SUMMARY TECHNICAL REPORT OF DIVISION 7, NDRC

VOLUME 3

AIRBORNE FIRE CONTROL

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
VANNEVAR BUSH, DIRECTOR

NATIONAL DEFENSE RESEARCH COMMITTEE
JAMES B. CONANT, CHAIRMAN

DIVISION 7
H. L. HAZEN, CHIEF

WASHINGTON, D. C., 1946

~~CONFIDENTIAL~~

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NOTES ON THE ORGANIZATION OF NDRC

The duties of the National Defense Research Committee were (1) to recommend to the Director of OSRD suitable projects and research programs on the instrumentalities of warfare, together with contract facilities for carrying out these projects and programs, and (2) to administer the technical and scientific work of the contracts. More specifically, NDRC functioned by initiating research projects on requests from the Army or the Navy, or on requests from an allied government transmitted through the Liaison Office of OSRD, or on its own considered initiative as a result of the experience of its members. Proposals prepared by the Division, Panel, or Committee for research contracts for performance of the work involved in such projects were first reviewed by NDRC, and if approved, recommended to the Director of OSRD. Upon approval of a proposal by the Director, a contract permitting maximum flexibility of scientific effort was arranged. The business aspects of the contract, including such matters as materials, clearances, vouchers, patents, priorities, legal matters, and administration of patent matters were handled by the Executive Secretary of OSRD.

Originally NDRC administered its work through five divisions, each headed by one of the NDRC members. These were:

Division A—Armor and Ordnance
Division B—Bombs, Fuels, Gases, & Chemical Problems
Division C—Communication and Transportation
Division D—Detection, Controls, and Instruments
Division E—Patents and Inventions

In a reorganization in the fall of 1942, twenty-three administrative divisions, panels, or committees were created, each with a chief selected on the basis of his outstanding work in the particular field. The NDRC members then became a reviewing and advisory group to the Director of OSRD. The final organization was as follows:

Division 1—Ballistic Research
Division 2—Effects of Impact and Explosion
Division 3—Rocket Ordnance
Division 4—Ordnance Accessories
Division 5—New Missiles
Division 6—Sub-Surface Warfare
Division 7—Fire Control
Division 8—Explosives
Division 9—Chemistry
Division 10—Absorbents and Aerosols
Division 11—Chemical Engineering
Division 12—Transportation
Division 13—Electrical Communication
Division 14—Radar
Division 15—Radio Coordination
Division 16—Optics and Camouflage
Division 17—Physics
Division 18—War Metallurgy
Division 19—Miscellaneous
Applied Mathematics Panel
Applied Psychology Panel
Committee on Propagation
Tropical Deterioration Administrative Committee

NDRC FOREWORD

As EVENTS of the years preceding 1940 revealed more and more clearly the seriousness of the world situation, many scientists in this country came to realize the need of organizing scientific research for service in a national emergency. Recommendations which they made to the White House were given careful and sympathetic attention, and as a result the National Defense Research Committee [NDRC] was formed by Executive Order of the President in the summer of 1940. The members of NDRC, appointed by the President, were instructed to supplement the work of the Army and the Navy in the development of the instrumentalities of war. A year later, upon the establishment of the Office of Scientific Research and Development [OSRD], NDRC became one of its units.

The Summary Technical Report of NDRC is a conscientious effort on the part of NDRC to summarize and evaluate its work and to present it in a useful and permanent form. It comprises some seventy volumes broken into groups corresponding to the NDRC Divisions, Panels, and Committees.

The Summary Technical Report of each Division, Panel, or Committee is an integral survey of the work of that group. The first volume of each group's report contains a summary of the report, stating the problems presented and the philosophy of attacking them, and summarizing the results of the research, development, and training activities undertaken. Some volumes may be "state of the art" treatises covering subjects to which various research groups have contributed information. Others may contain descriptions of devices developed in the laboratories. A master index of all these divisional, panel, and committee reports which together constitute the Summary Technical Report of NDRC is contained in a separate volume, which also includes the index of a microfilm record of pertinent technical laboratory reports and reference material.

Some of the NDRC-sponsored researches which had been declassified by the end of 1945 were of sufficient popular interest that it was found desirable to report them in the form of monographs, such as the series on radar by Division 14 and the monograph on sampling inspection by the Applied Mathematics Panel. Since the material treated in them is not duplicated in the Summary Technical Report of NDRC, the monographs are an important part of the story of these aspects of NDRC research.

