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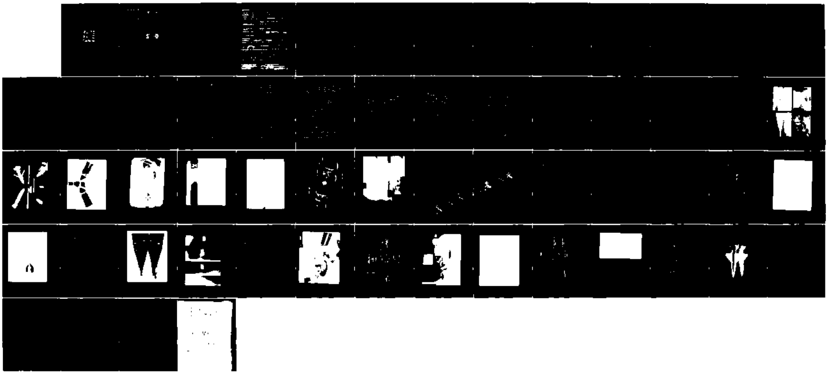

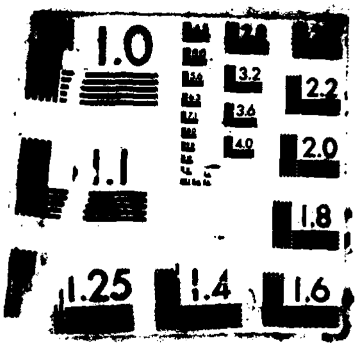
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Description and Capabilities of the Aeroballistic Research Facility

Robert L Kittyle, 1 Lt, USAF
James D Packard
G L Winchenbach

AERODYNAMICS BRANCH
AERODYNAMICS DIVISION

MAY 1987

FINAL REPORT FOR PERIOD JANUARY 1978 - JANUARY 1987

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FOR THE COMMANDER

Donald C Daniel

DONALD C. DANIEL
Chief, Aeromechanics Division

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The purpose of this report is to describe the Aeroballistic Research Facility located at Eglin AFB, FL, discuss the instrumentation systems contained in the facility along with the data analysis techniques used, and present typical data for various configurations that have been tested within the facility. The facility is a classic free-flight spark range containing orthogonal shadowgraph stations, corresponding chronograph system, and several supporting systems. The free-flight trajectories of various configurations are experimentally measured and analysed using both linear theory techniques and nonlinear numerical integration methods. Typical results for a spin stabilized projectile, statically stable (fin) missile, and an aircraft model are presented for illustrative purposes. The facility has undergone numerous changes and improvements since it became operational in 1976 and it is expected that this process will continue into the future.

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- Fin Stabilized Missile
- Aircraft Configuration

PREFACE

The work documented in this report was performed by the Aerodynamics Branch (FXA), Aeromechanics Division (FX), of the Air Force Armament Laboratory (AFATL), Eglin Air Force Base, Florida. The work was accomplished intermittently from January 1979 to January 1987 under the direction of Lt Robert L. Kittyle, Program Manager.

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SECTION I

INTRODUCTION

The Aeroballistic Research Facility is a free-flight aerodynamic test and research facility. It is part of the Aerodynamics Branch, Aeromechanics Division of the Air Force Armament Laboratory, Air Force Systems Command.

This facility is designed for exterior ballistic tests of gyroscopically stabilized, fin stabilized, or mass stabilized projectiles. Such testing includes bullets, missiles, rockets, and subscale aircraft configurations.

The purpose of this report is to update the facility description and capabilities presented in a previous report (Reference 1). Since this previous report was published, several improvements in the facility's instrumentation, data analysis routines, and launch capabilities have been accomplished. This present report incorporates a discussion of these improvements.

SECTION II

FACILITY DESCRIPTION

The Aeroballistic Research Facility is an enclosed, instrumented, concrete structure used to examine the exterior ballistics of various free-flight projectiles (Figure 1). The facility contains a gun room, control room, model measurements room, blast chamber, and the instrumented range.

The 207-meter instrumented length of the range has a 3.66-meter square cross section for the first 69 meters and a 4.88-meter square cross section for the remaining length. The range has 131 locations available as instrumentation sites. Each location has a physical separation of 1.52 meters and presently 55 of the sites are used to house fully instrumented orthogonal shadowgraph stations. The maximum shadowgraph window, an imaginary circle in which a projectile in flight will cast a shadow on both reflective screens is 2.13 meters in diameter. A laser lighted photographic station is located in the uprange end of the instrumented range. This photographic station yields four orthogonal photographs, permitting a complete 360-degree view of the projectile as it passes the station on its downrange trajectory. A view looking down the instrumented portion of the range is also shown in Figure 1.

Flash x-ray heads can be located within the blast chamber or the range proper if required. These flash x-ray heads can be combined inline or orthogonally. The purpose of these radiographic stations is to provide inspection photographs of the model-sabot separation process or model integrity as the model-sabot package exits the launcher muzzle and traverses the range. A Schlieren photographic station is also available when required and is normally located in the first instrumentation site. This Schlieren station is normally used to provide visual inspection of the far flow field. A direct spark shadowgraph station is permanently located in the range to provide near flow field visualization.

All the instrumentation systems have been designed and installed in such a manner as to permit the stations to be movable. Therefore, any station can be moved to another instrumentation site in order to accommodate special test requirements. The present locations of the various stations are tabulated in Table 1.

SECTION III

TEST CONDITIONS

The range is an atmospheric test facility where the temperature and relative humidity are controlled to 22 ± 1 °C and less than 50 percent respectively. The facility is capable of testing various model sizes and configurations. Some of the models and projectiles previously tested or presently scheduled for testing are shown in Figure 2. As evidenced by this figure both symmetric and asymmetric configurations can be tested. The physical measurements of the models (mass, inertias, centers-of-mass, and dimensions) are obtained on site, prior to testing.

The launchers and barrels presently available for use are tabulated in Table 2. As can be seen from this table, a wide variety of barrels and launchers are presently available; these include powder guns, compressed air launchers, and a two-stage light gas gun. Special or developmental launchers can also be readily adapted to the system. For models requiring sabots for the launching process (Figure 3), the developmental testing of the model-sabot package normally is accomplished on an open air range prior to testing in the Aeroballistic Research Facility. During this development phase, both high speed photography and witness panels are used to analyze the model-sabot separation process and resulting model trajectory. By conducting the development phase on the open air range the risk of damage or destruction to the more sophisticated instrumentation within the Aeroballistic Research Facility is minimized.

The test velocities attainable within the facility are a function of the launcher used for a particular test item. Tests have been conducted at subsonic, transonic, supersonic, and hypersonic Mach numbers (M = 0.4 to 10). Since the facility is an atmospheric test facility and the temperature is controlled, Reynolds number can be varied only by varying model scale for a particular test velocity.

SECTION IV

RANGE INSTRUMENTATION

1. SHADOWGRAPH SYSTEM

As previously mentioned, the basic instrumentation in the range consists of dual plane orthogonal spark shadowgraph stations. Each shadowgraph station consists of two cameras, two spark sources, two reflective screens, a power supply, and an infrared (IR) detection system. A sketch of a typical shadowgraph station is shown in Figure 4 and a typical shadowgram is shown in Figure 5.

The shadowgraph camera body consists of an aluminum casting with mating surfaces for lens, film back holder, spark gap housing, and three flanges for mounting. The lens is a 17.8-centimeter focal length F/2.5 Aero Ektar and the back is a 10.2- by 12.7-centimeter Graphlok. The solenoid operated shutter is a two-leaf capping type. Internally, each camera is equipped with 12 numeric light emitting diodes projected at 0.5 magnification onto the edge of the film for recording spark function time and other fixed data. The film used is 10.2 by 12.7 centimeters thick base Kodak Royal X-Plan film.

The spark source is a SS55 Modular Spark System, developed by Hi-Voltage Components, Inc. Included in the system is an energy storage capacitor, power supply, pulse pack, and a spark gap assembly. Six joules of energy are stored in a fast discharge coaxial disc capacitor, at 4800 volts. The power supply furnishes voltage for the capacitor and pulse pack. Voltage is adjustable from 4600 to 5000 VDC requiring a line voltage of 28 VDC. The pulse pack provides the initiate pulse to the spark chamber when activated by the infrared detection system. The spark gap assembly contains a Tungsten alloy probe pin forcing the discharge of the capacitor when activated by the pulse pack. The light emerges axially through a .022-cm orifice in the spark source housing. The spark light at half maximum intensity was 250 to 300 ns with a rise time to maximum intensity of 60 ns. A photograph of the camera-spark assembly is shown in Figure 6. A cross-sectional view of the spark system showing the relative locations of the coaxial disc capacitor, power supply, pulse pack, and the spark gap assembly is shown in Figure 7.

The power supply has two standard high voltage modules: one (-7.5 kV) charges the high voltage pulse generators and the other (0-20 kV) charges the main capacitor. These are mounted on a chassis along with dumping resistors, a panel meter, a variac, and the low voltage trigger. The chassis is mounted in a wheeled relay rack which also accommodates the chronograph chassis, the other camera, and the detector screen controls. There is one rack for each station, and there are provisions for remotely controlling the racks from the control console located in the control room.

The reflective screen material is Minnesota Mining and Manufacturing Company's high gain reflective sheeting laminate 6711. The average diameter of an individual lens (glass bead) element in the screen is 0.0051 centimeter. The screen sizes are 1.22 by 2.44 meters in the upper portion of the facility and 1.22 by 3.66 meters in the downrange portion. The screen material is mounted on a polyurethane-aluminum sandwich backing which, in turn, is mounted to the facility walls and ceiling.

An infrared detection system used to detect the approach of ballistic projectiles and trigger the spark sources is located at each shadowgraph station. The detection system, the Opos EO 130, consists of an IR transmitter and detector encased in one unit (Figure 8). The transmitter has 13 IR light emitting diodes. The light, with a wavelength of 880 mm, is transmitted across the hallway to the screen and reflected back to the unit. The detector is made up of 18 parallel coupled receiver-diodes with a built-in infrared filter. The diodes have a 20-degree or 35-degree beam width. Due to the fan-shaped area of one detector, the detection beams overlap. The combined output of the receiver diodes is amplified by an amplifier located in the unit.

2. CHRONOGRAPH SYSTEM

The chronograph system provides the required times of flight as the projectile traverses the instrumented portion of the range. Event times, corresponding to each spark source discharge, are obtained to a resolution of + 0.01 μ sec by electronic chronographs located at each of the 50 shadowgraph stations. Experience has indicated that both orthogonal sparks normally discharge within 0.3 μ sec of each other. The chronographs at each station operate under the control of the sequencer and in conjunction with the velocity data system, IR detection system, and the spark gap assembly. The timing system in all the chronographs is synchronized to a master 10-MHz clock located in the control console.

The sequencer provides the pulses listed below to the chronographs at the following times in the firing sequence: (1) -3.5 seconds - solenoid operated camera shutters open; (2) -2.0 seconds - clear (resets all chronograph counters to zero); (3) -1.5 seconds - start (counters synchronized to the master 10 MHz clock); (4) -1.0 second - fire (gun is fired); (5) +3.5 seconds - shutters closed; (6) + 10.5 seconds - strobe transfers accumulated time in chronograph counters onto the film.

When a projectile is detected, a 15-volt pulse initiates the discharge of the capacitor. A light sensing diode (MRD 300) located inside the spark gap cavity senses this discharge and, subsequently, stops the chronograph counter at the station. This results in the total elapsed time from the common start pulse to the passing of the test item.

Stations at the far end of the tunnel will take up to 3.3 μ sec longer to receive the common start pulse due to the lumped signal delays inherent in the connecting cables. This time delay has been measured at each station and is compensated for in the data reduction programs.

Four thumbwheel digits located on the chronograph chassis are available for fixed shot identification data to be placed on the film (Figure 5). A fifth digit, which is hard wired internally, identifies whether the film was from a wall or pit camera. The first four digits are common to both cameras.

A switch to select the sensitivity of the IR system is provided to accommodate the various size projectiles that may be tested in the tunnel. In the HI position a projectile as small as a BB is easily detected.

The simulate/real switch will normally be in the real position which indicates that the counters will be stopped by the pulses from the spark source. In the simulate position the counters are stopped by a pulse that would normally have originated from the MRD 300 light detector. With the switch in this position the spark gap assembly will not be triggered but the velocity pulse will be sent to the IBM 9001 for computation of the velocity between two adjacent stations.

3. ALIGNMENT SYSTEM

In ballistic range testing, the time history of the position and orientation of an object in free-flight is precisely determined at various locations along its trajectory. In order to obtain this precise position-orientation history an accurate reference system must be used. The reference system used in the Aeroballistic Research Facility consists of Kevlar® fiber bundles (henceforth called wires) with reference beads positioned at precisely ± 45.72 centimeters about 1.52-meter centers over its entire length. Two Kevlar® wires are strung in front of the wall-mounted reflective screens and two are strung below the ceiling-mounted reflective screens. With this positioning, two beads on each wire are in the field of view of each camera (Figure 5). The range coordinates of each bead are well known. The relative positions of the wires (and therefore the beads) are maintained with the alignment system.

The major components of the alignment system are shown in Figure 9. Numbered callouts are explained in legend for Figure 9. They include: four overhead endpoint trusses labelled endpoint truss position 1, 2, 3, and 4; three overhead midpoint trusses labelled midpoint sag position 1, 2, and 3; a water level system; translators; a catenary movement detection system (henceforth called sensors); a master catenary; and the Kevlar® catenary wires with beads. A complete description of the alignment system is presented in Reference 2.

A right-handed coordinate system, where x is downrange, y is crossrange, and z is vertical, has been defined for the range. The crossrange coordinate is defined with the use of a master catenary which determines the x-z plane. The vertical coordinate is defined by the water level system, using the equipotential lines of the earth's gravity as a basis. The water level system determines the x-y plane. The first bead on the lower wall catenary is chosen as the origin (0, 0, 0) of the range reference system.

Each catenary wire is approximately 70 meters long. Therefore, three lengths of wire are needed to span the length of the range. As there are four catenary wires, the reference system requires a total of 12 lengths of wire. The three consecutive spans of wire comprising one of the four catenaries are coupled together by the alignment system so as to act as one 207.26-meters long wire. Each end of the 12 lengths of wire is held in place with a flat clamp. This clamp is attached to a translator, or a series of translators, depending upon the wire being considered. The translators are teamed with a series of sensors which detect any movement of the catenary wires from their preset positions.

Located within each endpoint truss is an Invar® bar, a low expansion nickel alloy, with calibration marks precisely 1.52 meters apart. This bar positions the ceiling catenaries a constant, arbitrary distance from, and parallel to, the plane of the master catenary. The upper wall catenary at each endpoint truss position is initially placed parallel to, but some arbitrary distance from, the x-z plane. The lower wall catenary is placed in a position parallel to the plane of the master catenary and in plane with the upper wall catenary.

For endpoint truss positions 1, 3, and 4, one translator located at the end of each truss accounts for any translator movement necessary to keep the two ceiling catenaries and the upper wall catenary in alignment. A plumb line is dropped from a bracket in each endpoint truss to the floor. As the truss is repositioned, the plumb line moves. When this plumb line movement is sensed, a translator moves the lower wall catenary, maintaining the catenary a constant distance from, and parallel to, the plane of the master catenary. Endpoint truss position 2 is similar to endpoint truss positions 1, 3, and 4, except a separate translator moves the upper wall catenary corresponding to any movement of the plumb line.

