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ROBERT HARRINGTON KENT

1886—1961

A Biographical Memoir by
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July 1, 1886–February 3, 1961

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ROBERT HARRINGTON KENT was born in Meriden, Connecticut, on July 1, 1886. He attended Harvard University, obtaining his Bachelor of Arts degree in 1910 and his Master of Arts degree in 1916; in 1953 his alma mater conferred upon him the honorary degree of Doctor of Science. After graduation he became an assistant instructor in physics and a part-time instructor in mathematics at Harvard. He was an instructor in electrical engineering at the University of Pennsylvania from 1916 to 1917.

In 1917 Kent entered the Army and was commissioned a First Lieutenant in the Ordnance Department. He was assigned to the Office of the Chief of Ordnance, Washington, D.C., and in June 1918 was ordered to Tours, France, on the staff of the Chief Ordnance Officer, American Expeditionary Forces. He was in charge of ballistic work and was responsible for the preparattion of firing tables for the use of American artillery.

He resigned from the Army and entered upon duties as a civilian in July 1919 in the Office of the Chief of Ordnance, Washington, D.C. In 1922 he was transferred to the Aberdeen Proving Ground, Maryland. He worked continuously in the field of the relatively rare and complex science of ballistics; he was probably our country's greatest expert in interior, exterior, and terminal ballistics, and was exceptionally adept in all fields of science and engineering that support ballistics. Moreover, Kent was a highly competent, self-taught statistician. Kent became Associate Director of the Ballistic Research Laboratory when it was organized in 1938 and held the same title after the organization was expanded a few years later to become the Ballistic Research Laboratories (BRL). In the early years he was associated with (then) Colonel H. H. Zornig and (then) Major-Colonel Leslie E. Simon, who were the first and second directors of the BRL.

Kent was Chairman of the Explosives and Armament Panel, United States Air Force Scientific Advisory Board, during World War II. He was also a member of the Adivsory Board, Naval Ordnance Test Station, Inyokern, China Lake, California.

He was a fellow of the American Association for the Advancement of Science and of the American Physical Society. He was a member of the Institute of Mathematical Statistics, the Institute of Aeronautical Sciences, the National Academy of Sciences (1951), and Phi Beta Kappa.

He was decorated with the Presidential Medal for Merit in 1946, the Potts Medal of the Franklin Institute in 1947, and the Campbell Medal of the (Army) Ordnance Association in 1955.

In the course of his two-score years in ballistics he made many original contributions to ballistics and also other sciences, as attested in his numerous published papers and reports. He was, almost surely, the country's only "complete" ballistician.

However, Kent's contributionns to his fellow men, his leadership, his warm friendship, and his generous understanding are no less important than his scientific work. He was a master of the art of gathering together people of competence and infusing them with the scientific method and causing them to produce new and original work. He was more than a mere catalyst because, unlike a catalyst, he almost invariably entered into the reaction that he stimulated and made important contributions to the work that his guidance and suggestions had initiated.

KENT AS A STUDENT AND EDUCATOR

Kent's entire life was an intimate mixture of being a keen and intelligent student, doing important and absorbing work, and teaching in a competent and kindly way those people who chose to be his students and who needed his help. Even his own formal education was interrupted by periods of teaching. His family first sent him to Columbia College to become a preacher; somewhat against the wishes of his family, he managed to transfer to Harvard and was graduated a Phi Beta Kappa, in 1910. In the next six years he was both student and teacher. He taught physics and mathematics at Harvard while leisurely studying for his Master of Arts degree, which he obtained in 1916. He also passed his examinations for his doctor's degree, but at this point he had a fundamental difference with Harvard. Kent wished to write his doctoral thesis on the determination of the laws of intermolecular repulsion from the experimentally determined virial coefficients in Van de Waal's equation. Harvard insisted that physics was an experimental science and declined to award a doctorate for theoretical work only. As a matter of principle, Kent declined to undertake the experimental work. Thus it was that a man who was destined to blend beautifully the keen reasoning of the theorist with the objectivity of the experimentalist sacrificed his doctorate as a protest against the rigid rules of Harvard. How strongly Kent felt about his principle is illustrated by the fact that, until he received his honorary doctorate from Harvard in 1953, he would never permit his being addressed as "Doctor" Kent. The unknowing person who so addressed him was immediately greeted with a friendly smile and the good-humored rejoinder, "Thank you for the doctorate."

