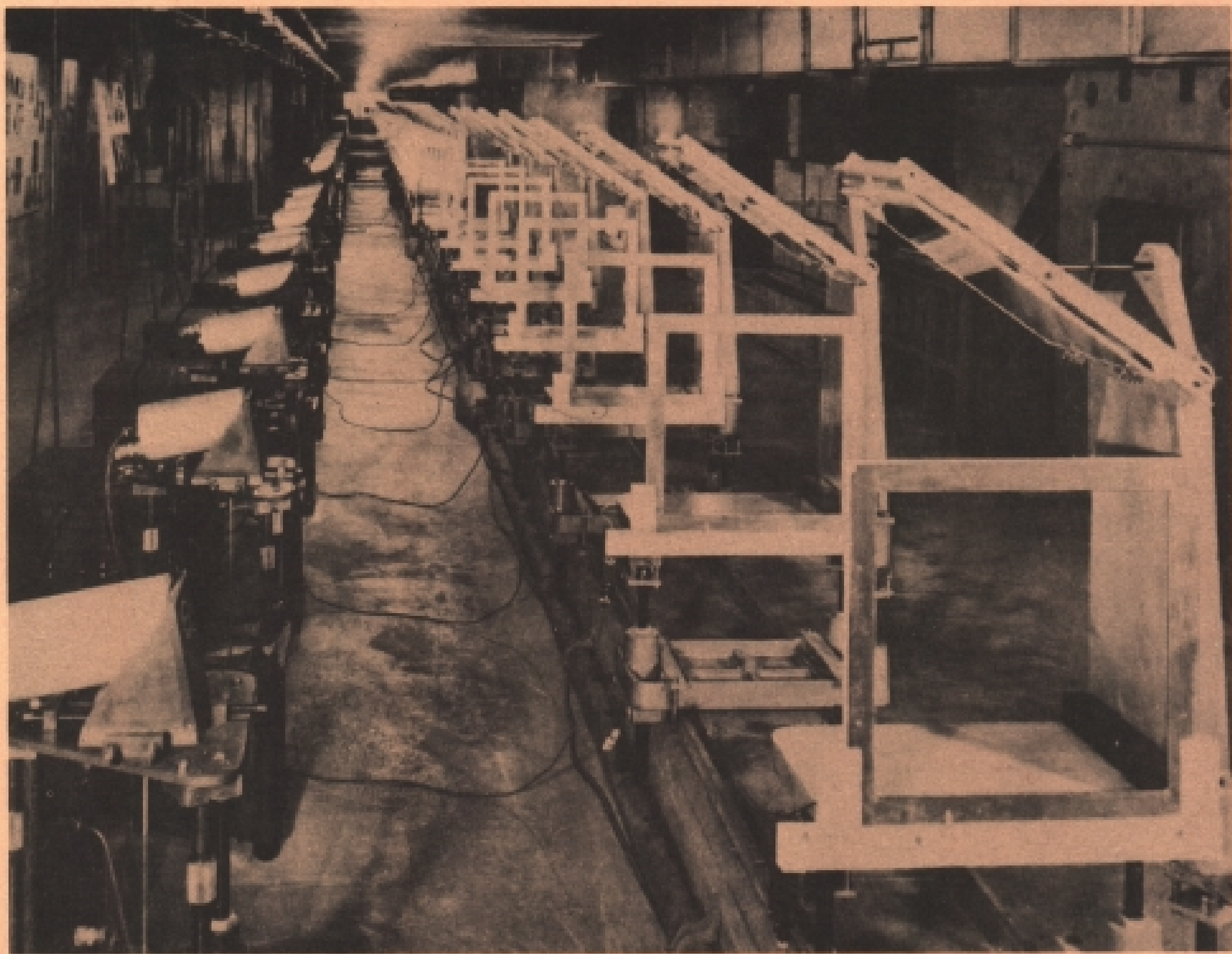
HISTORIC BALLISTIC FACILITY



AERODYNAMICS RANGE

A NATIONAL HISTORIC MECHANICAL ENGINEERING LANDMARK

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

21 OCTOBER 1982

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

NATIONAL HISTORIC MECHANICAL ENGINEERING LANDMARK*

AERODYNAMICS RANGE

ABERDEEN PROVING GROUND, MARYLAND

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This was the world's first large-scale, fully-instrumented ballistic range producing data on the aerodynamic characteristics of missiles in free flight. A host of supersonic aerodynamic designs of four decades have used the information developed here. The facility's unique technology became the foundation of similar installations worldwide.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS - 1982