A water level system, corrected for the earth's curvature, is used to define the zero reference for the vertical range coordinate. Polyvinyl Chloride (PVC) tubes (2.54 centimeter ID) are mounted on one wall parallel to the plane of the master catenary. This tube extends the length of the range. Sections are also run parallel to the crossrange direction, perpendicular to the master catenary, inside all endpoint and midpoint trusses.

The plumb line dropped from the truss of endpoint truss position 2 has a marker glued on it near the floor. This marker-sensor combination is preset in some arbitrary initial position. Two sensors, attached to the truss, monitor any change in water level for span 1 and span 2. Any change from the preset position causes a pump to adjust the water level by adding or removing water. The water level at its preset position defines an x-y plane. With the use of a second marker on the plumb line, a translator at one each of the truss maintains the end of the truss in a plane parallel to the plane of the water level system. Another translator, located at the other end of the truss, maintains the whole truss in a plane parallel to the plane defined by the water level system. A third and fourth vertical translator, located at the lower wall catenary and upper wall catenary, maintains those catenaries in positions parallel to the plane of the water level system when the motion of a third and fourth marker on the plumb line is sensed.

Endpoint truss positions 1, 3, and 4 have one translator on either end of the overhead endpoint truss which maintains the truss, the ceiling catenaries, and the attached upper wall catenary in a plane parallel to the x-y plane of the water level. When any motion of a marker on the plumb line is sensed, the translator moves the lower wall catenary into a plane parallel to the plane defined by the water level system.

Three translators are located at midpoint sag positions 1, 2, and 3. The first translator maintains a vertical Invar bar a constant arbitrary distance from the plane of the water level system. This bar positions the attached sensors so they can measure the midpoint sag of the upper and lower wall catenaries. Two more translators are located along the ceiling to maintain the position of the sensors, which measure the midpoint sag of the two ceiling catenaries, a constant arbitrary distance from the plane of the water level system.

With the catenary wires in their preset positions, the midpoint sag sensor positions are set. The midpoint sag of each wire is then monitored in order to guarantee the same catenary curve at all times. This then maintains all reference beads in their preset downrange positions.

A sensor on the plumb line at endpoint truss position 1 triggers a translator which keeps the lower wall catenary in plane with the upper three catenaries. A translator located at the far end of the truss keeps the truss perpendicular to the plane of the master catenary. Endpoint truss position 2 contains the translators described above and the translators which work off the midpoint sag sensors. At each ceiling catenary position and each wall catenary position, catenaries from spans 1 and 2 are coupled by a translator. These translators move both span 1 and 2 wires simultaneously. Endpoint truss positions 3 and 4 are identical to the above. They consist of the translators which work off the midpoint sag position and 2 and 3 sensors, respectively, and a translator at the far end of the truss which retains the truss perpendicular to the plane defined by the master catenary.

Once in the preset position, the translators at endpoint truss position 1 do not move. The midpoint sag of each catenary wire is monitored at midpoint sag position 1. Any deviation from the preset sag sends a signal to the corresponding translator at endpoint truss position 2 which moves to adjust the tension in the catenary wires. This change in translator position causes the sag position at midpoint sag position 2 to change. When this change is sensed, a signal is sent to the translator at endpoint truss position 3. This translator moves to adjust the tension in the catenary wire and, therefore, maintains the preset sag positions. Finally, the sensors at midpoint sag position 3 detect a change in the preset catenary wire sag position. The corresponding downrange translators at endpoint truss position 4 then adjusts the tension in these catenary wires.

Power to the alignment system is normally off. Before each shot is fired, the power is turned on and a status and control panel is monitored. Any translator movement initiated by the sensors appears on the status and control panel as a lighted button. Therefore, when the power to the alignment system is turned on and all the translator lights on the status and control panel are off, the wires and the reference beads are in the preset positions.

4. LASER-LIGHTED PHOTOGRAPHIC STATION

The facility contains one laser-lighted photographic station located in the uprange end of the instrumented section. This photographic station obtains four orthogonal photographs, yielding a complete 360-degree view of the projectile as it passes the station on its downrange trajectory. A sketch of the laser-lighted photographic station is shown in Figure 10. The laser is an Apollo Model 5HD Q-switched ruby laser. The laser has an energy of four joules with a pulse width of approximately 20 nanoseconds (nsec). The total beam divergence is 6 milliradians at the half power points and the initial beam diameter is 1.59 centimeters.

The laser beam is split such that four beams of equal strength are passed into each of the four beam divergers. The beam divergers consist of 12.7 centimeters at the approximate range centerline. Located at about 45 degrees from the centerline of the diverged beams are four, high grade, first surface mirrors. A commercial view camera with a 30.5-centimeter focal length lens is positioned in front of each mirror and focused approximately to the range centerline.

The triggering system used for this station is an Opos infrared emitter and detector identical to the ones used for the shadowgraph stations. Shot and camera identification information is strobed onto the film prior to loading the film cassettes into the individual cameras. The film used is 10.2- by 12.7-centimeter Kodak Linagraph Shellburst film. Typical laser lighted photographs of models in free-flight are shown in Figures 11 and 12.

5. X-RAY PHOTOGRAPHIC STATION

The x-ray station uses a Hewlett Packard Model 730-4/2350 flash x-ray system with four remote x-ray heads containing hard x-ray tubes. The remote heads and associated film holders can be configured into four inline stations or positioned orthogonally on a light aluminum framework located within the blast chamber.

The high voltage power supply, nitrogen pressurized high voltage pulsers, remote trigger amplifiers, and nitrogen bottles are located in the hallway adjacent to the blast chamber. The projectile is detected by a light screen or similar trigger device mounted on the front of the aluminum framework. The high voltage is set remotely from the main console in the control room. Appropriate trigger delays are dialed in at the delay trigger amplifiers. Coarse delays of 10 sec, 100 sec, 1 msec, 10 msec, and 100 msec can be switched in and a precision 10-turn heliopot adds in any delay between the course settings.

The film presently being used is Kodak RP-54 (?X-OMAT) x-ray film in the 35.6- by 43.2-centimeter and 35.6- by 91-centimeter formats. The film holders also contain Radelin TI-2 intensifying screens. For quick x-ray inspection there are also four Hewlett Packard 43132 x-ray Polaroid Radiograph Cassettes which use Type 52 Polaroid film in the 10.2- by 12.7- centimeter format. These cassettes also contain integral intensifying screens. Figure 13 shows typical x-ray penetration and operating characteristics of the system.

6. MULTISPARK STATIONS

At present, five of the 56 shadowgraph stations are complete multispark stations. The purpose of these photographic stations is to provide a high density of position-orientation measurements over a short flight interval.

This is required in order to define the angular motion of an object which has a very high nutational rate. These stations are very similar to the single spark stations presently installed with the exception of the four spark sources surrounding each camera and the size of the reflective screens. The reflective screens are 2.44 meters square and the triggering is accomplished using the same IR screens previously discussed. When the model penetrates the IR screen the first pair of orthogonal sparks is discharged consistent with the delay corresponding to the expected velocity; timing data will be obtained for only the first pair of spark charges. The remaining three pairs of sparks are discharged in sequence, also consistent with the expected velocity. A perspective sketch of a multispark station is shown in Figure 14.

The four spark sources are designed such that each illuminates only a 0.61-meter strip of the reflective screens. Therefore, four photographs are obtained on each sheet of film and none of the images are double exposed (Figure 15). This system along with the 50 shadowgraph stations previously discussed can produce a total of 70 position-attitude measurements as the model traverses the instrumented portion of the range. For a complete description of the multispark stations see Reference 3.

7. DATA DIAGNOSTIC SYSTEM

To provide a pretest and posttest evaluation of the status of the range instrumentation, a data diagnostic system is incorporated into the ARF. All of the holophotal instrumentation previously described provides crucial information for the free-flight data reduction process. The failure of any number of stations could cause irrecoverable gaps in the data collection process. As already established, each station in the range uses photographic film as the data recording medium. This film is removed from the facility, processed, and returned to the range. Until the film is returned to the range personnel, no diagnostic analysis of the information on the film can be made to identify equipment failures. Since a typical shadowgraph station has several events which must occur before satisfactory pictures are obtained, each event or binary coded data (BCD) point can be analyzed to produce some diagnostic information.

The major task involved with diagnosing problem areas is the acquisition and timely monitoring of the data. To accomplish this function, an IBM Systems 9001 microcomputer workstation was installed in the Aeroballistic Research Facility. The overall system is identified in block diagram form in Figure 16. Each holophotal station is linked to the tunnel acquisition unit. The interface system consisting of data interface modules and the tunnel data acquisition control (TDAC) provides for monitoring each station before, during, and after a test is conducted. Each module is a microprocessor capable of running short diagnostic programs cn the station equipment. The information from the modules is stored in the TDAC which is controlled by the IBM System's 9001 microcomputer. This computer forms the basis of the automatic data processing equipment. The microcomputer system contains 896K bytes of core memory, a 20-megabyte hard disk, a 5 1/4-inch floppy disk drive, a 9 track 1/2-inch tape drive, and a high resolution text/graphics display. The peripherals provide immediate and permanent storage for the data collected from the TDAC.

Following the input of all required data, a resident software program performs an analysis and produces a diagnostic printout. This information can then be used to determine which station may require attention before the next shot. The printout also provides a velocity profile of the test projectile by collecting each pulse from the IR detectors and pairing the event with the time of occurrence. With the distance between the detectors previously measured, velocities between each station are calculated.

8. FUTURE ARF SYSTEMS

Two ARF subsystems are currently under development for future data retrieval applications. One of these is a holographic station for obtaining holographic interferometer data. This system will be used to determine flow field air densities and, hence, pressure fields about the test body. This type of data will be used to visualize the flow and better understand the aerodynamics. Additionally, by being able to determine the pressure field off the body and at any location along the body, computational fluid dynamicists will be able to clearly determine pressure distributions without corrupting data with wind tunnel probes. The system will be based on an Apollo Model 22HD Double-Pulsed Holographic Laser. The estimated date of completion for this system is January 1988.

The second system that could revolutionize the data retrieval process is the electronic shadowgraph. The objective of this program is to determine the feasibility of installing electronic shadowgraph stations throughout the Facility. By digitizing, collecting, compiling, and displaying electronic projectile images from free flight tests, accuracy and efficiency of the Range can be improved. This system will enable engineers to immediately begin the data analysis process by eliminating film handling and reading. Technical challenges include developing a high resolution digital screen and camera. Installation of a prototype station is scheduled during FY87.

SECTION V

DATA REDUCTION

1. FILM READING

At present, the shadowgrams obtained during a test program are read and numerically coded using a Perkin-Elmer Model 1010A Microdensitometer System. This optical film reader is an adaptation of a commercially available microdensitometer designed to take accurate readings of the density of very small areas of photographic film and determine the precise location of these areas in relation to each other. The film reader consists of three main parts: the microdensitometer; a PDP11/04 minicomputer with a CRT terminal, printer, magnetic tape, and floppy discs; and an interactive software package. Once the film has been sorted and mounted on the reader, the points of interest on the film are coded and stored on data processing tapes. The projected image on the viewscreen can be magnified 20X, 40X, 60X, or 80X. The software has been written so that the minicomputer will perform rough positioning of the microdensitometer to the predictable film read points allowing the operator to accomplish the fine positioning. This system is depicted in Figure 17.

2. SPATIAL POSITIONS AND ORIENTATION

Once the range coordinates of both orthogonal shadows of a point on the model in space have been determined from the shadowgrams, the range coordinates of this point on the model are computed by finding the closest approach of two vectors. These two vectors are defined by rays connecting the predetermined spark gap coordinates to the measured shadow coordinates. Therefore, the point in space corresponds ideally to the intersection of the two vectors. Since some measurement error is expected in both the shadow measurements and the spark gap locations, the two vectors will not exactly intersect. The unknown point is therefore assumed to lie halfway along the shortest line connecting the two vectors.

When determining the spatial position and orientation of a model in free-flight, the positions of concern are those defining the center of mass of the model and the orientation defined by the direction cosines of the principal axis of the model with respect to the range axis system. In order to determine the direction cosines of the principal axis, the coordinates of two points lying on the principal axis are determined. The two points are generally the nose of the model and the center of the base. The vector defined by the two points and coinciding with the principal axis uniquely establishes the direction cosines. The coordinates of the center of mass are computed by using the known distance between the nose of the model and the center of mass (measured prior to launching) and recognizing that the center of mass lies on the principal axis. See Reference 4 for a complete mathematical treatment of this process.

3. COEFFICIENT EXTRACTION

Aerodynamic coefficients are extracted from the model's measured time, position, and attitude histories by using linear theory data reduction techniques of References 5 and 6, and the nonlinear numerical integration techniques of Chapman and Kirk (Reference 7). These techniques are incorporated into a system of four data reduction programs known as the Aeroballistic Research Facility Data Analysis System (ARFDAS), shown schematically in Figure 18.

The first of the four computer routines, ARFSYSTEM is the only interactive portion of ARFDAS. ARFSYSTEM enables the user to retrieve raw data from specific shots and input the physical properties and atmospheric conditions. Then a linear theory analysis (as discussed in Reference 8) is used to fit an epicyclic equation to the yawing motion of the projectile. This results in a set of coefficients suitable for initial estimates for six degree-of-freedom (6DOF) analysis. Finally, ARFSYSTEM allows the user to opt between three separate 6DOF routines: MLMFXPL, MLMBDFX, and MLMBALL.

MLMFXPL, shown in Figure 18, incorporates a fourth order Runge-Kutta routine for analyzing free flight motion of symmetric projectiles. A fixed plane reference system is used to facilitate the data reduction process. The program permits the user to accomplish linear and nonlinear data analysis which is discussed in detail in Reference 8. After individual data sets have been reduced, MLMFXPL has the capability of determining a common set of aerodynamic characteristics that best fit the measured position and orientation histories of up to five separate shots.

The second 6DOF computer program, MLMBDFX, is used for analyzing the motion obtained from asymmetric bodies (objects having only one plane of symmetry) such as aircraft configurations and some missile designs. This program parallels the procedures used in MLMFXPL but with a body-fixed reference system. For a complete description of this program refer to Reference 9.

The final 6DOF program shown in Figure 18, MLMBALL is identical to the first program, MLMFXPL, with the inclusion of forces and moments due to the motion of internal components. This routine is important for the analysis of projectiles with movable fuse mechanisms. Further details are given in Reference 10.

The four programs comprising ARFDAS are run on a CDC Cyber 176 computer and the execution of the programs is controlled from a remote terminal located at the facility (Figure 19). Each of the three 6DOF programs matches the theoretical equations of motion to the experimental trajectory using the Maximum Likelihood data correlation technique. This method of data correlation is extensively discussed in Reference 11.

4. PRECISION OF MEASUREMENTS

It should be recognized that the precision to which the spatial position and/or orientation of a model can be determined is related to the geometry of the model. For example, the range coordinates of a model's nose can be more precisely determined if the model has a sharp, well defined nose tip. Also, the orientation of a long model can be obtained more precisely than that of a short model because the two points on the principal axis which define the orientation are further apart and, therefore, any measurement errors associated with the two points have a smaller effect. This indicates that the spatial positions and orientations of a long pointed configuration are better determined than that for a short blunted configuration. Unfortunately, some projectiles fall into the latter category; however, most missiles and rockets are consistent with the first category. The present measuring capability of the facility is approximately 0.08 degrees and 0.03 centimeters, respectively, for the orientation and position of well-defined points in space.