In the long run Kent won. Eventually, Harvard did grant doctorates for theoretical work, and Lennard Jones gained very wide fame for work similar to that which Kent wished to do as his doctoral dissertation. In 1953 Kent, the world-renowned military scientist (both theoretical and experimental), was awarded an honorary degree of Doctor of Science. In awarding the degree, Harvard's President Conant observed with kindly good humor: "In a world of violence, he measures explosive forces and predicts where the modern arrows shot into the air will land." What more could one say of a man whose lifework exemplified so keenly the scientific method of hypothesis, experiment, and judgment of hypothesis?

In the interval between the award of his M.A. degree in 1916 and World War I, Kent spent a year at the University of Pennsylvania as an instructor in electrical engineering. One may well suspect that he wished a better background in electricity than he had gained from his physics and thus chose, like many academic people, to teach a course in a subject as an avenue to self-education. In any event, he learned well because he later did some illustrious electrical work in connection with instrumentation for ballistic experimentation; see, for example, "The Propagation of Electric Currents in Terminated Lines: Solutions of the Telegraphic Equation," *Physical Review,* Vol. 55, No. 8 (1939).

Kent never accepted a formal academic post after his year at the University of Pennsylvania, but his most important work as an educator still lay before him. He had a warm, generous personality, he had a depth of human understanding, he loved people, and he was ever happy to assist any intelligent and conscientious student. He gave lectures at the Ordnance School, Aberdeen Proving Ground, and the Navy Post Graduate School, Annapolis, Maryland; wrote prolifically for ordnance textbooks for the U.S. Military Academy, West Point, New York; was a leader in the colloquia at the Ballistic Research Laboratories; and was ever an aid to the Ballistic Institute (for graduate study) of the Laboratories. However, his most important educational work was a personal affair. The number of young Army officers that he assisted in scientific matters, guided, and stimulated is legion. When young officers who had been stationed with Kent wrote him about their problems, he never failed to give them personal assistance, references in the literature, and encouragement. He trained many officers for special assignments; however, his greatest continuing work consisted of the advice, council, and guidance he dispensed to his own staff and to many young men and women in the Ballistic Research Laboratories. He once gave a very interesting talk entitled "Two-Score Years in Ordnance." It might well have been entitled "Two-Score Years in Teaching."

KENT AS AN ARMY OFFICER

It is probable that Kent, himself, gave the best possible account of his brief (approximately fifteen months) career as an Army officer. The following are excerpts from his talk "Two-Score Years in Ordnance":

"When America got into World War I in 1917, I decided that I should do something for my country. I was, at that time, an instructor of electrical engineering at the University of Pennsylvania. When the term ended, I went to a recruiting officer of the Signal Corps to volunteer my services in the Aviation Branch of the Corps because I thought that would be the heroic thing to do. I was tremendously relieved when the officer told me that I was four months too old to be an aviator. Now at that time, of course, the landing speed of airplanes was 30 or 40 miles an hour. I think that the aviators of the present day are much braver than I would have been if I had entered the Signal Corps, because the landing speeds now are 80 or 100 miles an hour.

"From Philadelphia, I went to the Officers' Training Camp at Fort Oglethorpe, Georgia, a short distance from Nashville,* Tennessee, I believe. When they asked me what my choice would be—Infantry, Field Artillery, Coast Artillery—I thought that, since I had received some training in mathematics and physics, I should enter the Coast Artillery. About September, I think it was, we went down to Fort Monroe, Virginia, where my training for the Coast Artillery began.

"Now at Fort Monroe, at the close of the camp, there was an Ordnance officer who was recruiting for the Ordnance Department and he offered me a commission of First Lieutenant in Ordnance. I thought I didn't want to be an 'embusqué' [hiding behind the bushes], you know, and so I thought I would be brave and enter the Coast Artillery Corps in spite of the Ordnance officer's offer. However, when I told my company commander that I had been offered a commission in Ordnance as well as in Coast Artillery, he said, "Kent, I advise you to take Ordnance because, in my opinion, you're not a very military person." I must say that I stammered then worse than I do now. So that was the reason why I went into Ordnance.