In contrast to the information on radar, which is of widespread interest and much of which is released to the public, the research on subsurface warfare is largely classified and is of general interest to a more restricted group. As a consequence, the report of Division 6 is found almost entirely in its Summary Technical Report, which runs to over twenty volumes. The extent of the work of a Division cannot therefore be judged solely by the number of volumes devoted to it in the Summary Technical Report of NDRC: account must be taken of the monographs and available reports published elsewhere.

The Fire Control Division, initially Section D2 under the leadership of Warren Weaver and later Division 7 under Harold L. Hazen, made a significant contribution to an already highly developed art. It marked the entrance of the civilian scientist into what had hitherto been regarded as a military specialty.

It was one of the tasks of the Division to explore and solve the intricate problems of control of fire against the modern military aircraft. Gunnery against high-speed aircraft involves fire control in three dimensions. The need for lightning action and superlatively accurate results makes mere human skills hopelessly inadequate. The Division's answer was the development of the electronic M-9 director which, controlling the fire of the Army's heavy AA guns, proved its worth in the defense of the Anzio Beachhead and in the protection of London and Antwerp against the Nazi V-weapons. In addition to producing mechanisms such as the M-9, the Division made less tangible but equally significant contributions through the application of research methods which had a profound, even revolutionary, influence on fire control theory and practice.

The results of the work of Division 7, formerly Section D2, are told in its Summary Technical Report, which has been prepared at the direction of the Division Chief and has been authorized by him for publication. It is a record of creativeness and devotion on the part of men to whom their country will always be grateful.

VANNEVAR BUSH, Director
Office of Scientific Research and Development

J. B. CONANT, Chairman
National Defense Research Committee

FOREWORD

VOLUME 3 of Division 7, the Summary Technical Report of Section 7.2, NDRC, contains three parts. In Part I on aiming controls in aerial ordnance, Mr. G. A. Philbrick discusses the work of the Section in all fields except that of gunnery and the assessment of gunnery devices. Mr. A. L. Ruiz has contributed Part II, in which developments in aerial torpedo directors subsequent to those in which Mr. Philbrick took part are discussed. The third principal part of the report is that on aerial gunnery and assessment, written by Professor J. B. Russell.

It is indeed fortunate that such a large part of this work could be written by one individual, who could thus provide a unity of treatment which otherwise would be very difficult to obtain. In assuming responsibility for his part of the Summary Technical Report, Mr. Philbrick took on a heavy task—and discharged it with zeal. Under the circumstances a more conventional report would have fulfilled all the requirements, but Mr. Philbrick has served his reader a tasty dish of skilled technical exposition. We can ask no more.

In general the part contributed by Professor Russell stresses the instrumental features of aerial gunnery, and relies upon the writing of Dr. Paxson, in Volume 2 of the Summary Technical Report of the Applied Mathematics Panel, for the basic mathematical substance of the subject. Professor Russell brings to his treatment continuous experience in the field dating from before Pearl Harbor. He has participated in all of its growth, first as a Technical Aide in Section 7.2, and during the closing months of the war as an Expert Consultant to the Secretary of War.

H. L. HAZEN
Chief, Division 7

S. H. CALDWELL
Chief, Section 7.2

CONTENTS

PART I

AIMING CONTROLS IN AERIAL ORDNANCE

By *G. A. Philbrick*

PREFATORY COMMENTS

GENERAL

DURING the past three years and a half the present writer has served as technical aide to S. H. Caldwell, Chief of Section 7.2, whose section has been charged with airborne developments within the more general fire control framework of Division 7 of National Defense Research Committee [NDRC]. By delegation from the section chief, the writer has shared, with other technical aides and section members, several domains of responsibility in the conduct of research and development on airborne fire controls. The initiation for such work in typical cases occurs through a request by Army or Navy to Office of Scientific Research and Development [OSRD] for a particular study of development; following acceptance by the latter organization, which is made through agreements of the relevant section and division of NDRC, a program is laid out and presented as specification for a project to the appropriate contractor. Guidance of this project through the stages of theory or experiment, design or test, and the maintenance of liaison with the same agencies concerned, constitute functions of the NDRC section. Such duties have in turn become those of such operatives as the present writer, who enter personally into the technical phases of the development of the project as deeply as appears necessary or appropriate, and who answer to the section for the conduct and outcome of the work.