5. SAMPLE AERODYNAMIC DATA

A few typical aerodynamic coefficients and derivatives are shown in Figures 20, 21, and 22. These typical data were extracted from References 12, 13, and 14 respectively and are presented in order to indicate the type of data that can be obtained from the Aeroballistic Research Facility. However, it should be obvious that these are not the only coefficients and derivatives that can be obtained. In fact, all force and moment data, including their nonlinearities, can be determined from the measured free-flight motion patterns if these coefficients and derivatives have a measurable effect on the observed motion and if these effects can be modeled in the reduction routines. Also, when testing full scale configurations (which is frequently the case), such added benefits as flow observation, precise roll histories, and actual dispersion measurements can be invaluable to the analyst and test engineer.

SECTION VI

CONCLUDING REMARKS

Much of the instrumentation and techniques used in establishing the Aeroballistic Research Facility have been significantly altered over the past several years (Reference 1). For example, the automatic range calibration technique as discussed in Reference 4 and mentioned in Reference 3 has proven inadequate. Alternate means of calibrating the range (determining the range coordinates of the spark gaps and reference beads) have been developed and are presently used (Reference 15). These techniques are considered an improvement over the conventional techniques previously used. Changes have also been incorporated into the alignment system, spark gap design, and chronographs.

Frequently, when changes or alterations have been made, they have impacted the logic behind some other aspect of the facility. For example, when using the automatic range calibration technique it was advantageous to have the spark gap assembly mounted to the camera housing. However, since the automatic range calibration procedure has been discarded it would be more efficient from a maintenance viewpoint to separate the camera and the spark gap assembly. Also, even before the facility became operational it was apparent that some desirable features were lacking. The design and installation of systems such as the multispark shadowgraph stations and the IBM systems 9001 microcomputer (among others) were initiated.

The facility has been operational as of March 1976. It is expected that innovative systems and techniques will be continually tried and incorporated into the facility.

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Figure 1. Aeroballistic Research Facility
(Clockwise From Upper Left: Outside View, Range Instrumentation, Range Interior, Data Diagnostic Center)