"I arrived at the Ordnance Office in Washington about December 1, where I met Lieutenant James (Jimmy) Alexander. He was my co-ballistician in the Office of the Chief of Ordnance. About March 1918, Major F. R. Moulton came to take charge of Lieutenant Alexander and me in the Ballistic Section, Ammunition Branch, Gun and Carriage Division, Office of the Chief of Ordnance. Major Moulton had been Professor of Astronomy at the University of Chicago. He had a considerable reputation as the co-author of the Chamberlin-Moulton planetesimal theory concerning the origin of the solar

* Chattanooga, Tennessee, actually.

system. He was also well known for his computation of the orbits of the planets, for which he had developed methods of numerical integration.

"Shortly after Major Moulton arrived in Washington, Captain F. Wheeler Loomis came back from France and requested Moulton to undertake the computation of antiaircraft trajectories according to methods that had been developed by R. H. Fowler and others in Great Britain. Moulton replied that he was unwilling to undertake such computations. He intended to get out a better method than Fowler's in a short time. As a result of this, Captain Loomis went down to Aberdeen Proving Ground, where, in association with Major Oswald Veblen, the calculations were begun on the trajectories of AA [antiaircraft] guns.

"Major Moulton eventually developed his well-known method of numerical integration of trajectories of shell. This method and also various other matters are explained in his book *New Methods in Exterior Ballistics,* published in 1926. The book included a discussion of the motion of a spinning shell about its center of gravity. In this theory, Moulton gave the damping in pitch as the only means of damping of the initial yaw. He did not include the lift or the cross-wind force. The result was that he did not succeed in getting the initial yaw damped out, although he thought he did under certain circumstances.

"His method of the numerical integration of the trajectory of the shell was, however, a very important contribution to exterior ballistic theory. It was the method that was used in the computation of Volumes I, II, and III of the Tables for Exterior Ballistics.

"Lieutenant Alexander and I made firing tables for some ammunition for the 3.2-inch gun. In the process of making these firing tables, especially in the preparation of the tables for the wind effects, we discovered that an easy method of allowing for these effects was to use a platform which moved with the wind. Our ego was somewhat deflated a week later when we found that this was a well-known method in exterior ballistics.

"Incidentally, the startling news that the Germans had fired on Paris from a distance of 75 miles arrived at our office on 24 March. Lieutenant Alexander, by approximate methods, computed that a muzzle velocity of about 5,000 ft/sec should be sufficient to give a heavy 8-inch shell such a range.

"The Ordnance Department had made some American shrapnel for the French 75mm gun. I made some firing tables for these shrapnel in the office in the F street Building—no, it wasn't, it was probably in the Ford Building. We moved all around in those days. We would stay a month in one place and then we would stay a month in another place. We did a lot of moving. Anyway, I, with the aid of secretaries who were available there in the office, constructed firing tables for the American shrapnel in the 75mm gun. I had the firing tables sent to the government printer and had read the first proofs of the firing tables when I went overseas.

"About the end of June or the middle of July 1918, I entered the Office of the Chief of Ordnance Officer of the American Expeditionary Forces in Tours, France. Anyway, I waited and waited. Finally Colonel Steese, my immediate superior, said that they needed some firing tables for American shrapnel to use at the Field Artillery Center at Is-Sur-Tille. So I took the photostat copy of the table that I had brought with me to the French printer in Tours. In two weeks I had a couple thousand copies of the firing tables and I sent them to the Field Artillery Training Center.

"Ordnance had a lot of new ammunition that was going to be used, for which they needed firing tables. Some of it was for the 4.7-inch Gun Model 1906, which was one of the early guns with which we entered World War I. Then there was the

8-inch Howitzer and a 6-inch Gun Model 1905. These were American guns and we needed firing tables for all of them.

"I didn't know much then; well, perhaps I have learned something since. I just didn't realize that I could have written to my friend Major Veblen, who had charge of the firing tables and range firing at Aberdeen Proving Ground, and he would have been just delighted to have made the firing tables. So I did the best I could.

"Incidentally, there were some 6-inch shell that were sent over to be tested at a French camp called Mailly, 200 miles or so from Tours and about 100 miles from Paris. There was a Coast Artillery Colonel by the name of Rhodes who suggested a modification for the shell. These shell had a very interesting characteristic. They had a range that was practically independent of the elevation. If you pointed the gun this way [indicating elevation of 20°] they went so far; if you pointed the gun this way [indicating elevation of 45°] they had just about the same range!

