conducting the wire survey.

1. Checking the station co-ordinate system

The station co-ordinate system, described in detail in the section on the spark photography station, is built into the station. The initial step in the survey is to check that the vertical and horizontal plate holders are perpendicular, and are parallel to and 1.750 inches from the vertical and horizontal sides of the reference bar. This alignment is checked by means of a precision right angle knee, and depth micrometers. Those stations that deviate more than 1 minute of arc or 0.002 inch from the prescribed dimensions are rebuilt in the machine shop.

2. Placing the stations within a master co-ordinate system

The exact location of the master co-ordinate system is not determined from bench marks set in the range but from the measurements between the stations and the data produced by the wire survey. For the purpose of positioning the stations, working bench marks are developed as the survey progresses.

Five key stations are placed at 70 foot intervals on the range track. The remaining 40 stations, divided into 5 equal groups, are placed at five foot intervals about these key stations. The origin of the master Z axis is now located by the origin of the local Z axis of the first key station.

A convenient horizontal trajectory in the range is approximately 37 inches above the floor and centered over the range track. The first and last stations are adjusted so that the center of the fields of the two stations approximately coincide with this trajectory. These stations are leveled to an accuracy better than 1 minute of arc by the three threaded legs supporting the top frame.

A transit is set up at a mid-range position. By the use of a special target constructed from a machinists height gage (fig. 20), the heights of the two stations are adjusted to be equal. The working bench mark for the origin of the Y master axis is now the optical axis of this transit.

Since the two end stations are level, their Y axes are vertical. The vertical plane containing these Y axes is used to locate the working bench mark for the origin of the master X axis. This bench mark is a 300-foot length of 0.012 inch piano wire, suspended over the stations. The wire is supported by a pair of cylinders 295 feet apart. Their axes are approximately parallel to the range X axis. Each cylinder has two grooves 3.000 inches apart. The piano wire lies in the groove closest to the vertical plate of the stations. A plumb line is supported in the other groove. The two cylinders are moved in the X direction until the wire is three inches from the vertical edges of the reference bars of the end stations. The two plumb lines provide bench marks for the orientation of the local Z axes in rotation about the master Y axis.

Each station in the range can now be positioned using these bench marks so that the local axes are parallel to the master axis and the local origins are some predetermined distance from the master origin. The three linear and three angular adjustments necessary to position the stations are done in five steps. Since the movement of the station in any one direction may adversely effect the adjustments of the previous steps, the procedure is an iterative process. The adjustments required in each successive performance of the five steps are smaller and the steps are repeated until all dimensions are within the allowable tolerances. To limit the number of iterations, reasonable tolerances are permitted for setting the linear co-ordinates. These are measured accurately as described in the next section and in the wire survey. An attempt is made, however, to hold the angular adjustments to close tolerances. Thus no further measurement of the angular position is made.

The movement of the co-ordinate system, the permissible tolerance, and the apparatus used to determine the deviation from the prescribed position are described for the five steps as follows:

Step 1. Each station is moved to set the local Z co-ordinate. The distances between Z fiducial notches are measured with a tape. Tolerance is 0.02 foot.

Step 2. Each station is oriented so that the X and Y axes are parallel to the master axes. This is achieved by leveling the horizontal plate of the station. The levelness is indicated by the precision level (Fig. 20). Tolerance is two divisions on the level which represents 0.001 inch per foot.

Step 3. Each station is adjusted to set the local Y co-ordinate. The transit and the height gage are used to measure the height (Fig. 20). Tolerance is 0.1 inch.

Step 4. Each station is adjusted to set the local X co-ordinate. The equipment shown in figure 21 is used to indicate when the station is in proper position. The right cylinder gage, 2.9 inches in diameter, is placed on the horizontal plate of the station touching the 1-1/2 x 3 x 12 inch parallel bar that is positioned 3.000 inches from the vertical side of the reference bar, by means of gage blocks. The cylinder is so located that the line of contact with the parallel bar is approximately in the local XY plane. When the 300-foot piano wire makes contact with the cylinder, the station is positioned in the X direction. Contact of the wire and cylinder closes an electrical circuit which lights a neon lamp. The tolerance is 0.01 inch.