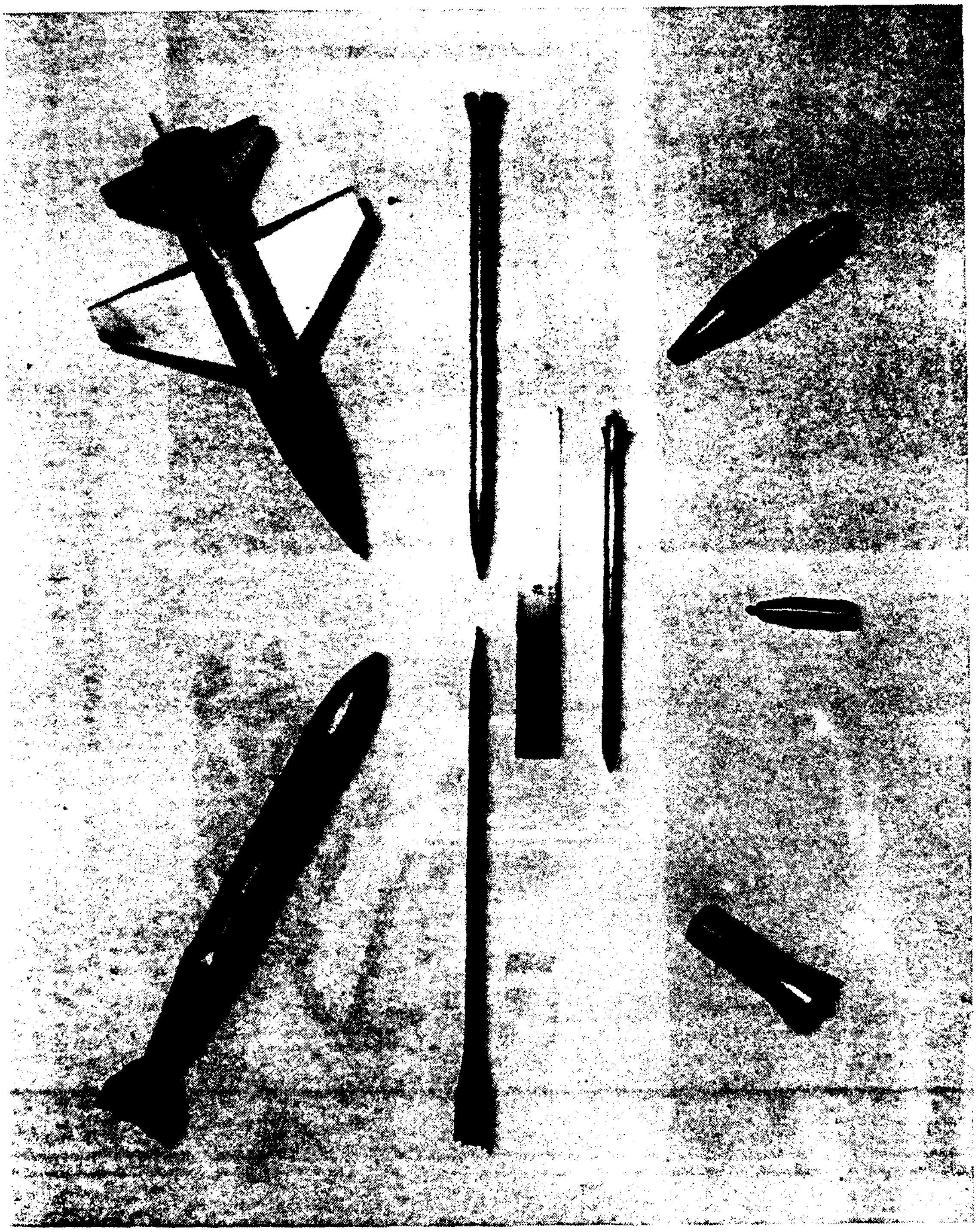


Figure 2. Typical Models and Projectiles

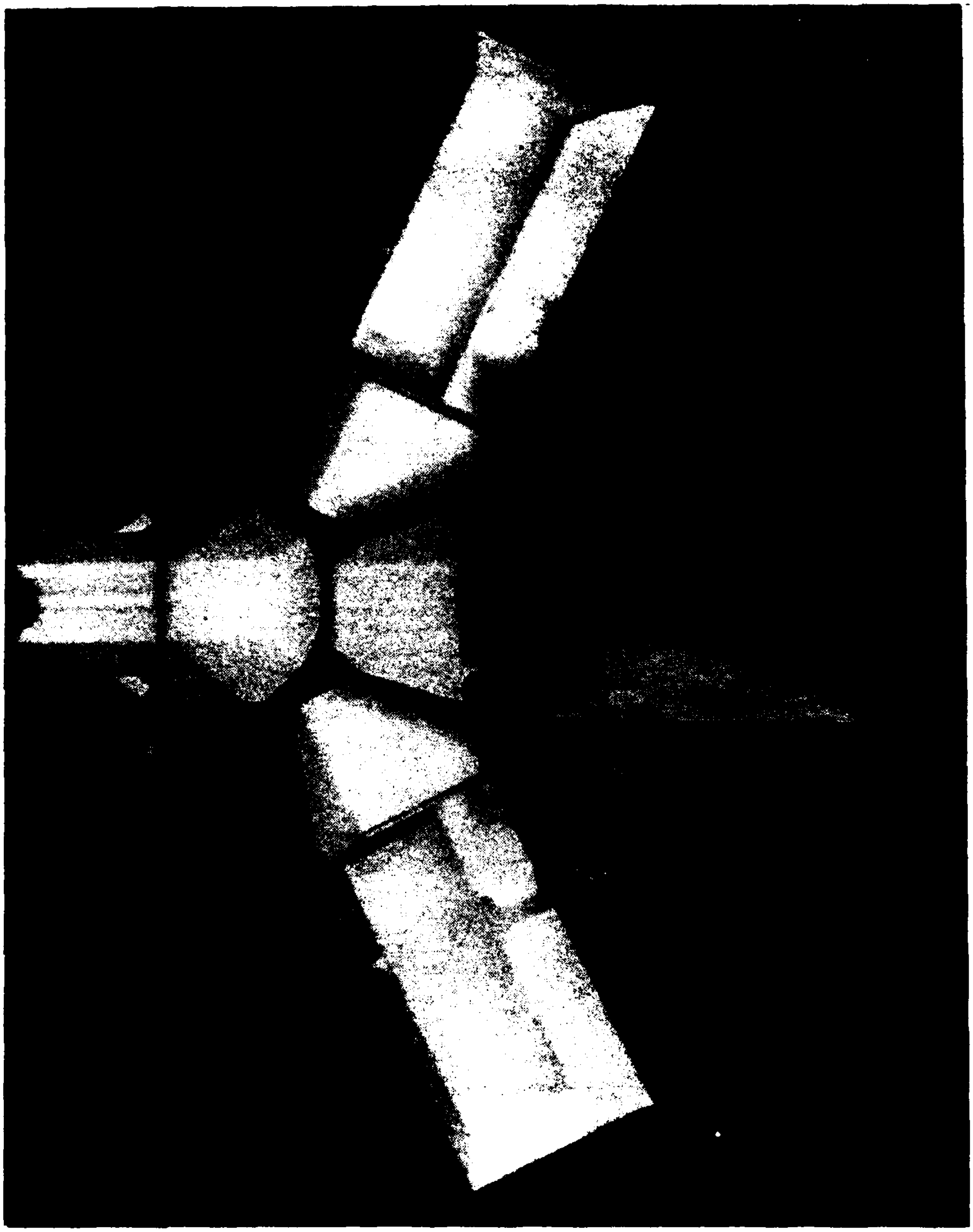


Figure 3. Typical Model·Sabot Package

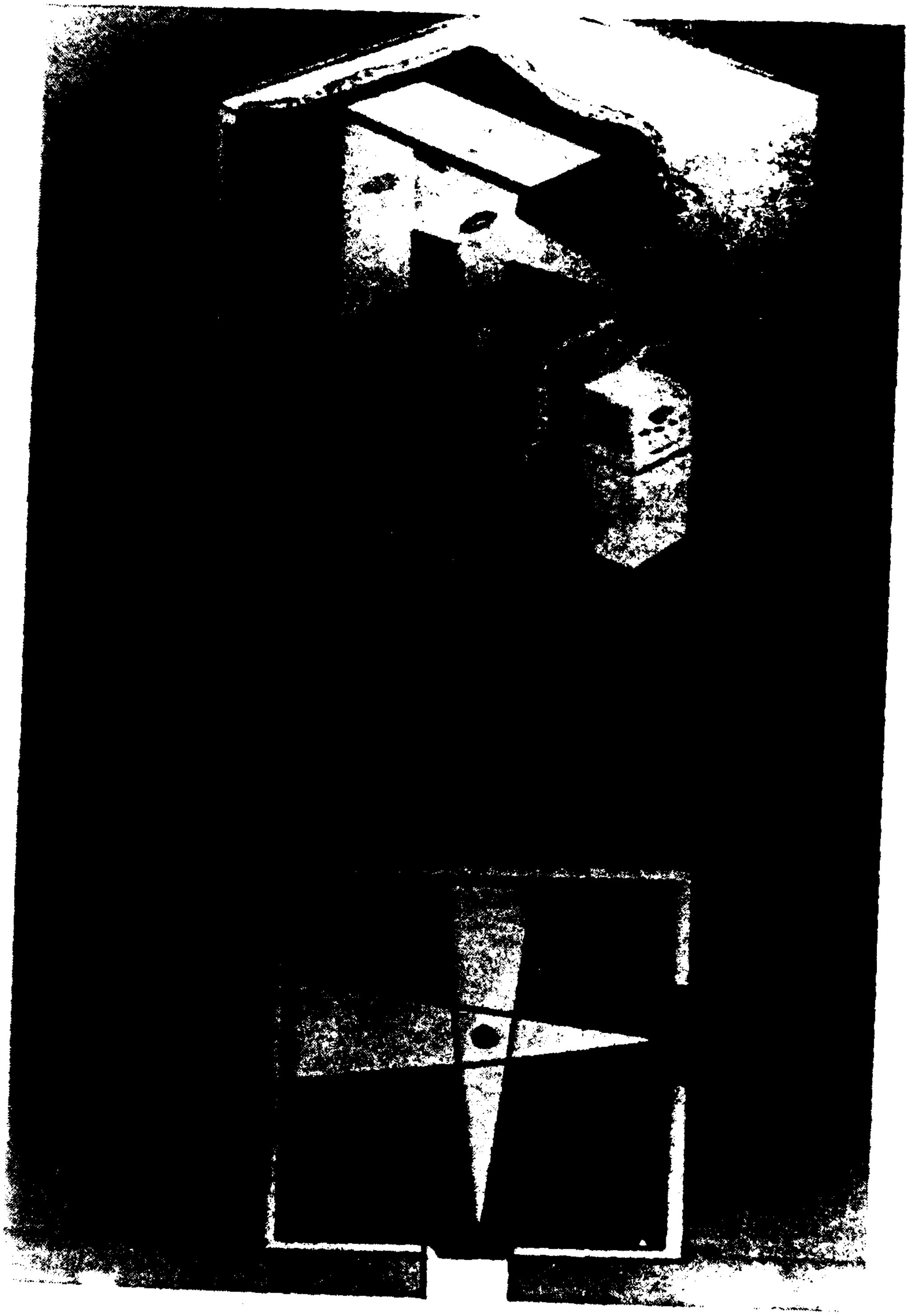


Figure 4. Typical Shadowgraph Station

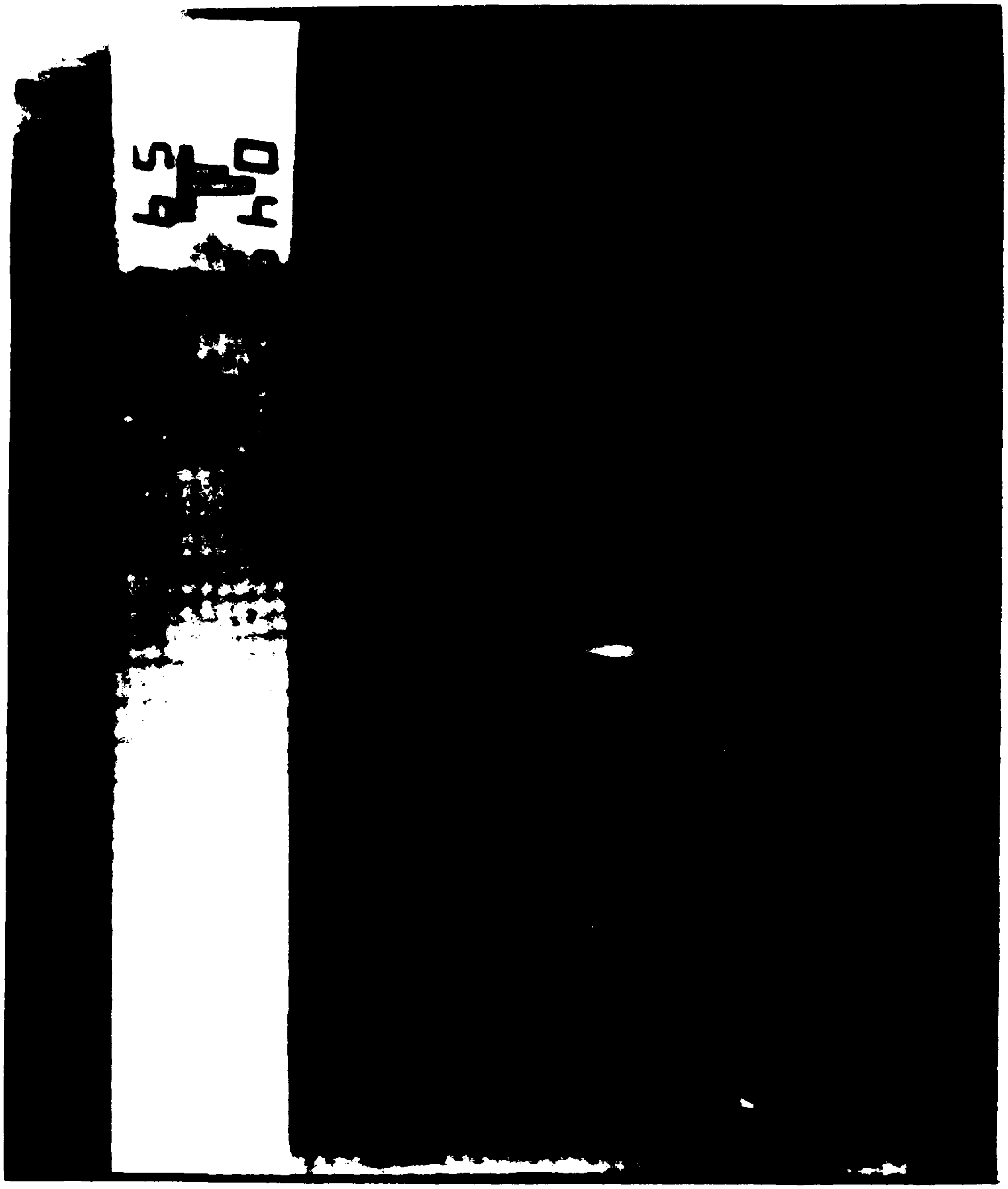


Figure 5. Typical Shadowgram

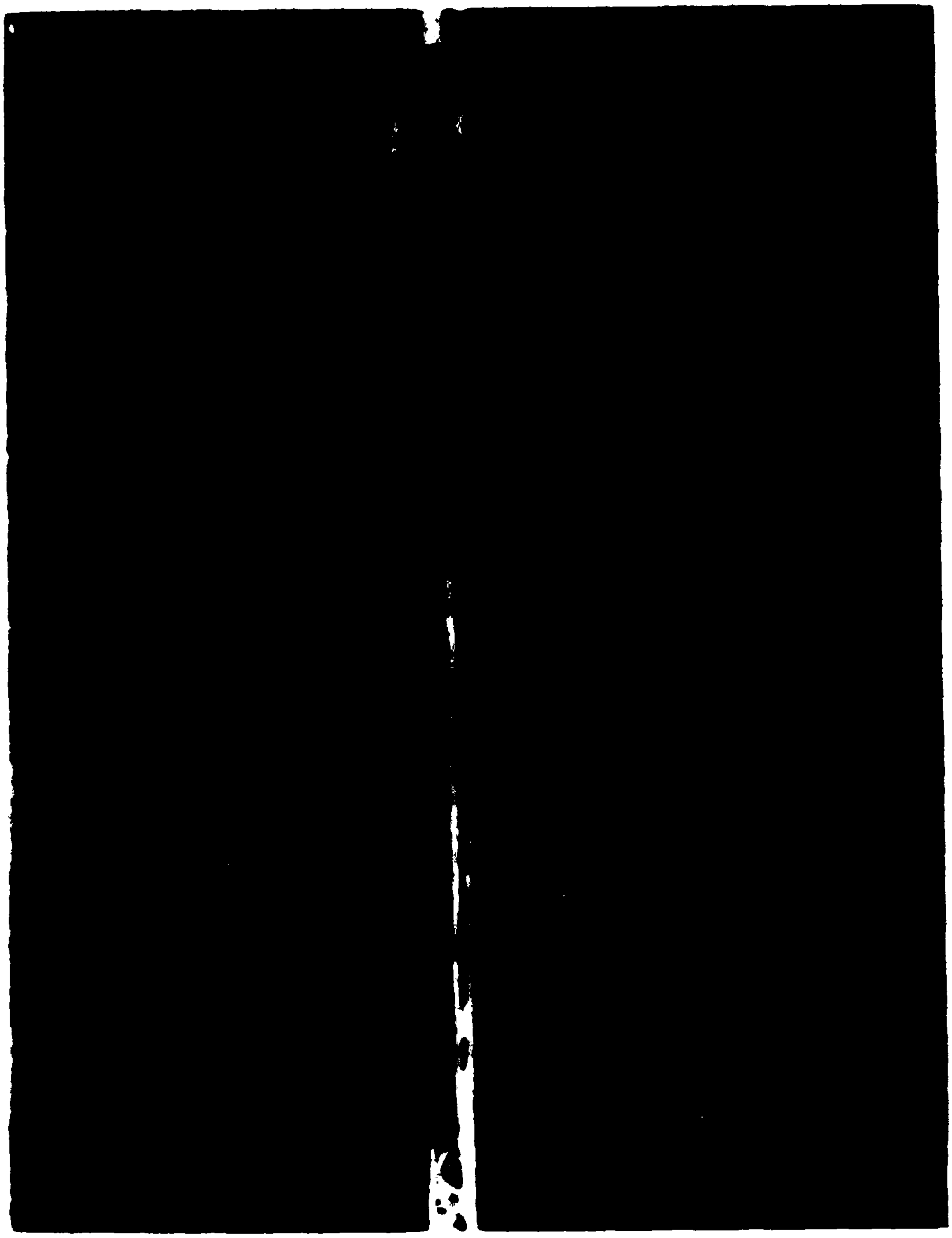


Figure 6. Shadowgraph Camera and Assembly

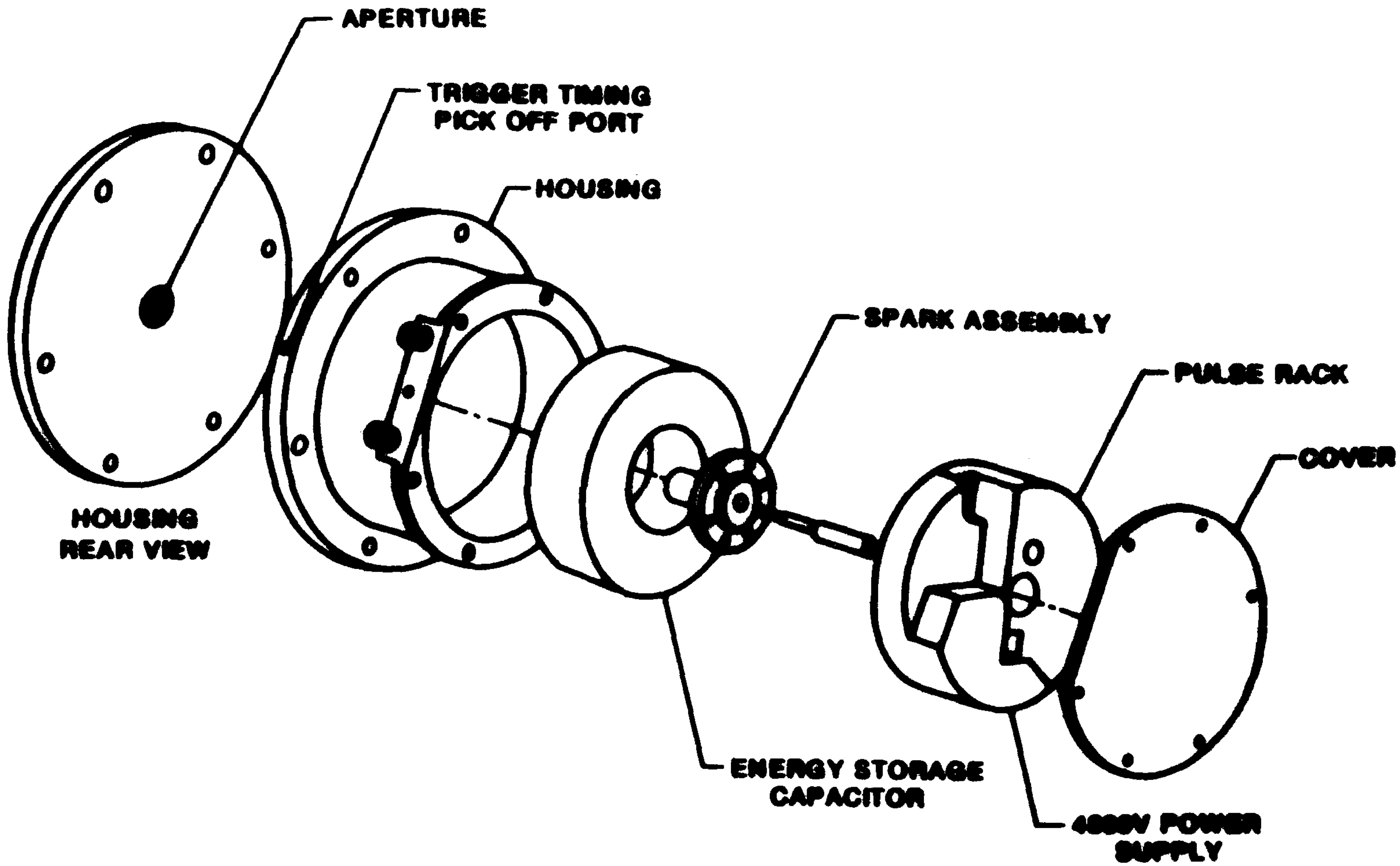


Figure 7. Exploded View of Spark System

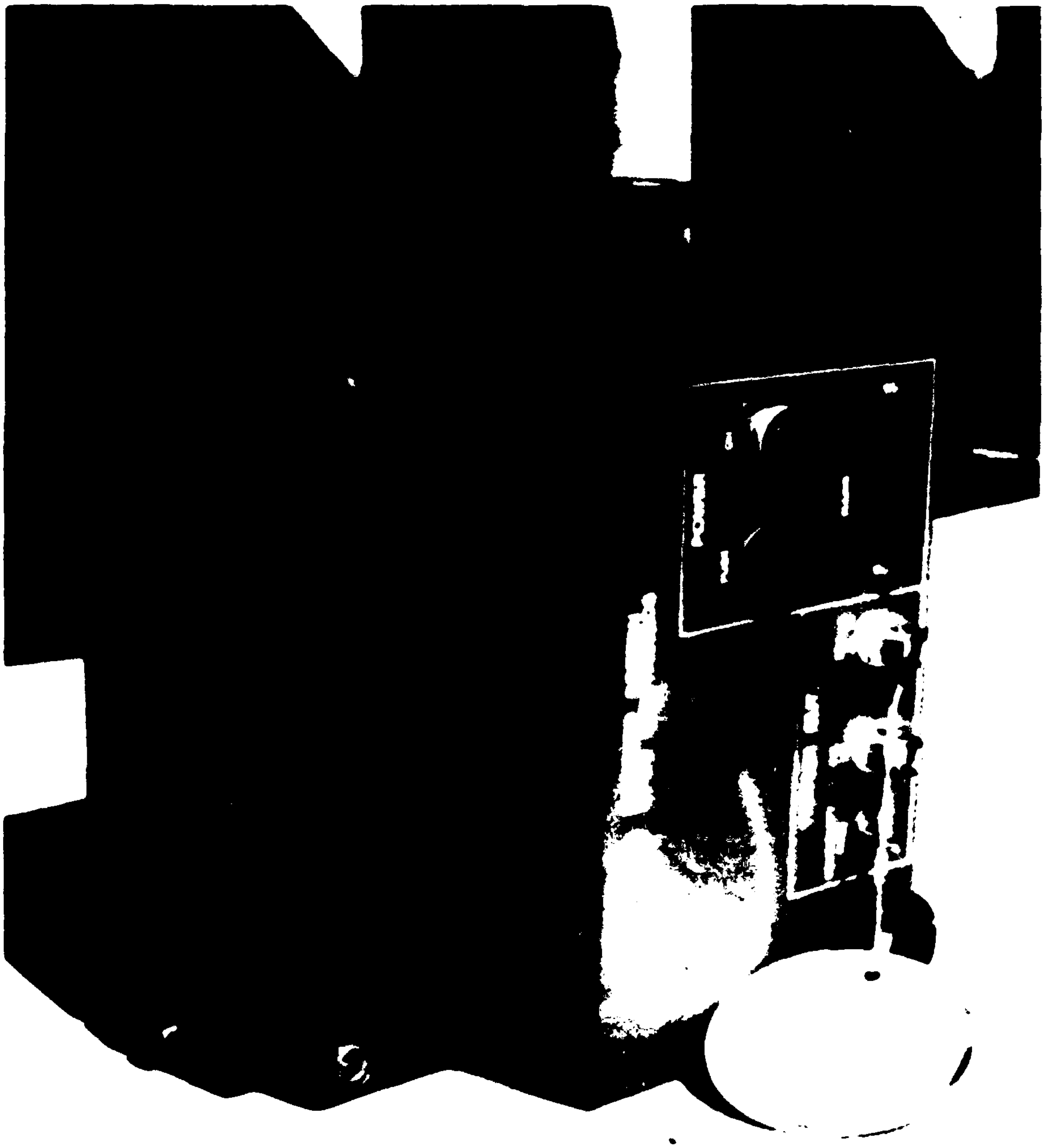
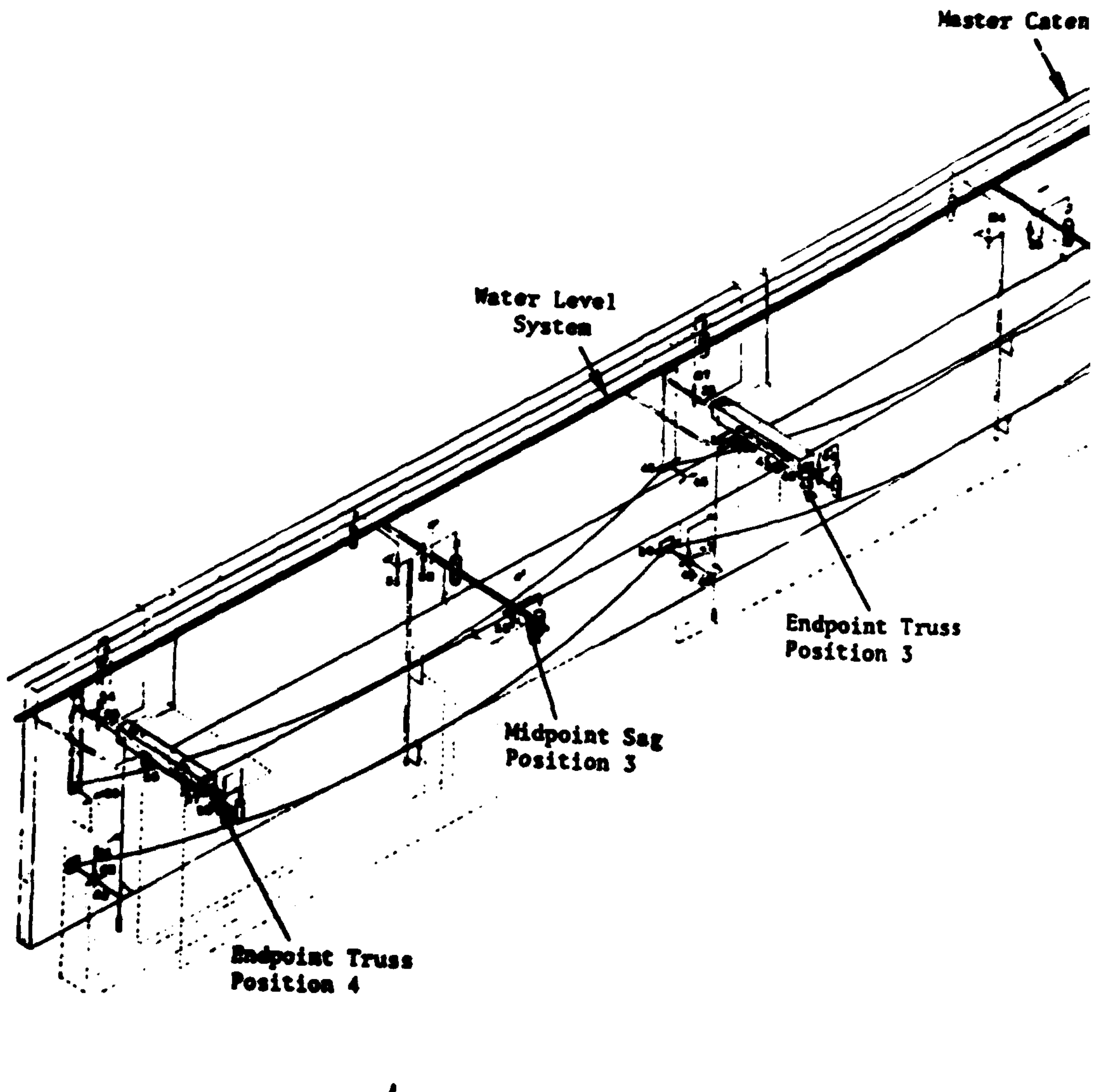