"There was a time in April 1919 when they wanted me to take back a company of troops to the United States. Since I really had not been associated with the troops at all, I knew I would do a very poor job of taking a company of troops back. Fortunately they wanted some new firing tables so they ordered me back to Tours. Finally I got back to the United States on the Fourth of July 1919."

In addition to his rather tedious duties with respect to firing tables, Kent served the Chief Ordnance Officer as his representative at various tests and demonstrations of American and French weapons. These latter duties afforded him an opportunity for association with some brilliant young British scientists who had entered into war work. Among these were Captain Fowler and Captain Crow, later to become Sir Ralph Fowler and Sir Alwyn Crow.

In the course of his associations Kent gathered many ideas which he later exploited for the American Army. His ideas for the 3.3-inch aerodynamics range were obtained from Captain Fowler and the American Captain Alexander. He became familiar with the British solenoid chronograph on a visit to Shoeburyness in 1918.

The ideas, or the stimuli for ideas, which Kent acquired abroad were developed by him so effectively in subsequent years that our foreign friends learned to look to Kent's work to find answers to their problems.

Kent returned to this country as a captain in 1919 and was offered a permanent commission. He might have been a general years ago and retired from the Army, if the uniform had been different. However, Kent simply could not stand the restraint and heat of puttees around his legs, so he resigned his temporary commission and entered civil service with a view to using the fruits of science and engineering to improve our weapon systems.

KENT AS A CAREER BALLISTICIAN

When Kent began his career as a civilian ballistician, he worked first in the Office of the Chief of Ordnance and originated the famous 3.3-inch gun program which was to give the first scientific bases for the drag functions of artillery shell and for the design of projectiles of modern shape.

However, with the limited appropriations obtained as a result of the depression of 1921, the Ordnance Corps felt it could not maintain him in Washington. Also, Kent was impatient with the remote control of the experimental phases of his work at the Aberdeen Proving Ground, so he was transferred to Aberdeen in 1922.

During the sixteen years from 1922 to 1938, Kent was the outstanding carrier of the torch of science in the Army. Some men achieve a degree of greatness such as Kent had already achieved by 1922, and then become a landmark rather than a beacon. Kent was a beacon, but not a landmark, because his scientific modesty, his warm human qualities, and his scorn of all pomp and ceremony precluded his ever allowing any one to look up to him as being the dignified incumbent of some authoritative official position. His scientific product was prodigious, and his applied research drew on almost all fields of science and engineering.

In 1920 he measured the loss of spin of projectiles. Because he did not know much about chronographs at that time, he had a misplaced confidence in the accuracy of the Boulengé chronograph. It was not until he talked to Fowler in 1938, who told him that the British suspected from their fuse that projectiles did lose spin, that he reworked the results of 1920. He found that there was indeed a substantial loss of spin. His results have been confirmed by modern experiments.

Stimulated by Fowler's work on yawing shell in Great Britain, he investigated the force system of a yawing shell. Each area of investigation in one field led him naturally to investigations in others. For example, having studied the flight of the shell, he then had to study the effect of the launching conditions, such as the clearance between the bourrelet and the bore. It was appropriate that he was placed in charge of the interior ballistic firings for the 240-mm howitzer. For these, he perfected the piezoelectric gauge.

An enumeration of all his work having to do with the fundamental principles involved in projectiles, bores of cannon, heat transfer, ignition of propellants, bombs, armor plate, fuses, recoil mechanisms, and other types of material and components would be tedious. There is hardly a nook or cranny in the whole field of modern weapons that escaped Kent's scrutiny or failed to benefit from his searching and scholarly study and his brilliant rationalization.

His achievements are especially marked because they were done not in the rich atmosphere of stimulation by daily association with many distinguished colleagues but almost in an atmosphere of seclusion, in the sense that only Kent and less than a dozen others of real professional training were working together. These sixteen years of effort contributed enormously to our readiness in Army weapons (including bomb design and bombing tables) when we were faced with World War II and have affected favorably practically every weapons system now extant.

One should not infer from the above remarks on the uniqueness of Kent's leadership that he worked under conditions of adversity. Invariably, each succeeding Commander of the Aberdeen Proving Ground learned to know Kent, and respected him and supported him. In addition, he received the warm support of officers who had served with him, officers whom he had instructed in courses at the proving ground, and officers and civilians throughout the world who took an intelligent interest in his work and with whom he kept up a voluminous correspondence.