SERVICE TO THE NATION

During the 1930's, research into advanced ballistic measurement techniques was begun at Aberdeen Proving Ground. Before the German Army entered Poland, exceptional data on the flight of projectiles were being provided. The crisis of World War II gave incentive to incorporate this pioneering research into the design and construction of the Aerodynamics Range at the U.S. Army Ballistic Research Laboratory. The facility was unique for its time and established the capability to study, in detail, the aerodynamics of bodies in supersonic free flight. The sequential, high speed photographic instrumentation in the Range has recorded the flight of projectiles, missiles, and aircraft important to the national defense. Personnel, working in this original installation, have contributed to technical disciplines ranging from photography and high speed circuit design to the theory of flight. The Range is recognized as the prototype for similar installations within the United States and abroad.

*The Aerodynamics Range is the 79th Landmark--State, National, and International--to be designated by the ASME since the program began in 1973. For a complete list and information about the ASME History and Heritage Program, please contact the ASME Public Information Department, 345 E 47th Street, New York, NY 10017 [212-705-7740].

FIRST MEETING OF THE SCIENTIFIC ADVISORY COMMITTEE, BRL, SEP 1940

In 1742, Benjamin Robins used a ballistic pendulum to measure the muzzle velocity of a projectile fired from a cannon. His velocity was much higher than those values predicted by existing theory. Basically, the theory assumed the round was flying through a vacuum; therefore only a modest muzzle velocity was needed to explain the ranges typical of early artillery. Robins' experiment presented the theorist with a contrary fact and led to the identification of aerodynamic resistance or drag as a force which had to be reckoned with. It also confirmed the need for valid measurements to accompany analytic developments.

By the early part of the twentieth century, theoretical ballisticians were again ahead of their experimentally inclined brothers. Designers had replaced the spherical cannon ball with streamlined shapes typical of modern shell. While such profiles reduced aerodynamic drag, they also tended to be unstable and required spin, obtained from rifled gun tubes, to provide gyroscopic stability. If not given sufficient spin, the projectile would in flight leading to a drastic increase in drag. While theory could predict performance, measurements were not providing useful comparisons.

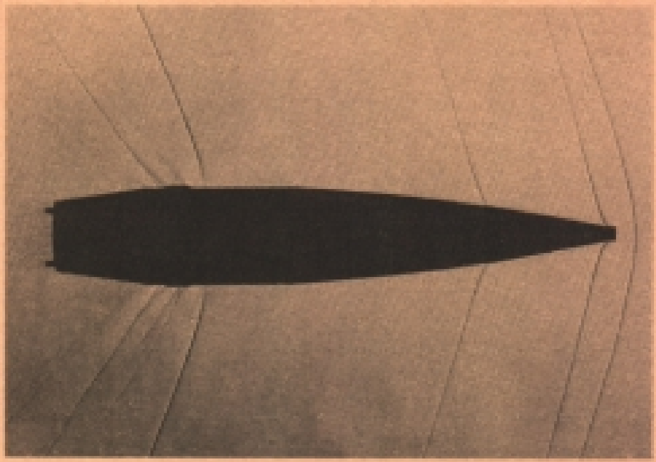
Flight velocities were being measured by firing a magnetized projectile through solenoid coils placed at predetermined intervals along the trajectory and recording on a drum chronograph the time interval between the electric pulses generated by the missile passing through the coils. The angular motion of the projectile, which gives a strong indication of flight stability, was measured by firing through an array of cardboard sheets placed at intervals along the trajectory. The dimensions and orientation of the "key hole" that the missile punched in the sheets described its attitude. These techniques created problems since they interfered with the flight of the round and were not sufficiently precise to provide the information required by modern theorists.

To improve the quality of ballistic data, advanced diagnostic techniques were examined by R. H. Kent at Aberdeen Proving Ground. Together with Dr. Alexander C. Charters, Bob Kent developed the technology which laid the groundwork for the design of the Aerodynamics Range. Their facility was constructed in time to perform invaluable service during a period international crisis. Fundamental contributions were made to the science of ballistics in the areas of data acquisition and analysis, the theory of projectile flight, and the analysis of supersonic aerodynamics. Parallel efforts In the development of tactical and strategic weapons design data contributed to the security of the free world.