Figure 8. Infrared Detection System


Master Caten
Water Level
System
Endpoint Truss
Position 3
Midpoint Sag
Position 3
Endpoint Truss
Position 4

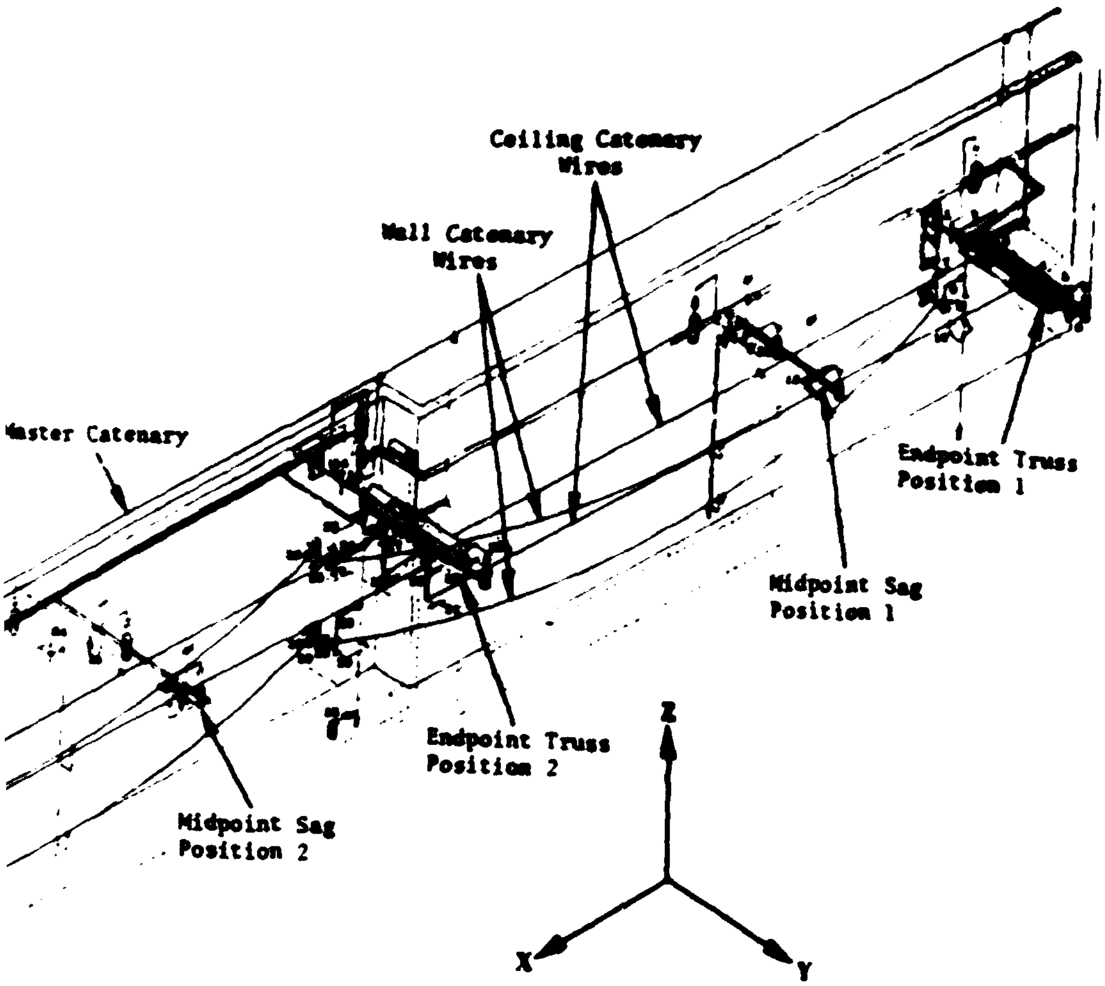


Figure 9. Alignment System Sketch

27/28 blank

Legend for Figure 9.

Endpoint Truss Position 1

1. Z movement of overhead truss and top wall catenary; senses fluid level.

2. Y movement of overhead truss and interconnecting top wall catenary senses master catenary.

3. X movement; endpoint adjusting translator.

4. X movement; endpoint adjusting translator.

5. Z movement of far end of overhead truss. Senses water level to maintain level of overhead wires.

6. X movement of far end of overhead truss. Senses master catenary to maintain truss perpendicular to plane of master catenary.

7. X movement; endpoint adjusting translator.

8. Z movement of endpoint of lower wall catenary; senses marker on plumb line from truss.

9. X movement of endpoint of lower wall catenary. Senses plumb line from overhead truss.

10. Y movement of endpoint of lower catenary. Senses plumb line from overhead truss.

Midpoint Sag Position 1

11. Z movement of wall Invar® bar. Senses water level. Holds and positions sensors for midpoint sag measurement.

12. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag. Moves endpoint at endpoint truss position 2.

13. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag.

Endpoint Truss Position 2

14. Z movement of overhead truss. In addition, this device serves as a means of maintaining the water level in link two of the level system.

15. Y movement of overhead truss; senses master catenary.

16. X movement of catenary interfaced to midpoint sag sensor. Moves both span 1 and 2 wires.

Legend for Figure 9.(Continued)

19. X movement of catenary, interfaced to midpoint sag sensor. Moves both span 1 and 2 wires.

22. X movement of far end of overhead truss. Maintains truss perpendicular to plane of master catenary. Senses master catenary.

23. Z movement of upper wall catenary. Senses marker on plumb line from over head truss.

24. Y movement of upper wall catenary. Senses plumb line hung from overhead truss.

25. X movement of upper wall catenary. Senses midpoint of span 1 catenary and moves accordingly. Moves span 1 and 2 wires.

28. Z movement of lower wall catenary. Senses marker on plumb line from overhead truss.

29. Y movement of lower wall catenary. Senses plumb line hung from overhead truss.

30. X movement of lower wall catenary. Senses midpoint of span 1 and moves accordingly. Moves span 1 and 2 wires.

33. Sensor reference for maintaining water level a constant distance from this point while the second pump system maintains a level height difference of 30.48 cm ± 0.0025 cm for the other link.

Midpoint Sag Position

34. Z movement of wall Invar® bar. Senses water level. Holds and positions sensors for midpoint sag measurement.

35. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag. Moves endpoint at endpoint truss position 3.

36. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag.

Endpoint Truss Position 3

37. Z movement of overhead truss and top wall catenary. Senses fluid level.

38. Y movement of overhead truss and interconnecting top wall catenary. Senses master catenary.

40. X movement of overhead catenary, interfaced to midpoint sensor for midpoint sag position 2.

42. X movement of overhead catenary, interfaced to midpoint sensor for midpoint sag position 2.

Legend for Figure 9. (Concluded)

43. X movement of far end of overhead truss. Senses master catenary to maintain truss perpendicular to plane of master catenary.

44. Z movement of far end of overhead truss. Senses waster level to maintain preset level of overhead wires.

46. X movement of upper wall wires. Senses midpoint of span 2.

47. X movement of lower wall wires. Senses midpoint of span 2.

48. Z movement of lower wall catenary. Senses marker on plumb line hung from overhead truss.

49. Y movement of lower wall catenary, senses plumb line hung from overhead truss.

Midpoint Sag Position 3

51. Z movement of wall Invar® bar. Senses water level. Holds and positions sensors for midpoint sag measurement.

52. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag. Moves endpoint at endpoint truss position 4.

53. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag. Moves endpoint at endpoint truss position 4.

Endpoint Truss Position 4

54. Z movement of overhead truss and top wall catenary. Senses fluid level.

55. Y movement of overhead truss and interconnecting top wall catenary. Senses master catenary.

56. X movement of overhead catenary, interfaced to midpoint sensor for span 3.

57. X movement of overhead catenary, interfaced to midpoint sensor for span 3.

58. X movement of far end of overhead truss. Senses master catenary to maintain truss perpendicular to plane of master catenary.

59. Z movement of far end of overhead truss. Senses water level to maintain preset level of overhead wires.

60. X movement of upper wall catenary. Senses midpoint of span 3.

61. Z movement of lower wall catenary. Senses marker on plumb line hung from overhead truss.

62. X movement of lower wall catenary. Senses midpoint of span 3.

63. Y movement of lower wall catenary. Senses plumb line hung from overhead truss.

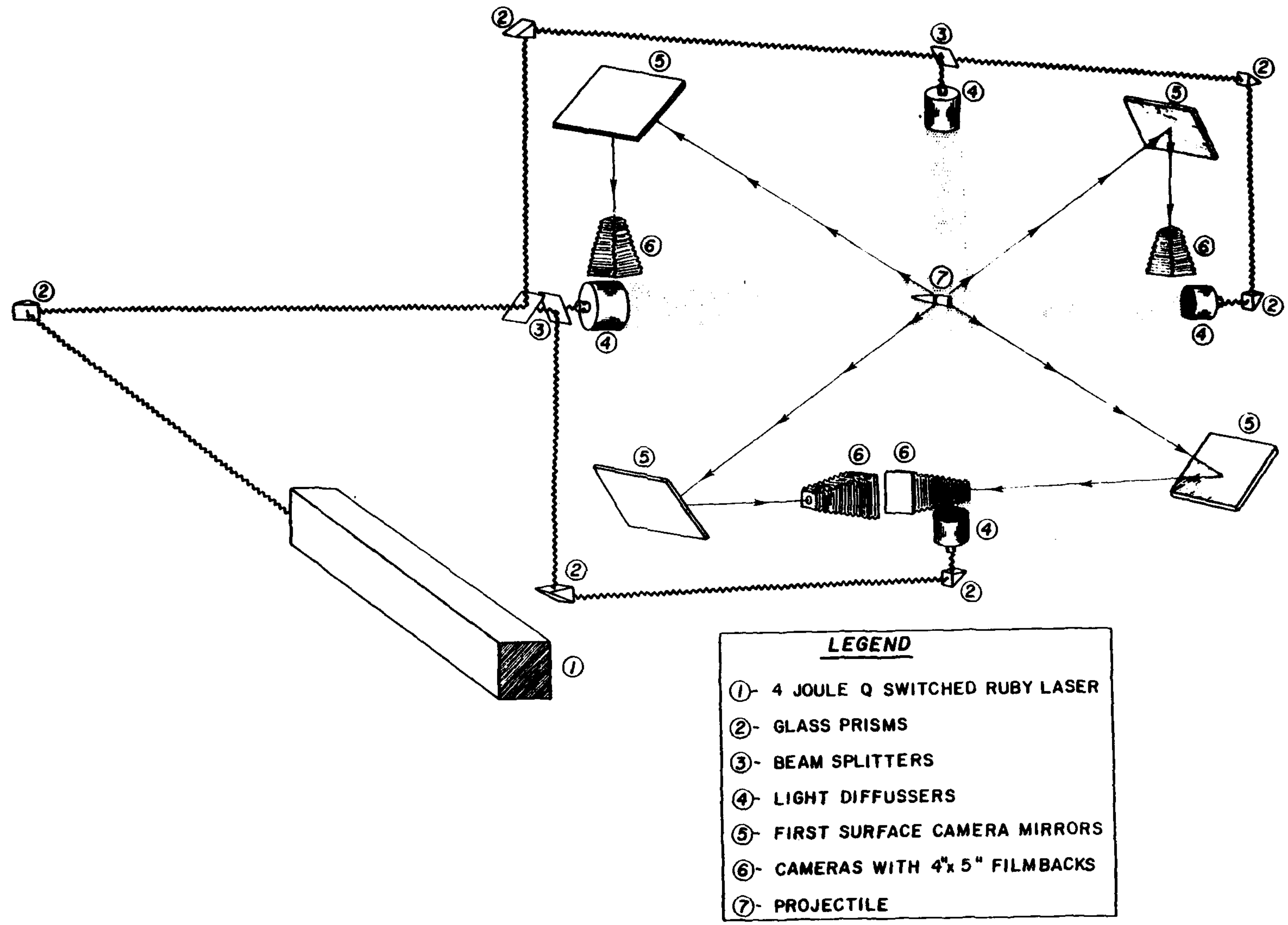


Figure 10. Sketch of Laser – Lighted Photographic Station

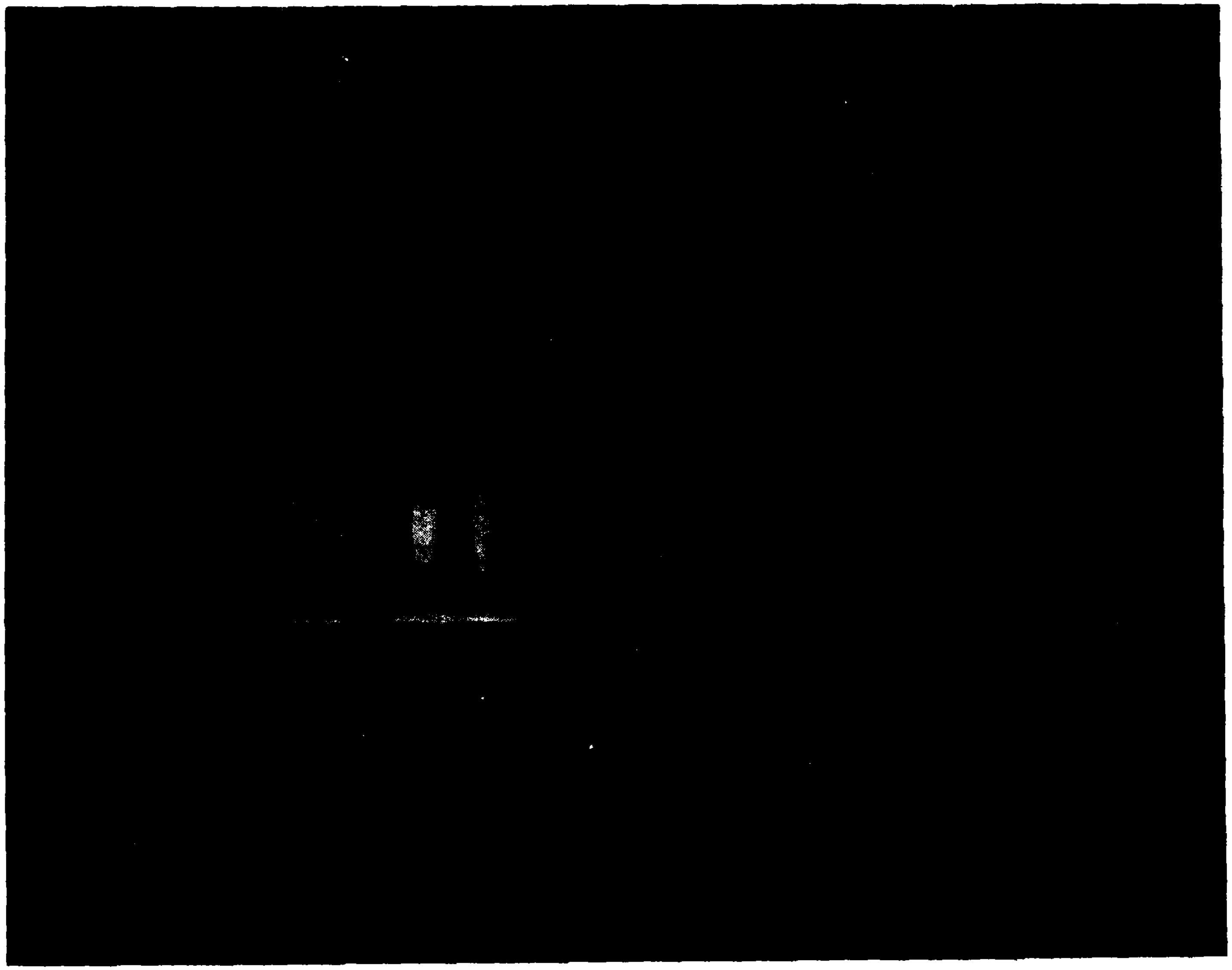


Figure 11. Typical Laser-lighted Photographs (30 mm Projectile)