Step 5. The station is rotated about its local Y axis until the local Z axis is parallel to the plane of the piano wire. The telescope shown in figure 21 is used while adjusting the station. The scope has three-inch rings and touches the side of the 1-1/2 inch parallel bar. Therefore its optical axis is parallel to and six inches from the vertical edge of the reference bar, and three inches from the right cylinder gage. Since the piano wire is touching the cylinder (from Step 4), the local Z axis is parallel to the wire when the cross hairs of the scope intersect the plumb lines on the farthest supporting cylinder. Tolerance is 1 minute of arc.

3. Measuring the co-ordinates of the local origin with respect to the master origin

The origin of the Z co-ordinate in the master axis system lies in the XY plane passing through the fiducial Z notch of station 0. The distance between stations is obtained by means of a precision taping procedure. The first measurement is between the key stations of the five groups of stations. A 70-foot invar tape, calibrated to an accuracy of 0.001 foot by the Bureau of Standards, is suspended over the station fiducial bars. The tape, under precise tension, is supported on roller bearings placed in the XY plane of the stations. A fixture placed on the station permits a steel finger to be placed over the tape so that the side of this finger lies in the XY plane of the station. The station's location with respect to the calibrated tape mark is measured with a traveling stage microscope (Fig. 22). Two measurements are taken for each interval. For the second measurement the tape is reversed and the fixtures interchanged. The two measurements of the interval agree to better than 0.0005 foot. The remainder of the stations are measured by taping the successive five-foot intervals about the key stations. The procedure is similar to the key interval measurement except that a calibrated 5-foot bar and dial indicator are used (Fig. 23).

The difference in height of the key stations is obtained by means of a precision surveyors level and a special target. The target is constructed from a machinists height gage with a 0.004 inch slot built into the indicator finger. This slot is illuminated from the rear with mono-chromatic light. All measurements are taken from the top of the reference bar. Repetitive measurements agree within 0.002 inches.

4. Surveying the spark gap position

The next step in the survey is to locate the point light source and its virtual image with respect to the station axis system. The point light source is located in the XY plane with a Y co-ordinate of 8.159 inches and an X co-ordinate of 54.5 inches. A special optical gage was designed so that the optical axis lies in the XY plane and is parallel to and 8.159 inches from the X axis. The spark gap frame is adjusted so that the 0.050-inch diameter hole in the gap lies on the optical axis of the scope. The X co-ordinate is then measured with a specially designed fixture. This apparatus is shown on a station in the range in figure 24.

The virtual image of the light source is located from the horizontal plate in the same manner. In this case the angle of the mirror is adjusted so that the image of the gap coincides with the optical axis. The heights of two points on the mirror equidistant, 8.159 inches, from the YZ plane are measured. A modified height gage and gage blocks (Fig. 25) are used to obtain this dimension. The position of the virtual image of the gap can be computed from the geometry. These measurements are used in the reduction of range data[5].

5. Conducting the wire survey

The final step is the wire survey. A 300-foot length of 0.012-inch piano wire is suspended over the stations from two supports at the ends of the range. Tension on the wire is 20 pounds. The wire is positioned over the end key stations to lie 8.159 inches from the origin of the X axis. The height of the catenary is so adjusted that the image of the wire can be obtained on all stations and the catenary is symmetrical over the key stations. The electronic equipment is adjusted so that all the stations can be fired simultaneously. Spark photographs of the wire are obtained at all stations. The plates are processed and measured. The data is reduced using procedures similar to those used in round reduction. In the X direction the wire is assumed to be a straight line. The station constant known as the "Correction to X_{cg}" is obtained by a least squares fit of the data. In the Y direction the wire lies in a catenary. Five points on this catenary are known from the Y survey of the key stations. The constant known as the "Correction to Y_{cg}", is obtained by fitting the data of the wire survey to this catenary.