SUBJECT MATTER

By reasons of familiarity and plausibility, the material treated in the following pages is naturally restricted to those branches of airborne fire control with which the writer has been concerned at first hand. Although rather generously distributed over the field, these branches have not been all inclusive. They are considered sufficiently pervasive, however, to warrant the title given to the present report. In particular, the subject matter revolves about the development of computors and computing sights for aerial torpedoing, bombing, and aerial rocketry, with a final attempt to combine all of these functions with that of fixed gunnery for the fighter airplane. The most impressive omission is that of flexible gunnery, for while the writer has been exposed to and has gained familiarity with the equipment and developmental procedures in this branch, he has had little or no tangible responsibility there. Another characterization of the present material refers to the character, or technical position, of the researches which are reported upon, and reflects the corresponding nature of the activities of the writer. The latter has been substantially a creature of the laboratories, operating for the most part between theory and design. His contacts with the using Services have usually been with respect to a particular equipment under development, and his involvement with proving organizations and with aerial firing tests has been for the specific purpose of gaining knowledge of the properties of one device rather than of a larger category. That is to say, the morphology of localized apparatus, from the instrumental standpoint, is here stressed rather than a broader survey of available ordnance or a presentation of assessment techniques, in spite of the recognized status of the latter. The flavor is thus dynamical rather than statistical, constructional rather than evaluational, instrumental rather than logistic, and physical rather than administrative. This is not to indicate any absolute preference or desirability, but straightforwardly to identify the aspect of the material to be treated, and to admit that this aspect stems, quite naturally, out of the writer's own predilections and propensities, quite aside from whether these are important.

In addition to the description, in successive developmental forms, of a number of specific computing devices and controls, considerable space is here allotted to certain tools of research themselves, where it is felt that these constitute advances in the techniques of instrument development or design. It is believed, for example, that the use of increasingly compre-

hensive electronic model structures can bridge enormous gaps which classically have intervened between theory and concrete facilities. Such model structures, owing to their ability to "cooperate" with the real human operator and to incorporate discontinuities against which analysis is almost completely impotent, can bring realism to the laboratory and can shorten the interval over which optimum dynamics are attained. With completely automatic assemblages the need for such models is as great or greater.

As to weapons, we are concerned here with the airplane, the projectile, and the man at the firing-key, the whole group operating as a unit. The airplane types include principally the fighter, fighter-bomber, and bomber. The projectiles are bomb, guided bomb, rocket, torpedo, and bullet or shell, in approximately that order of concern. A typical aiming control, or computing sight, involves a group of input variables, which may be either manually or automatically introduced, a computer proper, and a presentation-component or *sight* whereby the aiming process is reduced to some sort of null between an index and the target. Automatic firing may be involved, either permanently or at the choice of the operator.

It is difficult confidently to predict the shape of fire controls for the future, at least from the present standpoint. The trend toward more thoroughgoing automaticity is certainly evident, with the task of the operator becoming increasingly supervisory and eclectic. At this level the distinctions between offense and defense, and even between strategy and tactics, are so interwoven with other relationships as to be almost nonexistent, so that we shall not here presume to speak of these. While the rocket and guided bomb, together with their logical combinations, are outstandingly weapons of great future significance, the bomb, bullet, and shell are simple structures which should not be ignored. As to superexplosives, with potentially a million times greater payload ratio, the need for fire control should not decrease any more than as between flintlock and main battery. While the appearance and character of weapons may suffer revolutionary changes, in whatever era, with the science even of orbital underwater trajectories being replaced, for example, by that of underground trajectories, it will still be essential to direct and deliver fire in the vicinity of the target. Of the homing and automatic interception missiles on whose protection survival may depend, and which ultimately may truly battle among themselves, those with the more recondite controls will triumph along with their masters.

COLLEAGUES

In view of the apparent virtuosity of this report, the framework of personnel within which the writer has operated deserves particular comment. Both categorical and special, the people among whom the progress herein reported has taken place have made it what it is.

The staff of NDRC Section 7.2, with chief, members, and fellow technical aides, has been closest of all to these operations, and knows most about them. Thus are listed: S. H. Caldwell (Chief), J. B. Russell (since transferred to the Office of the Secretary of War), A. L. Ruiz, H. C. Wolfe, C. G. Holschuh, W. A. MacNair, E. G. Pickels, E. W. Paxson, and (latterly) A. F. Sise; in whose collective company it has been an honor for the writer to work. Knowledge of the branches of airborne fire control which are not herein treated, and more complete discernment of those which are, must be sought among these gentlemen. Also within Section 7.2 as technical aide, R. M. Peters is to be mentioned by the writer as his staunch mathematical assistant. She has helped materially in every phase of progress, and is to be credited with whatever significant mathematics adheres to the present report.