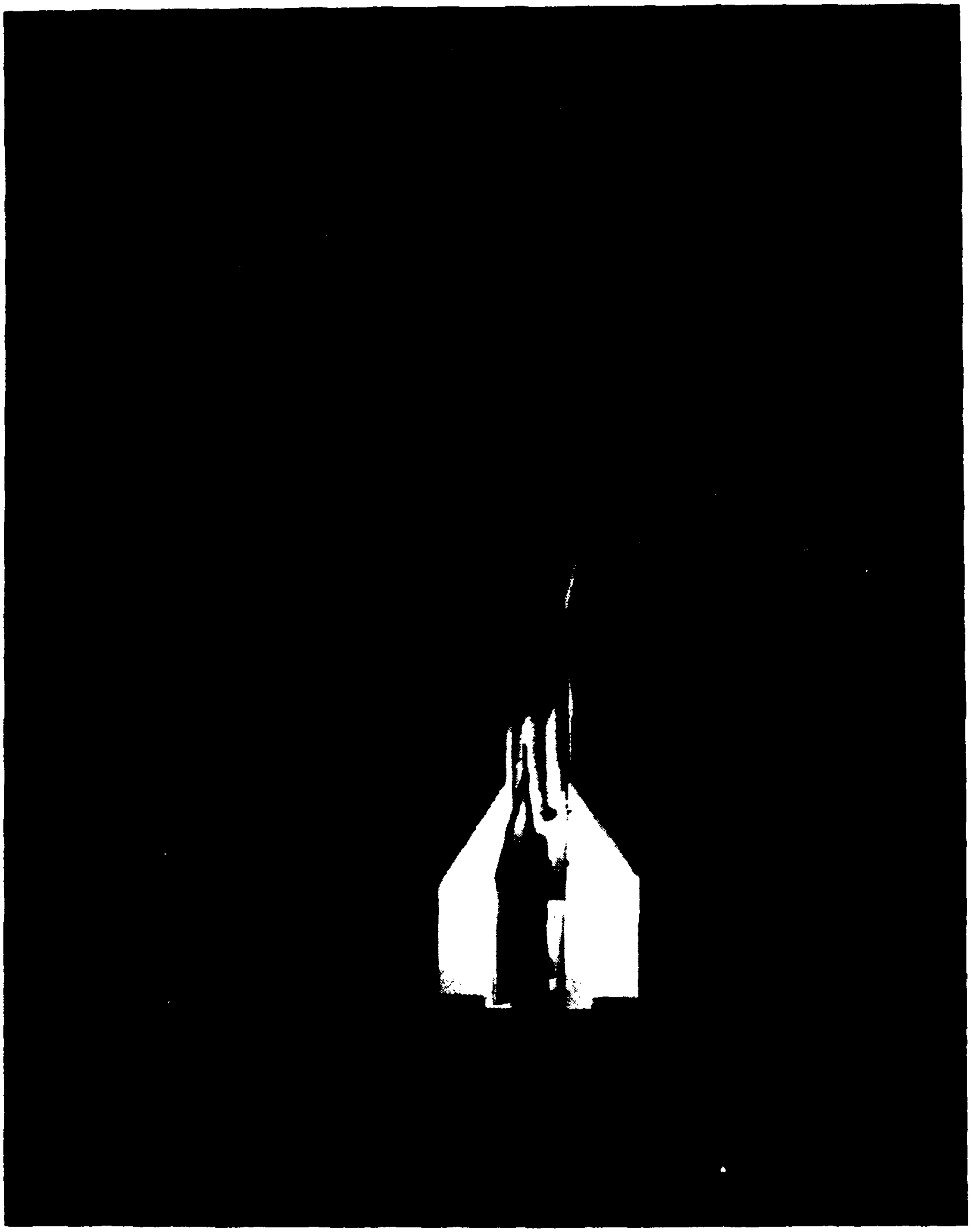
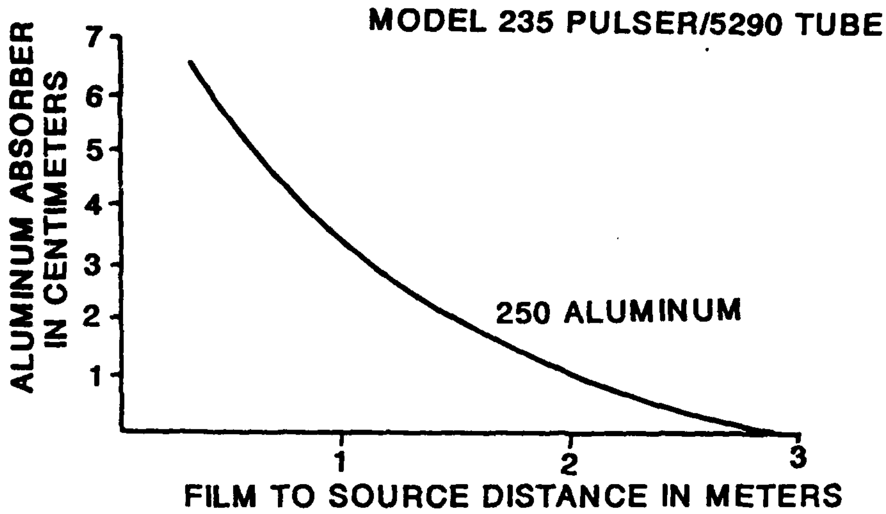
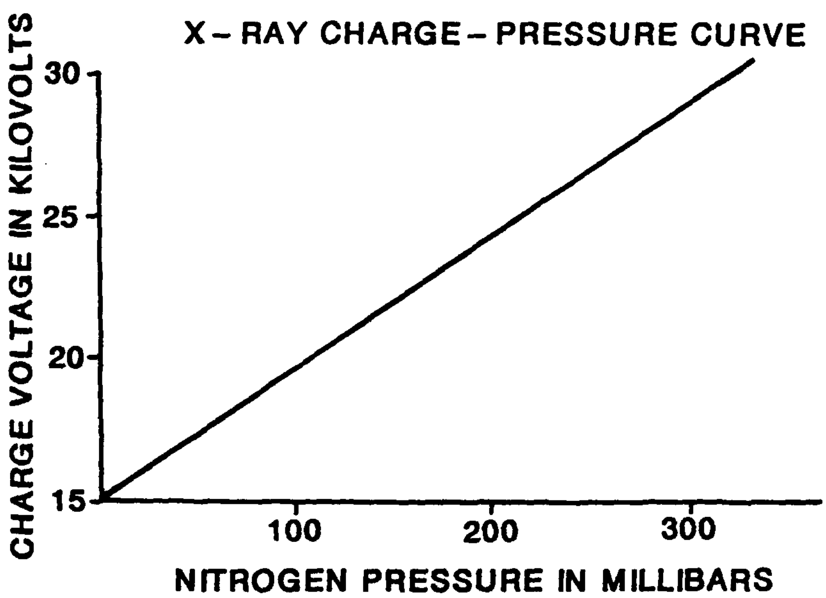


Figure 12. Typical Laser-Lighted Photographs (Missile Configuration)