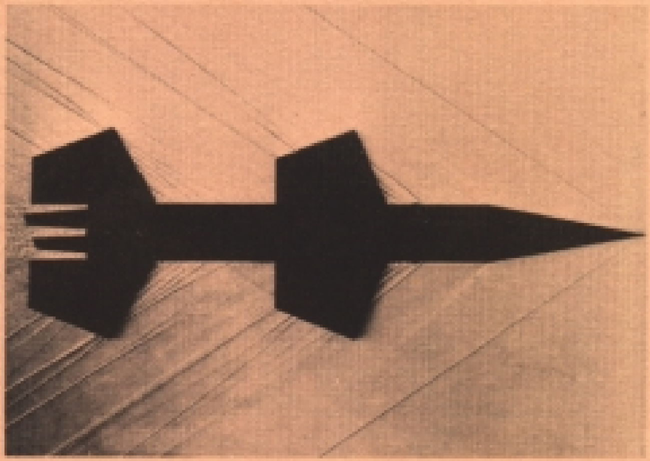
SPARK SHADOWGRAPHY

Accurate observation of fast-moving objects is essential to progress in many fields of science and technology. One method to freeze motion is through the use of flash photography where a short duration light source exposes the image on

TYPICAL SPARK SHADOWGRAPHS



SPIN-STABILIZED PROJECTILE



MISSILE

film. One of the shortest duration light sources available is the spark discharge. The first spark photograph was made in 1851, when an unblurred picture of a newspaper clipping attached to a revolving drum was obtained by use of a spark from a Leyden cell. While significant advances had been made since the first experiment, there remained much to be done before the technique could be used to photograph the free flight of projectiles.

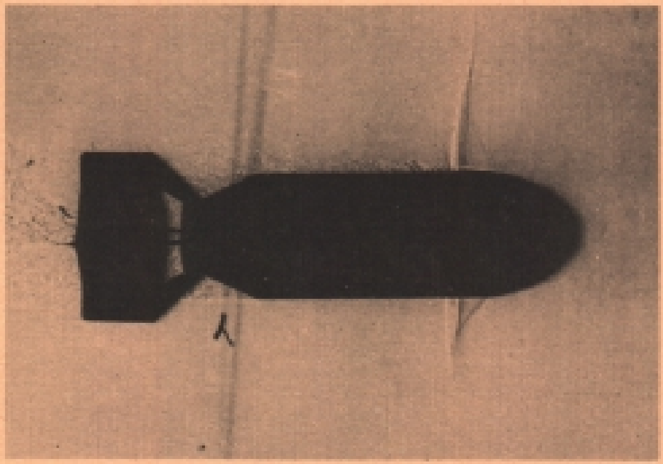
There were three basic requirements for a ballistic spark photography range: a light source one-millionth of a second in duration and of sufficient intensity to expose a photographic plate; interference free synchronization of the light source triggering with the passage of the projectile; and arranging an array of photographic stations along the trajectory in sufficient density to provide useful data.

By 1940, typical exposure times were one-ten thousandth of a second; unfortunately, this led to a photograph of a caliber 0.50 bullet appearing as a 4-inch blur. Dr. A. C. Charters of BRL together with Dr. Lewi Tonks of General Electric Company, Schenectady, developed a high speed spark gap with durations of one-microsecond. This permitted the acquisition of high quality photographs of projectiles in flight. To solve the triggering problem, the design team took advantage of a phenomenon first observed in research by the Italian Army, namely, the build-up of an electrostatic charge on a projectile in flight. Since a moving charge produces a magnetic field, Charters and Tonks realized that this field could be detected and used to provide a non-intrusive trigger source to synchronize the photographic systems.

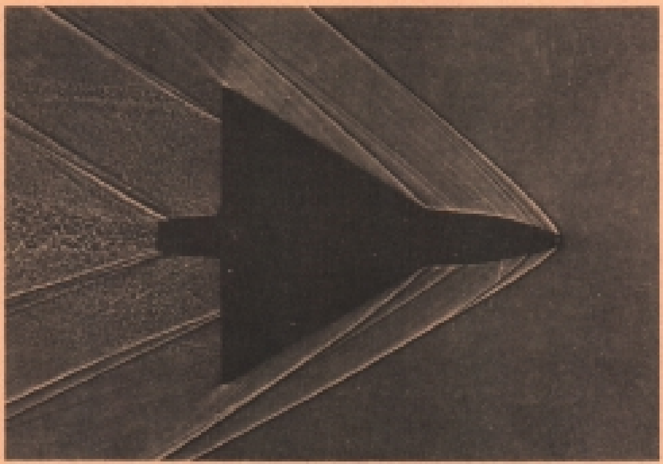
Once the instrumentation was proven, the Aerodynamics Range was initially configured with fifty, orthogonal spark shadowgraph stations positioned along its 300-foot length. Timing data on spark firing was recorded on a drum chronograph and, subsequently, on electronic counters. Accurate interpretation of the massive amounts of data produced by the Range required a considerable amount of analytical work. From the set of one hundred photographs, the spatial location and orientation of the projectile had to be computed. To insure accuracy in these calculations, the Range had to be precisely surveyed. The analysis and survey systems were developed in parallel with the physical plant by BRL mathematicians and scientists.