The remainder of Division 7, with H. L. Hazen as chief and K. L. Wildes as divisional technical aide, and with the adjacent section chiefs, D. J. Stewart, E. J. Poitras, and I. A. Getting, has served in all connections as guidepost and beacon. Considerable and appreciated interchange has been enjoyed with such members and technical aides of adjacent sections as G. R. Stibitz, L. M. McKenzie, and J. F. Taplin.

Of other divisions of NDRC with which developmental business has been conducted,

Division 5 should be mentioned especially. Control apparatus for new missiles has been dealt with in this relationship, both through an arranged collaboration between the two divisions, and by the writer as an officially appointed consultant to Division 5 itself. Constructive and informative intercourse has taken place with H. H. Spencer, Chief, Division 5, as well as with J. C. Boyce, L. O. Grondahl, P. Mertz, and E. W. Phelan, among others. Further relations have been important with Division 3 (F. L. Hovde) on rockets, with Division 4 (A. Ellett) on toss bombing, with Division 6 on antisubmarine warfare, with Division 14 on radar and with Section 16.1 (T. Dunham, Jr.) on optical instruments. Valuable personal contact on professional matters has been possible also with W. Weaver, T. C. Fry, J. D. Williams, M. S. Rees, and others of the Applied Mathematics Panel. Among other groups which cannot be mentioned in entirety are the administrative and engineering staffs of OSRD and NDRC, both central and local.

A detailed accounting of the Service agencies and personnel which have been directly concerned with these efforts would be all out of order in the present location. Such agencies and personnel will appear, however, in reference to the project chronologies in the main body of the report. Relations with the Services have, on the whole, been extremely pleasant and positive. The writer's dealings have been predominately with the Navy, and within Navy with the Bureau of Ordnance, and within BuOrd with the aircraft fire control sections: Re4 (Re4d), Re8 (Re8c). Further extensive affairs have been enjoyed with NAS Norfolk, NAF Philadelphia, NAS Squantum, NAS Quonset, NOTS Inyokern, NOP Indianapolis, and the various special devices depots, to mention only several branches. The Navy projects on which the writer has been engaged, and which are herein reported upon, include NO-106 (torpedo director: now TD Mark 32), NO-129 (antisubmarine bombsight: now BS Mark 20), NO-180 (maneuverable bombing target), NO-190 (blimp bombsight: now Mark 24), NO-191 (bombsight presetting computer), NO-216 (rocket sights: now RS Mark 2 and RS Mark 3, and computers Mark 35 and Mark 36), AN-4 (low altitude bombsight; BARB: now BS Mark 23), NA-168 (slant range computer), NO-242 (range-type torpedo director), NA-232 (Razon attachment for TA3 trainer), and NO-265 (pilot's universal sighting systems: now AFCS Mark 3). With the Army, we have dealt most directly with the armament laboratory (ATSC) at Wright Field, as well as with Langley Field, Foster and Matagorda Fighter Fields, Dover Air Base, and other installations. The Army projects have been AN-4 (low altitude bombsights), AC-36 (CRAB guided bombsight), and AC-121 (rocket sights). In the case of both Services, a good deal of work, both concrete and of an advisory nature, has been done under no official project whatsoever. Thus, in connection with projects which were related to those for which control numbers had been assigned to us, the writer was requested by BuOrd of Navy to advise directly on certain projects placed with Navy contractors. Instances include Specialties, Inc., at Syosset, New York, and Polaroid Corporation in Cambridge, Massachusetts.

CONTRACTORS

First, with regard at least to groups under contract to NDRC Section 7.2, it is well known that in general all organized technical pursuits under NDRC direction are set up through the facilities of such contractors. The present writer has had most to do with the contract (OEMsr-330) at The Franklin Institute in Philadelphia, where a major portion of the section's airborne fire control developments have been conducted. The research group here has been built, with considerable assistance and molding by the section, from a nucleus of four engineers to a staff of several score technical personnel, augmented somewhat by the staffs and facilities of several subcontractors. Laboratory, office, and drafting space have been prepared and occupied gradually as needed. Sharing such facilities as experimental, computing, drafting and model shop, the project staff blossomed horizontally into groups devoted to torpedoing, bombing, gunnery, rocketry and integrated equipments. The heads of these groups reported to the coordinator for