A. Penetration Characteristics



B. Operating Curve

Figure 13. Operating Characteristics of the X-Ray System

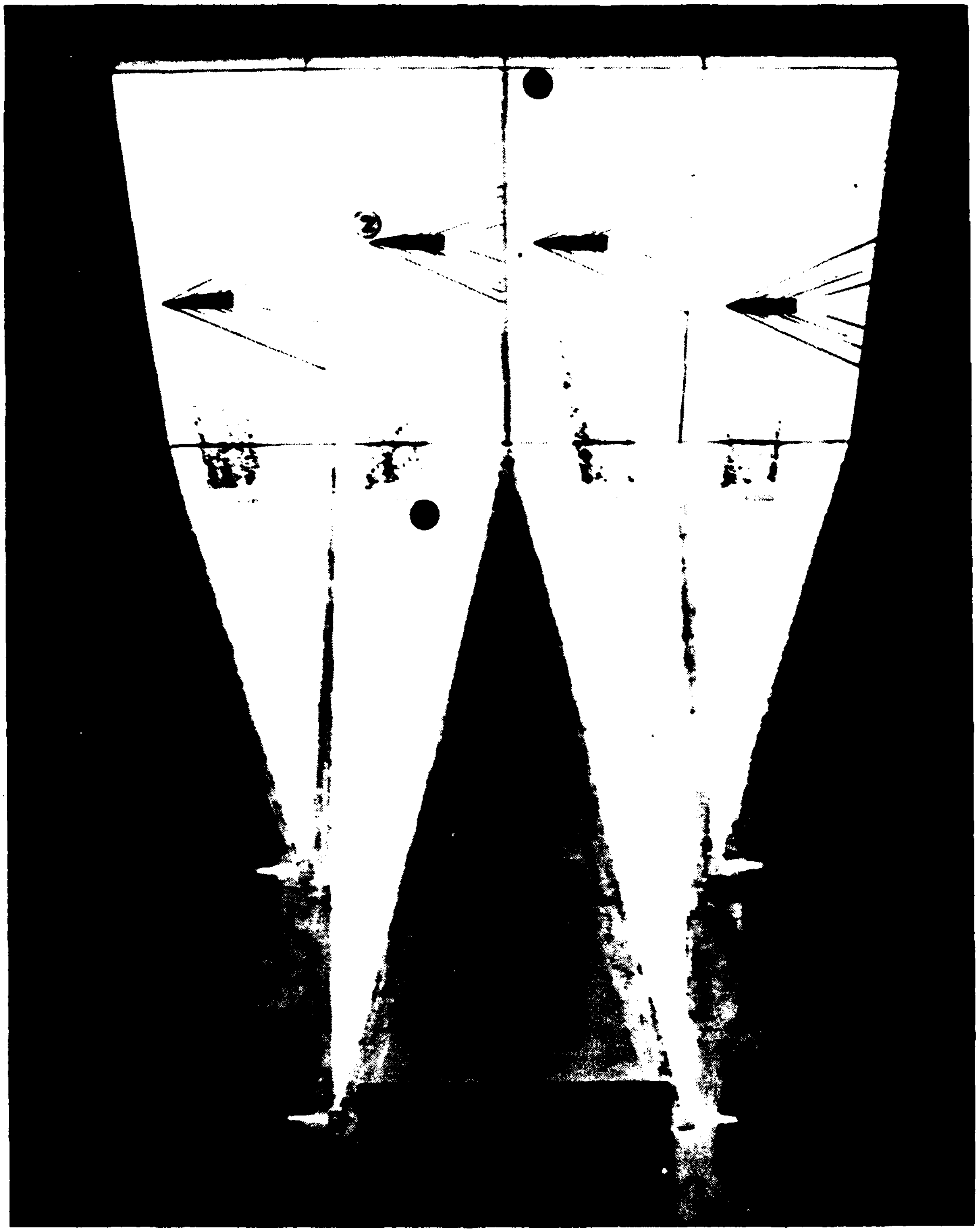


Figure 14. Perspective Sketch of a Multispark Shadowgraph Station

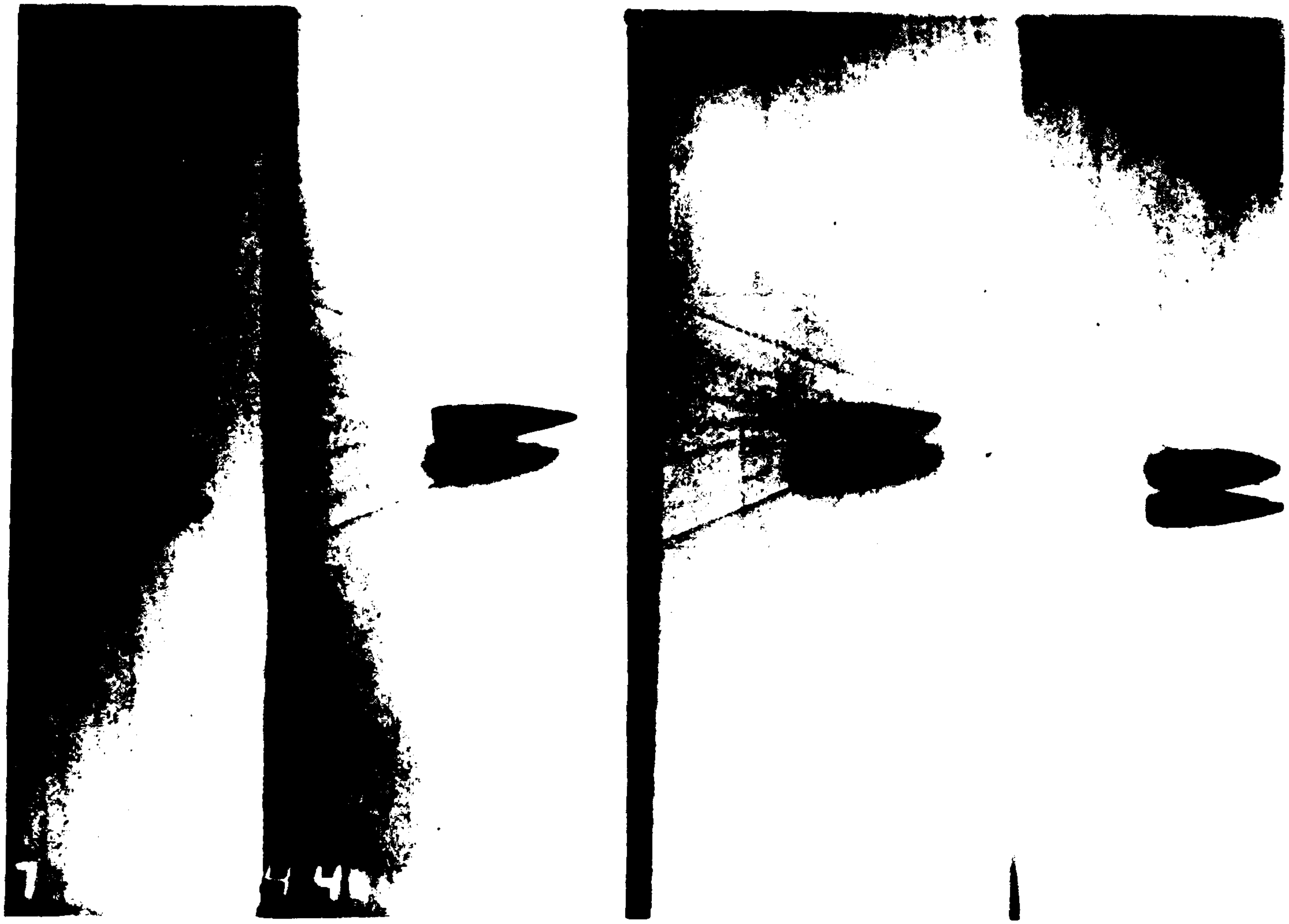


Figure 15. Typical Multiple Spark Shadowgram

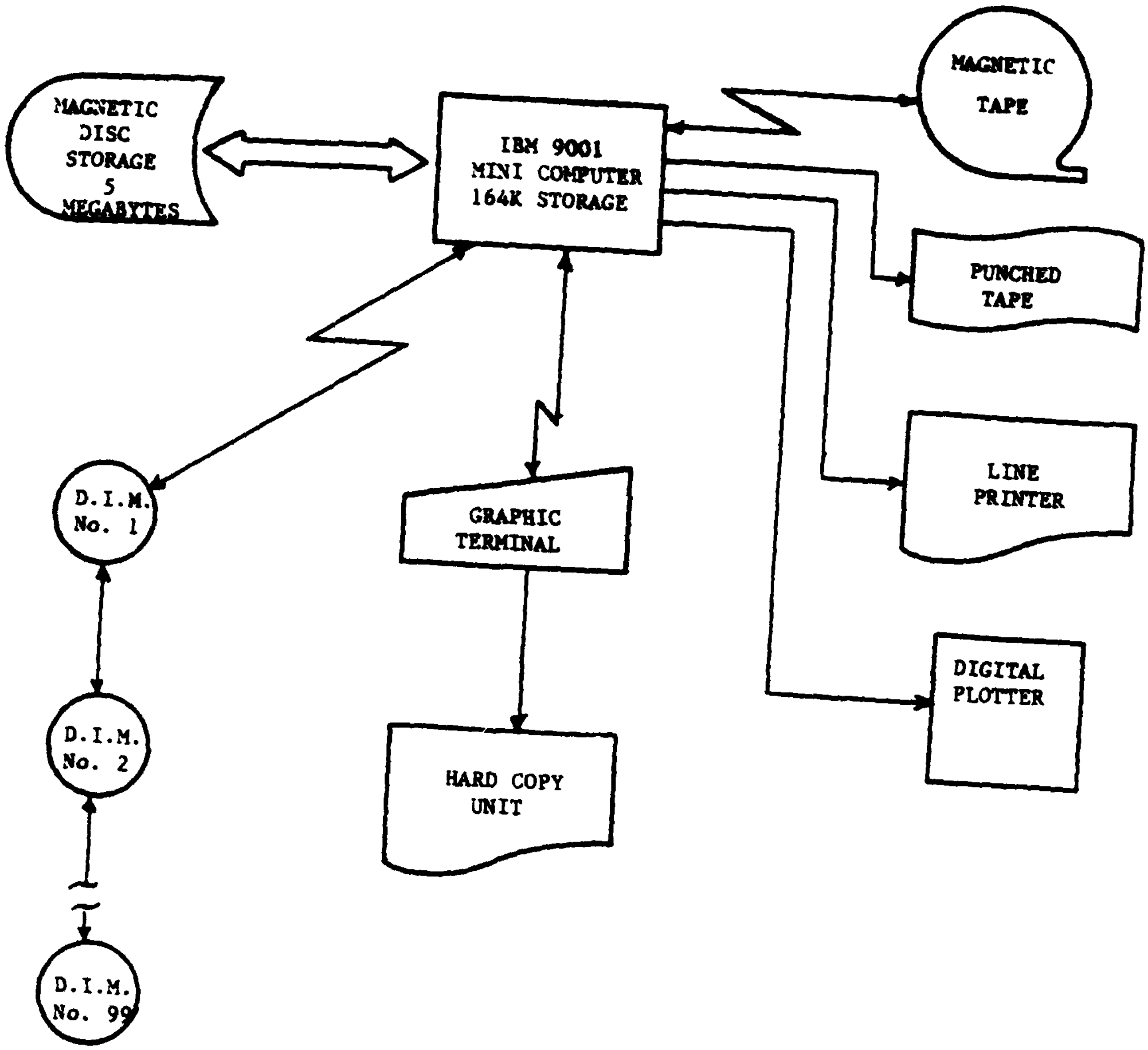


Figure 16. Data Diagnostic System

Figure 17. Shadowgraph Telereader

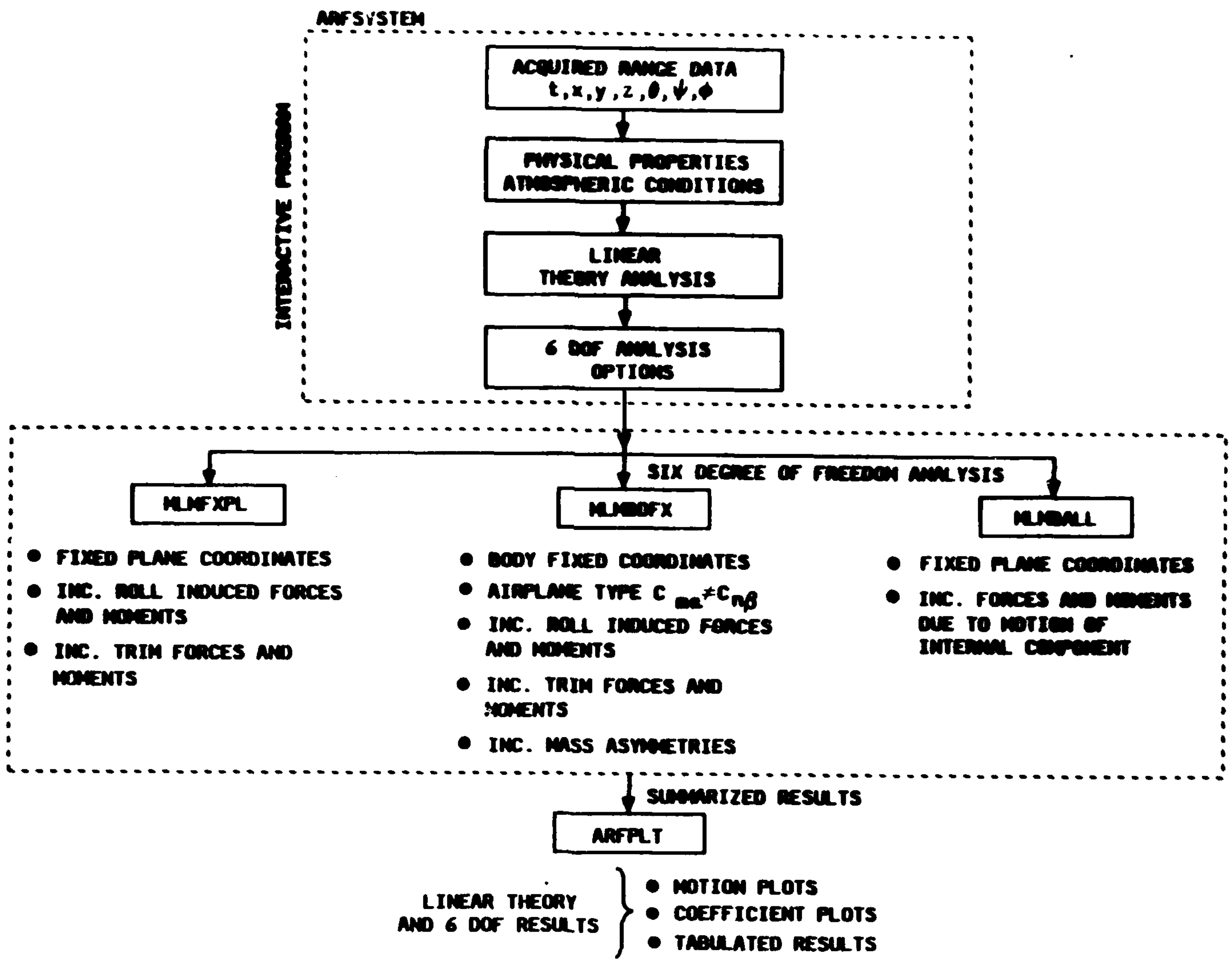


Figure 18. Aeroballistic Research Facility Data Analysis System (ARFDAS)