When put into use in 1943, the BRL Aerodynamics Range made possible, for the first time, the recording of accurate histories not only of projectile motion, but also of the detailed, transient flow structure about the round. Although the size of the Range limited its use to missiles of 40mm and less in diameter, there were no limitations placed on the imagination of the operational staff or on the configurations which required testing. By developing pioneering launch techniques, they were able to contribute to studies of projectile, missile, and aircraft aerodynamics in all flight regimes from subsonic through hypersonic velocities.

TAKEN IN AERODYANAMICS RANGE



BOMB



AIRPLANE

SUPERSONIC AERODYANAMICS

Shadwgraphs of projectiles traveling at supersonic velocities revealed in minute detail the shock wave patterns they created. Since projectiles, bombs, and missiles were the only objects during World War II capable of flight at these velocities, exterior ballisticians dealt extensively in the infant science of high speed gasdynamics.

In supersonic flight, shock waves develop in the air as the body passes. The "sonic boom" of high speed aircraft or "crack" of a bullet are characteristic shock processes. The presence of shock waves in the flow significantly influences drag and stability. Accordingly, study of these waves quickly became a program of major importance.

Toward the end of the war Dr. von Neumann, of BRL's Scientific Advisory Committee, suggested a wavelet theory on which a procedure for determining total airflow around a high-velocity projectile could be based. It had been noted that exceptionally good spark photographs of high-velocity projectiles in flight showed wavelets originating at different points on the surface behind the shock wave (and apparently caused by slight irregularities on the surface). When the shape of each wavelet was carefully examined and the information derived from the complete study put together, it was possible to determine the general characteristics of the flow.

In his classic paper, "Some Ballistic Contributions to Aerodynamics," Dr. Charters presented results of wartime research to the Sixth International Congress of Applied Mechanics in Paris in September 1946. This work provided experimental data to validate the aerodynamic theories of Theodore von Karman and G. I. Taylor. His investigations into the drag of slender, axisymmetric had direct application to both projectiles and aircraft. It is interesting to note that the first aircraft to attain supersonic flight, the Bell, X-1, rocket plane, had a fuselage design configured after a 0.50-caliber projectile shape.

TRANSONIC AERODYNAMICS

When flying at speeds near the velocity of sound, experimental results indicated the existence of strong destabilizing aerodynamic loadings. Since existing wind tunnels exhibited influence of wall interference at transonic speeds, the BRL Aerodynamics Range was employed to develop the stability characteristics of missile in this flight regime.

The flow in the vicinity of the projectile base was determined to be particularly critical. Since boattails were commonly employed to aerodynamic drag, transonic flight dynamics of such designs was of practical interest. Test firings quickly uncovered potential difficulties with certain boattail configurations. The results of these early studies corrected problem areas and still form a baseline for modern projectile design.

Another flight vehicle with transonic problems were bombs dropped from high altitude. As they accelerated, the bombs passed through transonic velocities where flight instabilities could develop influencing accuracy and proper fuze functioning. Many bomb models were fired in the Aerodynamics Range to correct or uncover potential difficulties. Among the more important were the early atomic bomb shapes.

SERVICE SUPPORT

To give maximum assistance to weapons and ammunition designers the exterior ballisticians at BRL devoted a considerable part of their time to service work. Models of new designs of shell, rockets, guided missiles, and bombs were tested in the free flight range to provide data needed by designers. In addition, a large amount of troubleshooting was done to determine, for example, what caused a new shell to be unstable in flight or a new rocket to be inaccurate.

The munition developments of World War II were considerable. The fin-stabilized, kinetic energy projectile was introduced by Germany late in the war. These projectiles were found to be inaccurate if they possessed aerodynamic or inertial asymmetries. Tests at BRL demonstrated that the effect of these asymmetries could be reduced, with an associated accuracy improvement, if an initial spin or roll was imparted to the round. However, it was also discovered that the permissible spin rate had definite limits. If it was too fast, a side force developed leading to instability. If it was too slow, resonance between roll and yawing motion could result leading to "catastrophic" growth in the yaw angle. These concepts form a basis of design for all modern fin-stabilized rounds.