The year 1938 was a turning point in Kent's career because that was the year in which the Ballistic Research Laboratory was organized under Colonel H. H. Zornig as Director and Kent as Associate Director. This was the beginning of a period in which Kent was forced gradually and reluctantly to shift his major emphasis from research work to research administration. Kent's research work continued at full pace for some time because the laboratory underwent no substantial expansion until about the beginning of World War II, when it expanded rather rapidly from about forty employees to five hundred.

One of the most cogent factors in the newly organized Ballistic Research Laboratory was the formation of the Scientific Advisory Committee, composed of eight men highly eminent in their respective fields of science who voluntarily served the laboratory. It is believed that the original idea for such a committee should be attributed to Colonel H. H. Zornig, the first BRL Director; but Kent's counsel in the selection of the members was most valuable, the well-known high caliber of his work contributed to persuading them to serve the government's best quality laboratory, and his warm, genial personality made every meeting a pleasure. The original committee consisted of Harold Urey, I. I. Rabi, Hugh Dryden, Bernard Lewis, A. W. Hull, Henry N. Russel, Theodore von Kármán, and J. von Neumann. Their first meeting was in September 1940; at the time of Kent's death in 1961, two of this illustrious group were still serving.

Kent paid considerable attention to various facilities the BRL acquired over the years. Perhaps he was prouder of the first United States supersonic wind tunnel, installed at BRL and dedicated in 1944, than of any other facility. Dr. Edwin P. Hubble was the first head of the Supersonic Wind Tunnel (or Exterior Ballistics) Laboratory and Kent was its second head when Hubble returned to the Mount Wilson Observatory at the end of World War II.

The Wealth of high-quality personnel obtained for the BRL was due in large measure to the able and influential assistance of Professor Oswald Veblen of the Institute of Advanced Study, Princeton, New Jersey, who, as a major, was in charge of ballistics at the Aberdeen Proving Ground during World War I. However, the able men who joined the BRL had to be oriented in their new type of war work, and Kent proved himself to be as competent a research leader as he had already proved to be a research worker. Kent's method of going about his work engendered an atmosphere of true scientific inquiry and filled his colleagues with enthusiasm, and his guidance led them to swift and fruitful achievements. Kent's powers were multiplied many times by his ability to work through others, and the people who are indebted to Kent are legion. Of course, Kent did not stick to science, to engineering, or even to technical matters. If anything was wrong, he either righted it or demanded a clean-cut accounting of the situation. He had no patience with decisions made without discussion with the people affected—and he was always one of the people affected!

Kent was a highly competent research leader, planner, and administrator of scientific effort. Not so much could be said for him as a manager and business administrator. One of his more businesslike colleagues once remarked, "Bob has a heart as big as a water bucket, and would pay every man the highest salary listed in the civil service table if he had the authority." However, Bob was sufficiently self-critical to sense his own weakness; the vehemence of his attack decreased with the remoteness of the subject of discussion from a scientific field, and he would generally yield on purely administrative matters. Kent's vigorously asserted right to differ was always on a purely intellectual and objective plane; it was never personal or emotional. Almost strangely his discussions won friends for him; they never made enemies. To technical personnel (and many line officers) throughout the Army, Army Air Corps, and Navy he was just plain Bob Kent, widely known and beloved by all.

THE MAN

Whereas the character of every man is unique, some men are exceptionally unusual and different. Kent's character was indeed outstanding. Without any known exception, every man who knew Kent liked him; most loved him. He was intolerant of hypocrisy and pretense to the point of deprecating dignity. He was charitable, not only in a monetary way, but in entertaining the views of others and in recognizing the rights of others, and he was ever the champion of the underdog.

He loved social contacts, conversation, and exchanges of views, and was distinctly of the opinion that a moderate amount of alcoholic beverage lessened inhibitions and promoted good-fellowship. It was customary for the staff of the BRL to give a cocktail party and dinner for the BRL's Scientific Advisory Committee during its two-day visits, and Kent insisted (seriously) that the informal cocktail party was the best part of the meeting because the committee members criticized and advised more freely under the relaxing circumstances. On such occasions it was easy to get him to play the piano, particularly if others would sing, and he preferred the Whiffenpoof Song. Kent was also very fond of playing tennis and continued the sport as long as he could.