APPENDIX C

List of Available Gun Tubes

APPENDIX C

List of Available Gun Tubes

Rifled Gun Tubes

Caliber	Type	Twist of Rifling Calibers per rev.
.22	Rifle	16
.30	Rifle	33
.50	Mann	30
		40
		60
		100
.60	Mann	18
20-mm	M2	10
		25.6
		40
		60
		100
20-mm	T100	10.2
		11
		15
20-mm	T69	10
		12
		15
		20
		25
		30
		50
		100
30-mm	Mann	16.5
37-mm	M3	25
57-mm	M1	30

Smooth Bore Gun Tubes

Bore Diameter	Type
20-mm	T69
.905	T69
1.500	M3
2.	M1
1.000	Light Gas

Special Bore Shapes

Railed Gun, Cruciform Bore, 20-mm Body Dia .320 x 2.7 inch slots.

APPENDIX D

Figures

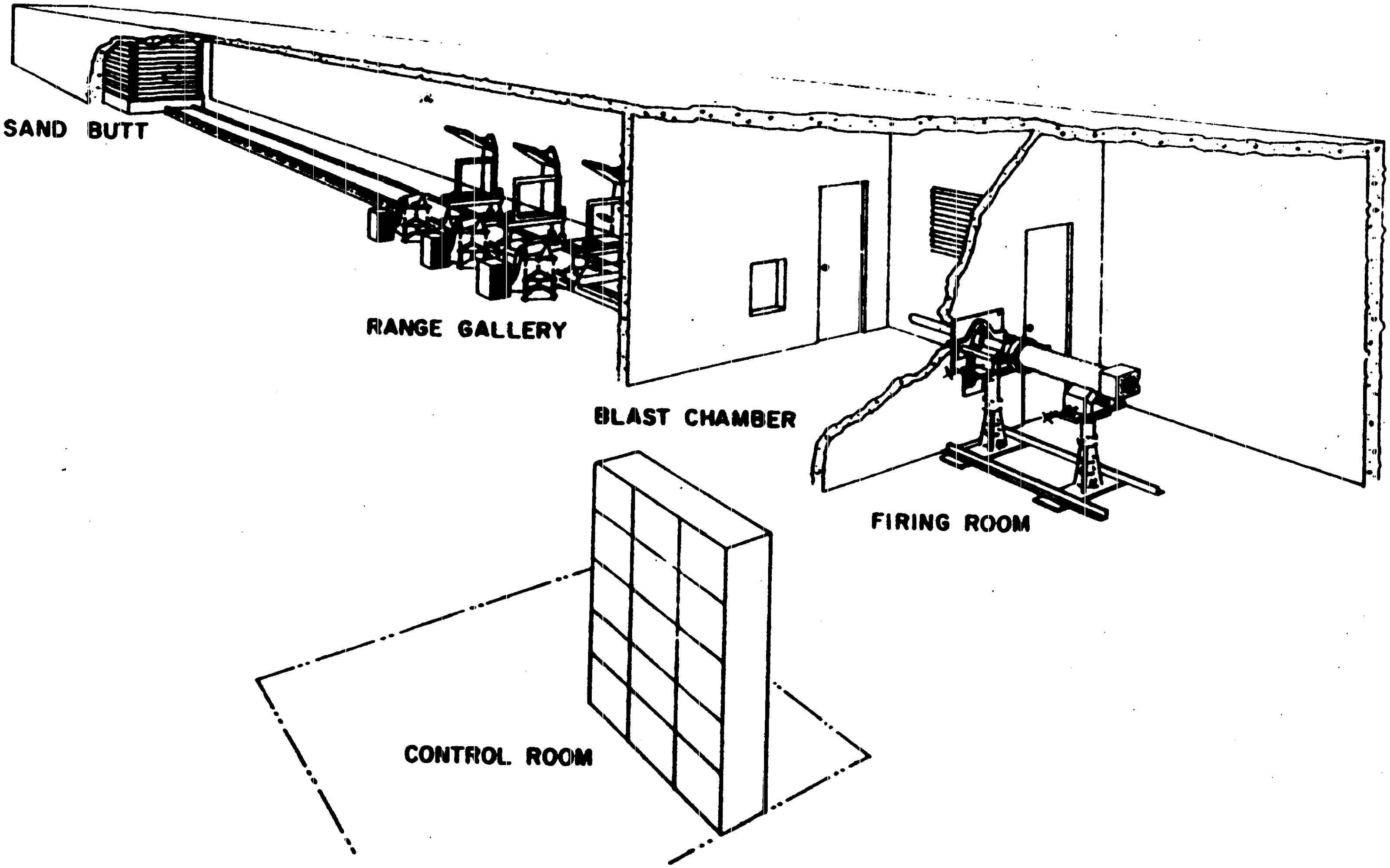