A fundamental contribution to the design of high explosive, shaped charge projectiles was made almost accidentally. During experiments to measure the drag on sharp- and blunt-nosed projectiles, it was found that the addition of a spike, protruding from the nose of a blunt projectile reduced the drag to a value near that of the streamlined design without the associated loss of stability. These results formed the basis for the design of the fin- stabilized, spike-nosed projectiles currently used with shaped charge warheads.

When high speed aircraft were introduced during and following the war, they imposed conditions of fire so different that completely new techniques for predicting flight characteristics of projectiles fired from aircraft guns had to be developed. In this case, the speed of the aircraft was a major factor affecting both the velocity and the yaw of projectiles. Heretofore, when the effects of aircraft speed were much less pronounced, the ballistics of such projectiles could be determined experimentally by ground firings. With modern aircraft, this data did not transfer to flight tests. Subsequently, Aerodynamics Range tests to measure the dynamic stability characteristics of rounds fired under the realistic conditions readily demonstrated that fire control solutions were incorrect. Based on validated aerodynamics, new solutions were computed which permitted accurate fire.

MECHANICAL SPECIFICATIONS

The Aerodynamics Range is an enclosed facility instrumented to launch a missile in free flight and record its motion over 285-feet of the trajectory. The 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 using spark 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 to an accuracy of 0-1-microsecond.

The range area consists of the firing room containing the launcher, the blast chamber isolating the instrument area from the muzzle blast, the range gallery containing the apparatus for recording the flight of the missile, and the control room from which operations and data recording are conducted. 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.

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, that at mid-range. 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.

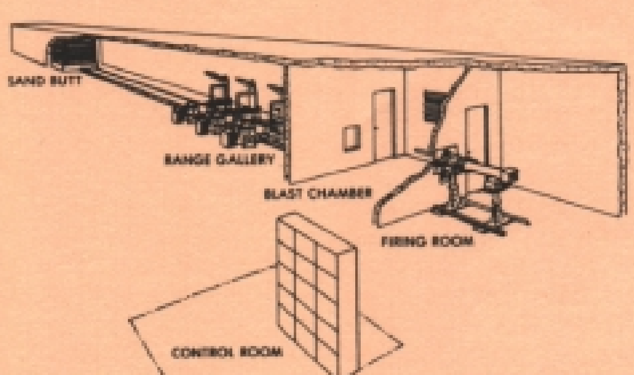
There are practical limits to the size, weight, and velocity that can be satisfactorily tested in the range. The minimum size, a 1/8-inch sphere, is determined by the sensitivity of the apparatus. The minimum velocity, 600-feet per second, is determined by the shape of the parabolic trajectory due to gravity. The maximum size missile, approximately a 1.5-inch body diameter, is determined by the ability of the blast chamber to withstand the muzzle blast.

The missile is launched from a gun mounted in the firing room with the muzzle in the blast chamber. The gun is positioned so that the trajectory traverses the field of the spark photography stations. The function of the stations is to provide position data on 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 breaks a light beam triggering spark light source. 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.

For the analysis of the range data, it is necessary 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.

The limitations on model scale imposed by the size of the facility resulted in the development of the BRL Transonic Range in 1954. The capabilities of the technology demonstrated by the range served to inspire a significant effort to construct similar facilities. The pressurized range constructed at the Naval Ordnance Laboratory, White Oak, MD, can be traced directly to the BRL Aerodynamics Range. Dr. A. C. Charters took much with him when he left for NASA-Ames Research Center and constructed facilities at that location. Other ranges at Eglin Air Force Base, Florida; Arnold Engineering Development Center, Tennessee; and even Meppen Proving Ground, Germany, can be related to early developments at BRL. The Range has served the nation in peace and in war. Today, it continues this tradition as a unique facility for producing high quality data in the field of ballistics.



SCHEMATIC OF THE FREE FLIGHT AERODYNAMIC RANGE

ACKNOWLEDGEMENTS

The Baltimore Section of the American Society of Mechanical Engineers gratefully acknowledges the efforts of all who cooperated in the dedication of the Aerodynamics Range as a National Historic Mechanical Engineering Landmark. Particular thanks are due to the staff at the Ballistic Research Laboratory who participated in the production of the commemerative brochure and the arrangements for the dedication ceremony.

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