Kent died on February 3, 1961. His carefully written will left appropriate things to people who he thought would have a special interest in them. He left instructions that he be cremated and that there be no regular funeral ceremonies or sermon. Instead, there was to be piano music (Robert Schumann's "Traumerei," Bach's "Jesu, Joy of Man's Desiring"); a male quartet of friends to sing "Integer Vitae," with words by Quintus Horatius Flaccus; the reading of Ecclesiastes XII, verses 1–12 only (specifically omitting the 13th and 14th verses); the playing of Chopin's Sonata in B-flat minor (with the funeral march); and the singing of "Gaudeamus Igitur" by the male quartet.

BIBLIOGRAPHY

KEY TO ABBREVIATIONS

APG = Aberdeen Proving Ground
BRL = Ballistic Research Laboratories (U.S. Army)
OCO = Office of the Chief of Ordnance (U.S. Army)
OTN = Ordnance Technical Note

Projectile design. Army Ordnance, 2:204, 1922.

Role of model experiments in projectile design. Mechanical Engineering, 54:641-46, 1932.

Special solutions for the motion of powder gas. Physics, 7:319-24, 1936; Journal of Applied Physics, 9:734, 1938.

The flight of the projectile. Journal of the Franklin Institute, 226:19-33, 1938.

Probability of hitting. Chapter XI in: *Elements of Ordnance,* by Thomas J. Hayes, pp. 469-87. New York, John Wiley & Sons, Inc., 1938. With L. S. Dederick. Chapter X, Exterior ballistics, pp. 397-468. With H. H. Zornig. Chapter XII, Bombing from airplanes, pp. 488-512.

The piezo-electric gage, its use in the measurement of gun pressures. Army Ordnance, 18:281, 1938.

The propagation of electric currents in terminated lines: solutions of the telegraphic equation. Physical Review, 55:762-68, 1939.

With A. H. Hodge. Use of the piezo-electric gage in the measurement of powder pressures. Transactions of the American Society of Mechanical Engineers, 61:197-204, 1939.

With L. S. Dederick and H. H. Zornig. *Exterior Ballistics,* ed. by Thomas J. Hayes. New York, John Wiley & Sons, Inc. 98 pp. (Reprint of Chapters X and XII of *Elements of Ordnance.*) 1940.

Some hydrodynamical problems related to ballistics. American Mathematical Monthly, 48:8-14, 1941.

With J. von Neumann. The mean square successive difference. Annals of Mathematical Statistics, 12:153-62, 1941.

Explosives and their military applications. Journal of Applied Physics, 13:348-54, 1942.

Note: A list of more than 200 titles of official reports, written by Dr. Kent for the Ordnance Corps of the Army, is deposited in

the Archives of the Academy. A few of these titles are listed below to exemplify the nature of the reports.

1919

With D. Armstrong. *The Problem of the Projectile.* AEF, France. Theory of 3.3″ experimental firings. Text for the U.S. Army Ordnance School.

1920

Loss of spin of projectiles. Ballistic section, APG Report.

1921

The force system acting on a yawing shell. Ballistic section, APG Report. [Notes on computations relating to projectile design including (1) computation of the stability factors of projectiles, (2) computation of the initial maximum yaw, (3) computation of damping factors of projectiles, and (4) calculation of the effect of yaw on range.] Ammunition Division, Manufacturing Service, Ordnance Department.

1923

With H. P. Hitchcock. The effect of cardboards on damping and phase. Ballistic section, APG Report.

Tolerance tests of 155mm projectiles. Ballistic section, APG Report.

1924

The effect of imperfect fit of ogives of 105mm shell on range. Ballistic section, APG Report.

Methods of determining velocities of small arms projectiles including also certain firings to establish the law of air resistance. First Report, ballistic section, APG Report.

1925

Methods of determining velocities of small arms projectiles including also certain firings to establish the law of air resistance. Second Report, ballistic section, APG Report.

1926

Report on piezo-electric pressure measurements in connection with program on powder pressures and muzzle velocities in 3″ A.A. Gun, Model 1925 No. 3. Ballistic section, APG Report.

Investigation of the trunnion reaction-time relation of various automatic weapons. First Report, ballistic section, APG Report.