Figure 19. Data Reduction Station

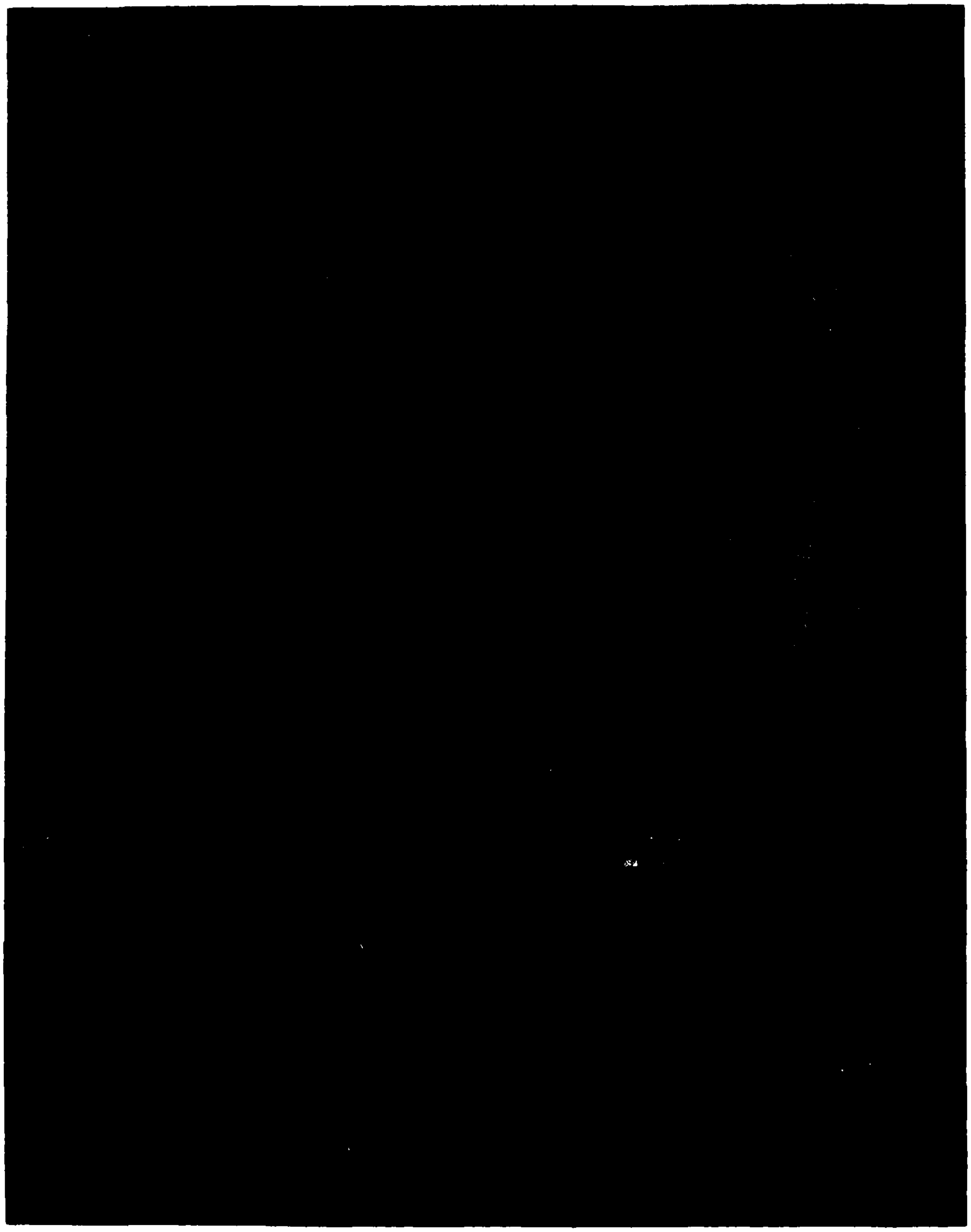


Figure 20. Typical Bullet Data

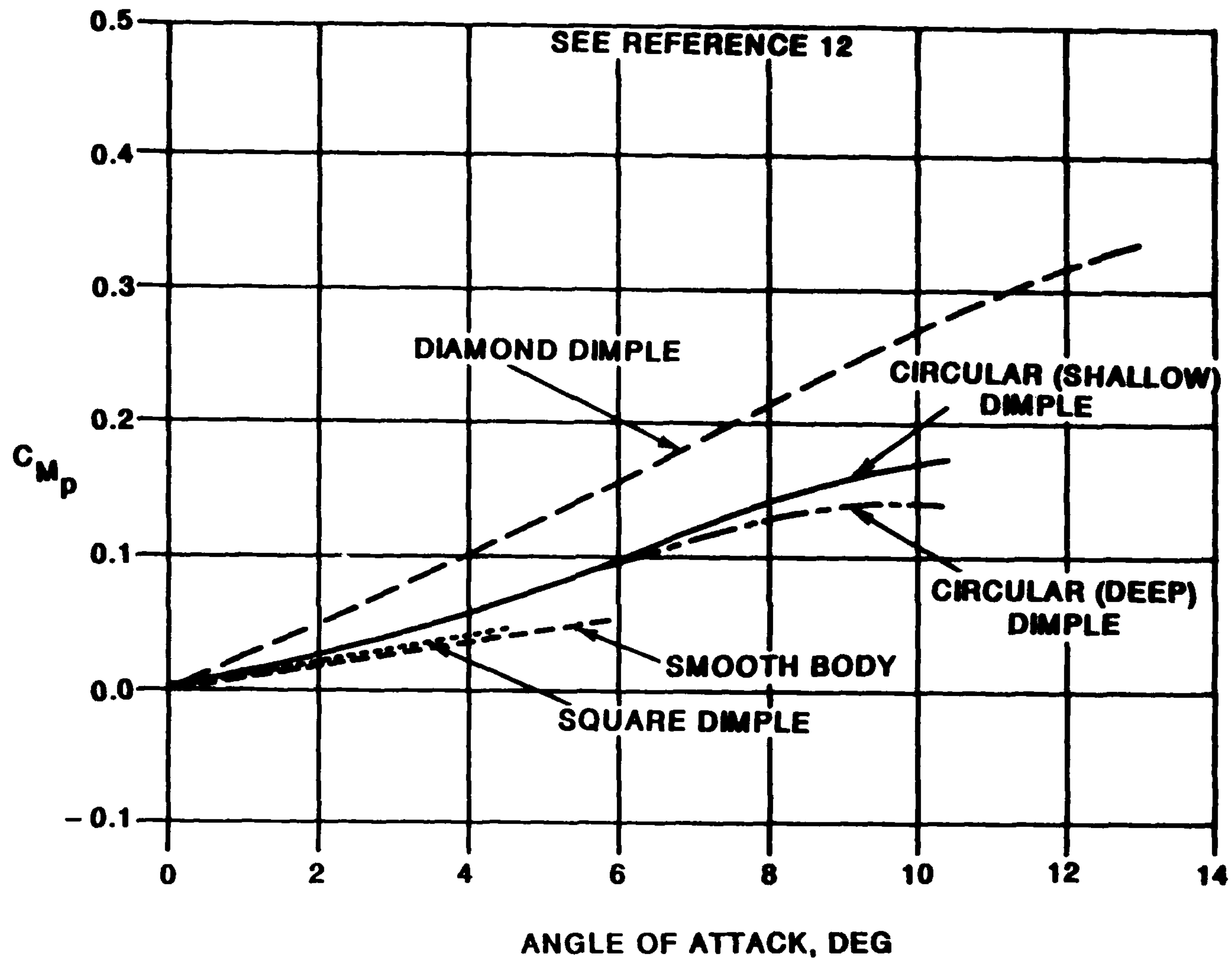
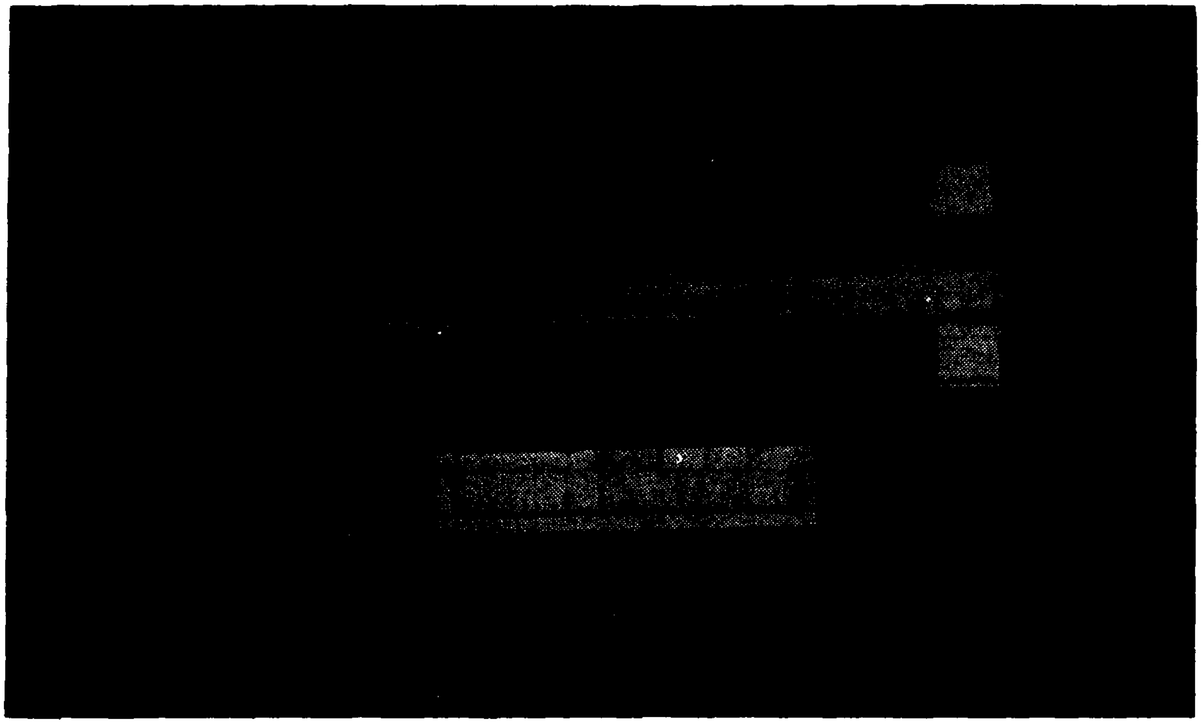


Figure 20. Typical Bullet Data (Concluded)



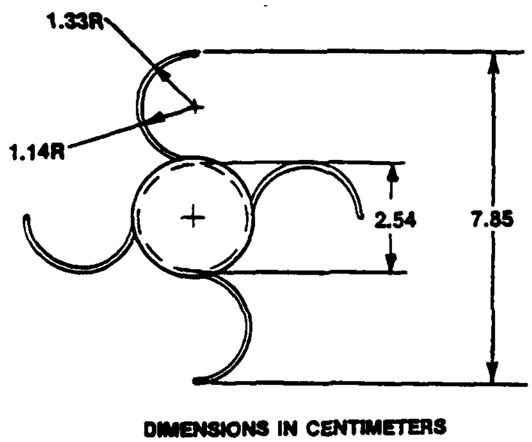
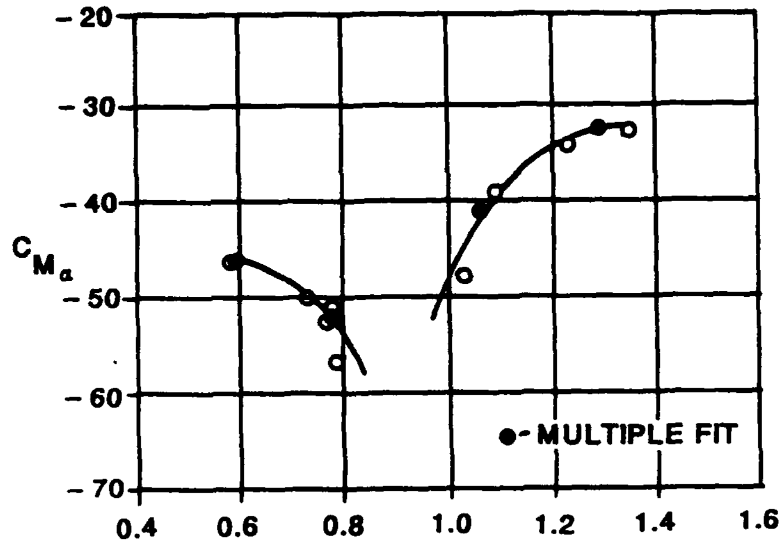


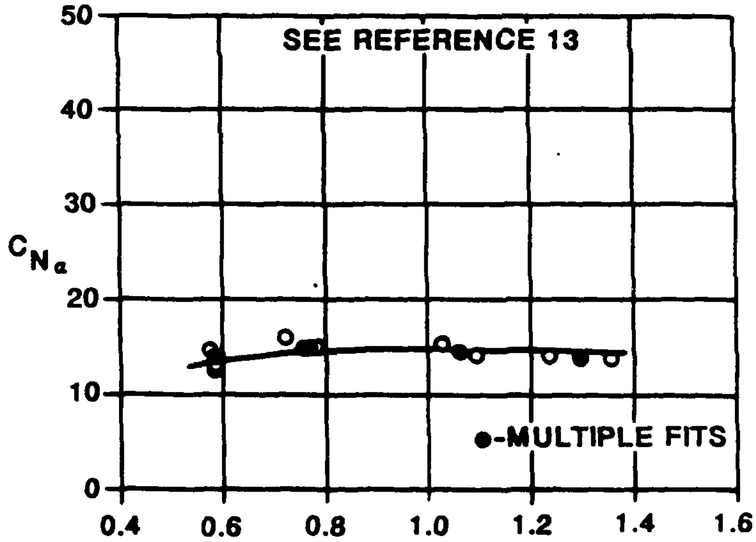
Figure 21. Typical Missile Data



MACH NO.

WRAPAROUND FINS

PITCHING MOMENT COEFFICIENT ($C_{m\bar{\alpha}}$) VERSUS MACH NUMBER



MACH NO.

WRAPAROUND FIN

NORMAL FORCE COEFFICIENT ($C_{N\bar{\alpha}}$) VERSUS MACH NUMBER

Figure 21. Typical Missile Data (Concluded)

Figure 22. Typical Aircraft Configuration Data

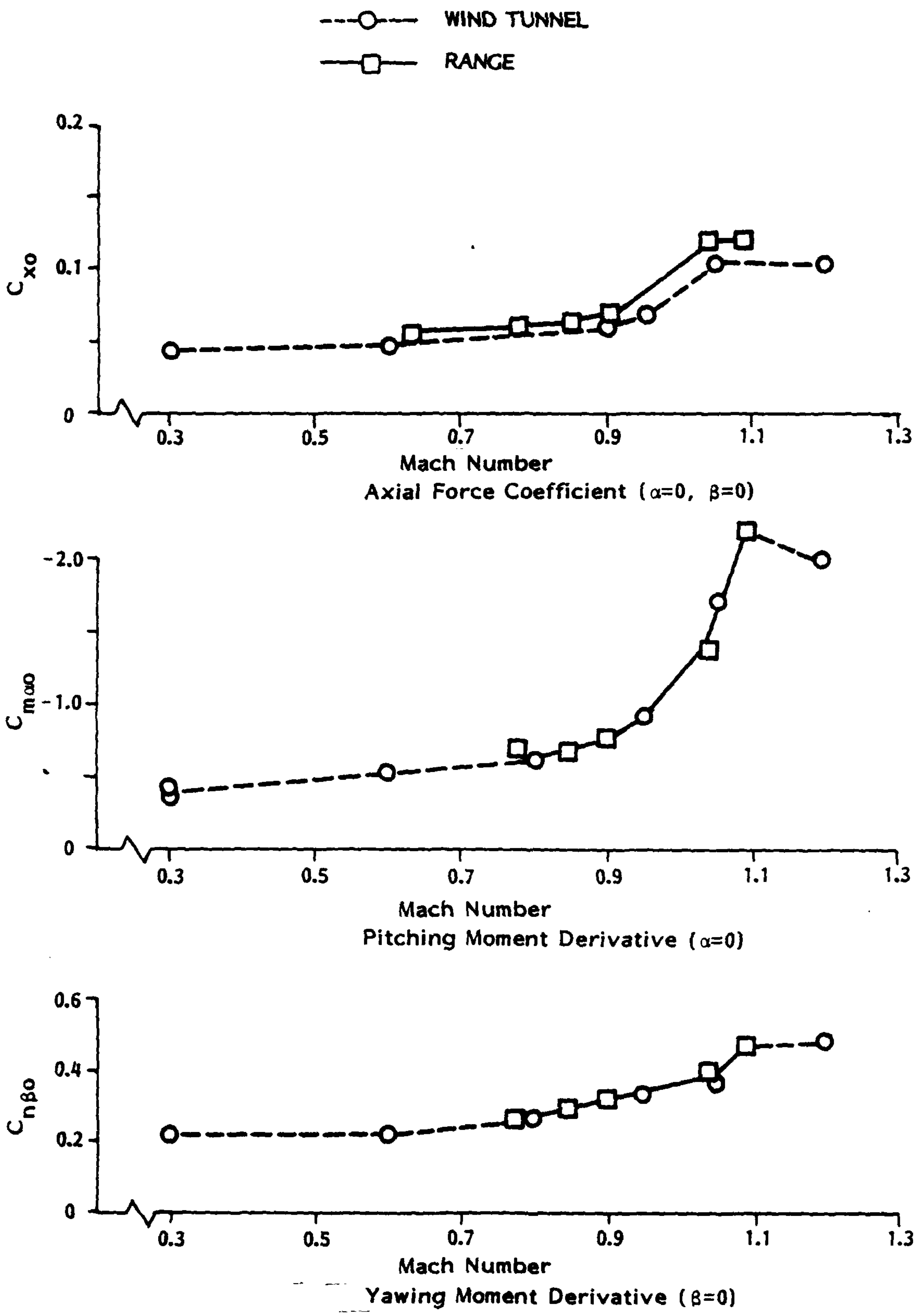


Figure 22. Typical Aircraft Configuration Data (Concluded)

TABLE 1. PRESENT LOCATIONS OF THE RANGE INSTRUMENTATION

Unit	Description*	Nominal Longitudinal Distance From Range Origin (ft)
X-Ray 1	Two orthogonal views	-26.247 to -45.932
X-Ray 2	(or four single plane)	-19.685 to -39.370
Schlieren	One view	1.500
SG** 1	Two orthogonal views	6.505
SG 2		11.513
SG 3		16.522
Holograph	360-degree view	21.522
SG 4	Two orthogonal views	26.502
Laser-Lighted	Four orthogonal views	31.502
Direct-Spark	One view	36.502
SG 5	Two orthogonal views	46.559
SG 6		56.546
SG 7		66.529
SG 8		71.529
SG 9		76.498
Multi-Spark	Eight photos	86.498
SG 10	Two orthogonal views	96.561
SG 11		116.561
SG 12		126.570
SG 13		136.554
SG 14		146.555
SG 15		151.542
Multi-Spark	Eight photos	161.542
SG 16	Two orthogonal views	171.551
SG 17		181.572
SG 18		186.601
Multi-Spark	Eight photos	196.601
SG 19	Two orthogonal views	211.294
SG 20		221.314
SG 21		231.285
SG 22		241.268
SG 23		251.281
SG 24		261.294

TABLE 1. PRESENT LOCATIONS OF THE RANGE INSTRUMENTATION (CONCLUDED)

Unit	Description*	Nominal Longitudinal Distance From Range Origin (ft)
SG 25	Two orthogonal views	271.276
SG 26		276.253
SG 27		291.288
SG 28		306.285
SG 29		321.363
SG 30		336.370
SG 31		351.409
Multi-Spark	Eight photos	356.409
SG 32	Two orthogonal views	381.515
SG 33		396.535
SG 34		411.501
SG 35		426.521
SG 36		441.501
SG 37		456.619
SG 38		471.607
SG 39		486.619
SG 40		501.590
SG 41		516.629
SG 42		531.641
SG 43		546.617
SG 44		561.613
Multi-Spark	Eight photos	571.613
SG 45	Two orthogonal views	586.668
SG 46		601.676
SG 47		616.679
SG 48		631.620
SG 49		646.616
SG 50		661.618

* All units yield two orthogonal views except where noted.
** SG = Shadowgraph

TABLE 2. AVAILABLE BARRELS AND LAUNCHERS

A. BARRELS

Bore Diameter (mm)	Range of Barrel Lengths (m)	Available Twist Rates (deg/cm)
20 ↓	1.2 - 1.5 ↓	Smooth 4.43 6.15 7.09 11.07 Various Gain Twists
25 ↓	2.13 ↓	4.76 6.56
30 ↓	1.3 - 2.6 ↓	Smooth 2.95 5.90 6.04 7.09 7.87 8.86 11.81
40 ↓	2.4 - 3.0 ↓	Smooth 7.10

B. COMPRESSED GAS LAUNCHERS

Bore Diameter (mm)	Range of Barrel Lengths (m)	Available Twist Rates (deg/cm)
152.4	3.7, 4.8	Smooth
203.2	4.8	Smooth
355.6	4.3	Smooth

C. LIGHT GAS GUN

Bore Diameter (mm)	Range of Barrel Lengths (m)	Available Twist Rates (deg/cm)
30	3.0	Smooth
40	3.0	Smooth