FIGURE 1. SCHEMATIC DRAWING OF THE FREE FLIGHT AERODYNAMICS RANGE

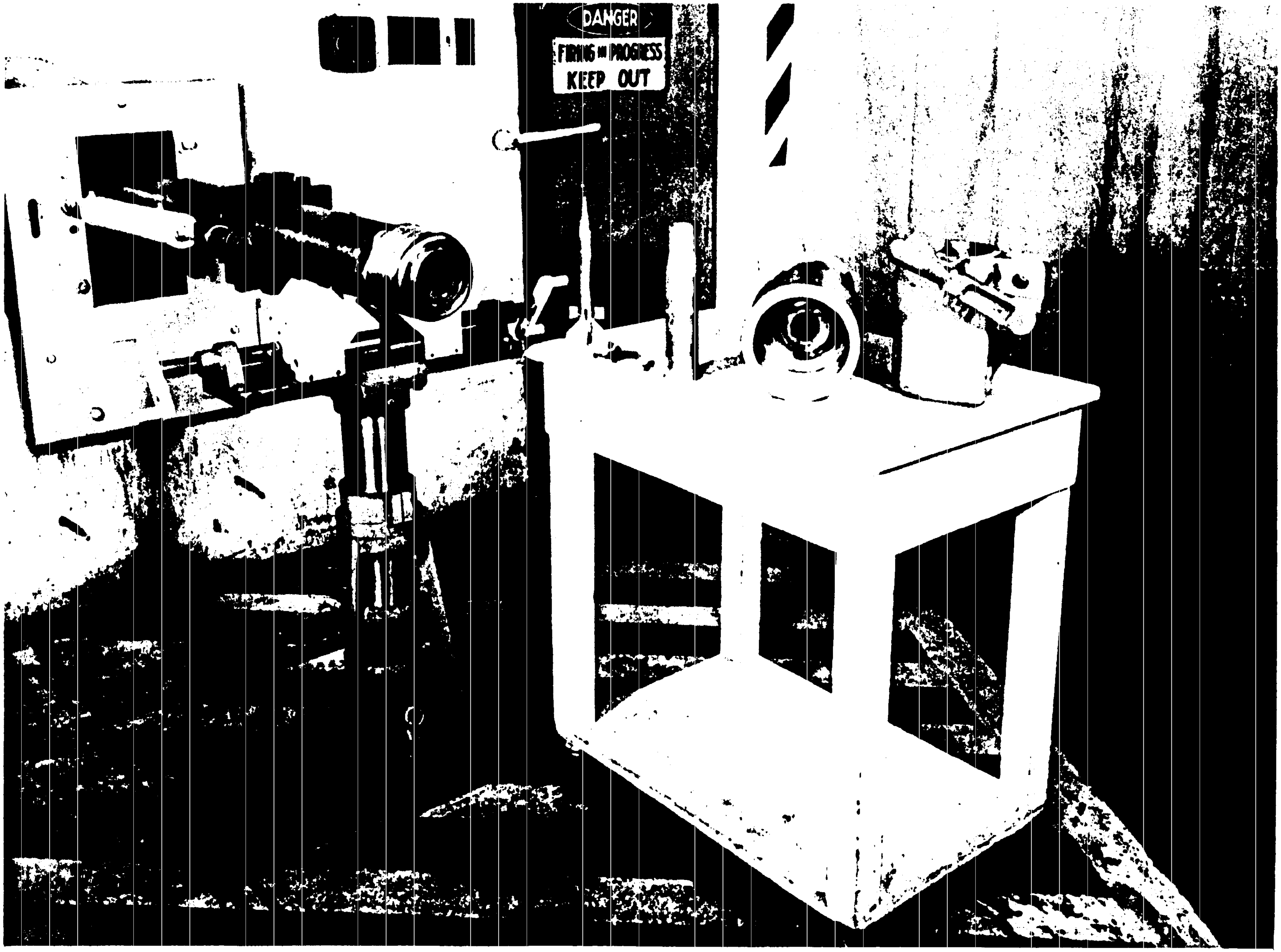

FIGURE 2. THE 20-MM RAILED GUN MOUNTED IN FIRING POSITION

FIGURE 3. THE FREE FLIGHT AERODYNAMICS RANGE

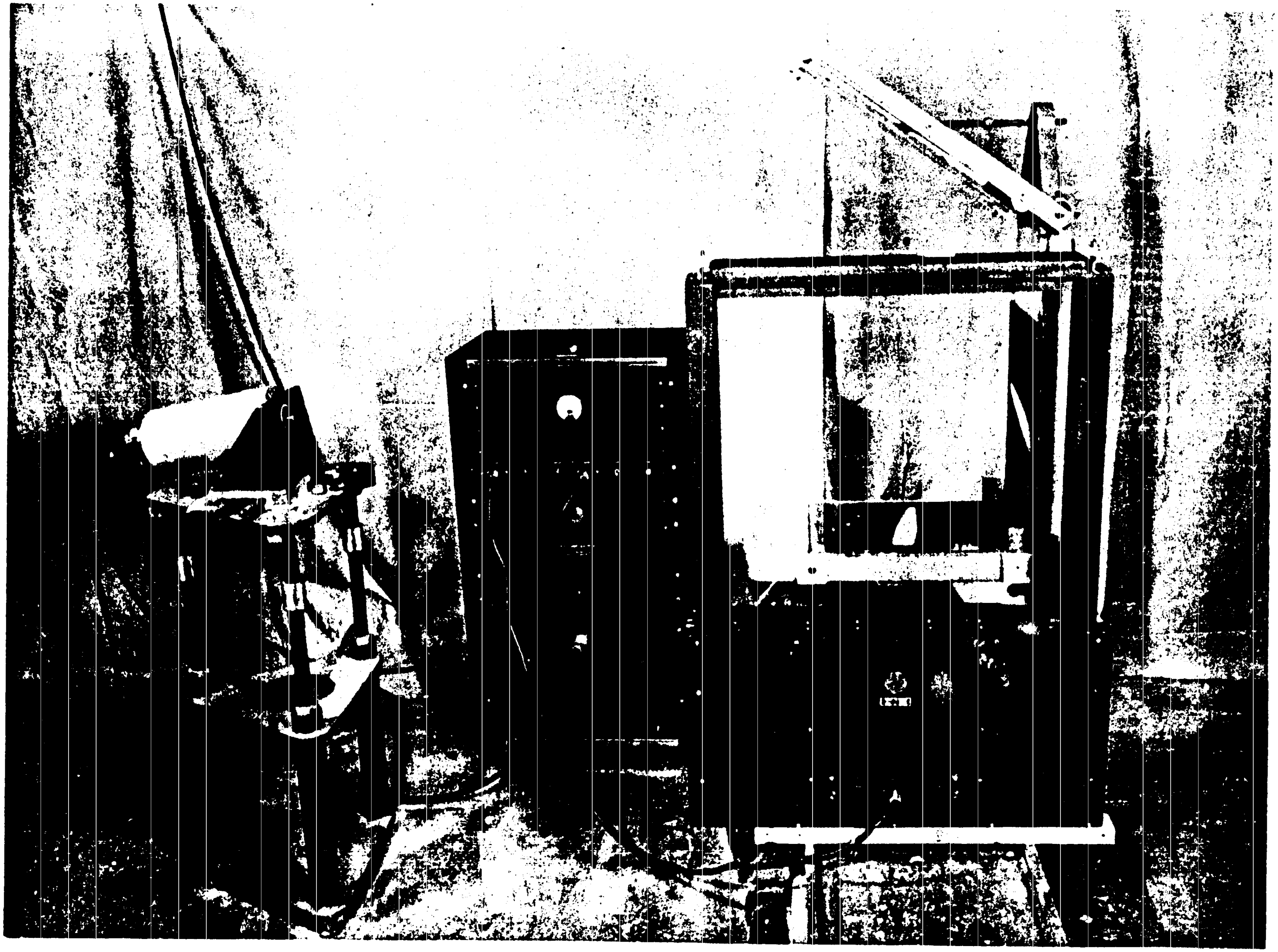

FIGURE 4. THE SPARK PHOTOGRAPHY STATION