1927

A trigger spark apparatus for Aberdeen chronograph. Ballistic section, APG Report.

The effect of temperature on pressure and velocity of small arms. First Report, ballistic section, APG Report.

Time pressure records by a piezo-electric method. OTN, OCO, U.S. Army.

1928

Determination of temperature of bore of cannon due to firing and the rate of cooling thereafter. First Report (75mm gun M1897, 155mm howitzer M1918, 155mm gun M1918). Second Report (75mm guns M1912 and M1897, 155mm gun M1918).

Description of an apparatus for recording the water impact of bombs. Ballistic section, APG Report.

Development of an apparatus for measuring velocity in the field (photo-electric cell). Ballistic section, APG Report.

With H. P. Hitchcock. A study of the dispersion in velocity of guns with a view to determining the optimum number of rounds for the test of a powder lot. Ballistic section, APG Report.

With H. P. Hitchcock. Effect of cross wind on the yaw of projectiles. Ballistic section, APG Report.

1929

With H. P. Hitchcock. Fourth partial report on interior ballistic firings. Ballistic section, APG Report.

Derivation of formula for centrifugal couple due to rotation of a projectile about a given axis. Ballistic section, APG Report.

The development of a chronograph to measure the time of flight of antiaircraft projectiles (fuze chronograph). Ballistic section, APG Report.

Application of the thermodynamical theory of gas equilibrium to the problem of flash reduction. Ballistic section, APG Report.

The development of the piezo-electric gage for large caliber guns. Ballistic section, APG Report.

1930

The effect of temperature on pressure and velocity of small arms. Ballistic section, APG Report.

Determination of temperature of bore of cannon due to firing and the rate of cooling thereafter. Fourth Report (examination of the condition of recoil mechanism Nos. 476 and 2257-8). Ballistic section, APG Report.

Penetration of armor plate by bullets. Ballistic section, APG Report.

Theory of the motion of a bullet about its center of gravity in dense media, with applications to bullet design. Ballistic section, APG Report.

Analysis of results of calorimetric measurements in connection with the test of cooling agents. Ballistic section, APG Report.

With J. R. Lane. Time required for bombs to penetrate water to various depths. Ballistic section, APG Report.

Measurements of the eccentricity of the center of gravity of unloaded 155mm shell, T1-E1. Ballistic section, APG Report.

1931

Effect of range wind on drift of projectile. Ballistic section, APG Report.

Theoretical basis for the proposed requirements for the acceptance of powder. Ballistic section, APG Report.

Determination of the pressures in cylinders filled with water due to the impact of the bullet against the column of water. Ballistic section, APG Report.

1932

Study of the method of conducting and analyzing the results of war reserve firings. Part V, shrapnel. Ballistic section, APG Report.

Program for fragmentation test of 105mm H. E. shell M1. Ballistic section, APG Report.

Depths of penetration of projectiles and times required. Ballistic section, APG Report.

1933

Consideration of the effect of the size of the projectile on the efficiency of its fragmentation. Ballistic section, APG Report.

Analysis of fragmentation results for the 17-lb and 30-lb bombs. Ballistic section, APG Report.

The duration of the elements of the firing cycle of machine guns. Ballistic section, APG Report.

1934

Test to determine whether the rate of burning of powder grains is proportional to the first power of the pressure (firings in closed chamber). BRL Report No. 10.

1935

With H. P. Hitchcock. The motion of caliber .30 bullets in a dense medium. BRL Report No. 1.

Method for determining the resistance function of a projectile when pursuing a high angle trajectory. BRL Report No. 5.

Influence of radiation on the ignition and burning of powders. BRL Report No. 9.

Some sources of error in piezo-electric and crusher gage measurement. BRL Report No. 26.

A possible explanation of muzzle bursts and expansions of howitzers. BRL Report No. 29.

1936

Precision of the Boulengé and solenoid chronographs. Test with modified circuits. BRL Report No. 24.

Determination of interior ballistic data by closed chamber experiments. BRL Report No. 32.

The smokiness of "smokless" powder. BRL Report No. 33.

The motion of the powder gas I.A. Special solution for the case of an imperfect gas. BRL Report No. 36.

Notes on the theory of recoil mechanisms for automatic weapons. BRL Report No. 40.

Roggla's equation and its application to interior ballistic problems. BRL Report No. 48.

Spring characteristics for triggering caliber .50 recoil mechanism. BRL Report No. 53.

A study of the statistics and methods of rating the performance of time fuzes. BRL Report No. 63.

1937

With L. S. Dederick. Statistical study of certain characteristics of copper cylinders. BRL Report No. 67.

With L. A. Carten. The functioning cycle of caliber .30 semiautomatic rifle. BRL Report No. 70.

An elementary treatment of the motion of a spinning projectile about its center of gravity. BRL Report No. 85.

The angle between the axis of a projectile and the axis of spin. BRL Report No. 88.

1938

The most economical sample size. BRL Report No. 96.

With H. H. Zornig. The stability factors of caliber .50 bullets fired from fixed guns in aircraft. BRL Report No. 97.

Target errors due to errors in altitude and air speed. BRL Report No. 112.

With H. P. Hitchcock. Applications of Siacci's method to flat trajectories. BRL Report No. 114.

A study of the distortion of chronograph signals transmitted by wires. BRL Report No. 121.

A comparison of antiaircraft guns of various calibers. BRL Report No. 125.

The probability of hitting an airplane as dependent upon errors in the height finder and the director. BRL Report No. 127.

1939

The probability of hitting various parts of an airplane as dependent on the fragmentation characteristics of a projectile. BRL Report No. 132.

A formula for the accuracy life of a gun. BRL Report No. 133.

A determination of the loss of spin of projectiles. Effect on mechanical time fuzes. BRL Report No. 154.

The probability of disabling an airplane. BRL Report No. 155.

With H. H. Zornig. A method of determining the relative efficiencies of two types of aircraft guns. BRL Report No. 170.

1940

With J. von Neumann. The estimation of the probable error from successive differences. BRL Report No. 175.

Theory of the Hopkins electromagnetic blastmeter. BRL Report No. 176.

1941

Means of obtaining greater armor penetration from anti-tank guns. BRL Report No. 214.

With L. S. Dederick. Optimum spacing of bombs or shots in the presence of systematic errors. BRL Report No. 241.

1942

The relative efficiency of mechanical and point detonating fuzes for antiaircraft shell. A review of papers on the subject. BRL Report No. 264.

With J. P. Vinti. Cooling corrections for closed chamber firings. With A. C. Charters. The relation between the skin friction drag and the spin reducing torque. BRL Report No. 287.

The technique of firing vertically for recovery. BRL Report No. 293.

1943

Preliminary report on work on hollow charges. BRL Memorandum Report No. 159.

With G. Birkhoff and D. R. Inglis. Comparative effectiveness of different 90mm shell against aircraft. BRL Report No. 310.

1944

With E. J. McShane. An elementary treatment of the motion of a spinning projectile about its center of gravity. BRL Report No. 459.

1945

Statosphere ballistic chart. BRL Report No. 525.

1946

With M. E. Harrington. Vertical trajectories of long range rockets. BRL Report No. 622.

1947

With A. S. Galbraith. Windage jump of a rocket fired nearly vertically. BRL Report No. 656.

1948

With A. S. Galbraith. A note on the stability conditions for spinning shell and rockets. BRL Report No. 664.

With J. H. Frazer, H. P. Hitchcock, F. G. King, J. R. Lane, and T. E. Sterne. A study of a family of antiaircraft weapons. BRL-TN Report No. TN-119.

Essential and desirable characteristics of bombs. BRL-TN Report No. TN-140.

1950

With F. G. King and H. K. Weiss. A study of intermediate anti-aircraft weapons. BRL-TN Report No. 283.

1951

The shape of a fragmentation bomb to produce uniform fragment densities on the ground. BRL Report No. 762.

With J. R. Lane, H. K. Weiss, and F. E. Grubbs. A family of field artillery. BRL Report No. 771.

1953

With F. G. King. Kill probability of the 127/60 gun for two drag estimates, and comparison with the Loki rockets. BRL Memorandum Report No. 721.

1954

Notes on a theory of spinning shell. BRL Report No. 898.

With L. E. Simon. Ordnance developments to increase accuracy of artillery fire. BRL Report No. 989.

With H. P. Hitchcock. Comparison of predicted and observed yaw in front of the muzzle of the 12 inch gun. BRL Report No. 990.