the contractor, who has been R. H. McClarren. Guidance in technical policy and project planning has been given by the section staff through the agency of a steering committee which was formed rather early in the history of this contract. McClarren served this committee as nonvoting secretary, and the remainder of the members was constituted of S. H. Caldwell (ex officio), A. L. Ruiz, H. C. Wolfe, E. G. Pickels, and until recently J. B. Russell, with the present writer as chairman. Aside from his existence in the latter capacity, however, the writer was also held responsible for a specific number of developmental projects as such. Although in connection with such projects he owes much to specific personnel at The Franklin Institute, mention of the numerous men thus concerned will be reserved for the more detailed and relevant portions of the report.

In connection with a contract undertaken for Section 7.2 by the Stanolind Corporation in Tulsa, Oklahoma, the writer was given surveillance of the development of a mechanical pursuit-collision course plotter, proposed by M. Alkan of Specialties, Inc., for assistance in the design of a Navy dive bombsight. Principal contact at Stanolind was with D. Silverman.

Through a contract with Columbia University, at the Marcellus Hartley Laboratory, the section conducted electronic projects under J. A. Balmford and J. R. Ragazzini there. As was the intent, such work largely served and supplemented that in progress within the larger group at The Franklin Institute, and covered certain servomechanism developments as well as simulative endeavors. In addition, however, electronic simulative studies were conducted on steered projectiles for projects being pursued by Section 7.2 in collaboration with Division 5. This branch of the contract was taken under the direct sponsorship of Division 5 in the summer of 1945 and was placed within a contract with Specialties, Inc. The reader is referred to Chapters 4 and 8.

Under contract to the section, The Bristol Co. has also contributed to researches at The Franklin Institute, and through the services of C. A. Mabey, A. W. Jacobson, and G. M. Thynell has aided in the preparation of special mechanical linkages for components of computing sights under development.

The writer has had considerably less to do with the others of the section's contracts, which include those at General Electric on B-29 computers, at Northwestern University on assessment methods, at University of Texas on gunnery evaluation, and at Jam Handy Corporation on vector sights, etc.

With several of the other contractors of Division 7, highly beneficial cooperation has been indulged in on projects of mutual interest. Through the provision, by Section 7.3 for example, of certain facilities of Lawrance Aeronautical Corporation, Linden, New Jersey, the design of pneumatic components has been greatly furthered on our Navy projects. Facilities also of Eastman Laboratories in Rochester have similarly been made available, under the stewardship and incentive of E. J. Poitras and J. F. Taplin of Section 7.3. An earlier example of such collaborative effort on pneumatic instrumentation, which resulted ultimately in bombsight Mark 23, involved the McMath-Hulburt Observatory at Lake Angelus, Michigan.

Far too numerous for exhaustive tabulation are the contractors of NDRC divisions other than Division 7. However, the Radiation Laboratory at the Massachusetts Institute of Technology [MIT] must be mentioned as being involved in several connections, in connection particularly with the provision of automatic plane-to-plane and plane-to-ground ranging equipment. Tangible help on a variety of problems has been received from many of the staff there. We mention also the California Institute of Technology, under Division 3, in connection with rockets, where C. C. Lauritsen, W. A. Fowler, C. G. Anderson, and others have rendered assistance. With that portion of the Bureau of Standards under Division 4, we have dealt profitably with W. B. McLean on toss-bombing studies. The contractors of Division 5 have been concerned, both through interdivisional collaborative arrangement, and by the writer directly as consultant to that division; these dealings are reported jointly since separation is not feasible. Such contractors include:

Gulf Research and Development Co. in Pittsburgh, where we have cooperated on guided bomb controls with E. A. Eckhardt, R. D. Wyckoff, and J. P. Molnar among others; RCA Laboratories (Zworykin) at Princeton in connection with television for homing bombs; Douglas Aircraft in Santa Monica, where W. B. Klemperer, E. W. Wheaton, and many others were extensively cultivated with regard to the ROKH projectile in its several phases; L. N. Schwien Engineering Co. in Los Angeles, with L. N. Schwien and H. A. VanDyke on stabilization and other control techniques; and Bendix Pacific Division in Hollywood, with W. S. Leitch on radio links.

Special mention must be made of the Applied Mathematics Group at Columbia, under contract to the Applied Mathematics Panel [AMP] of NDRC. Incalculable aid has been received from this group, with which we have worked quite closely on several fire-control projects. The notables include S. MacLane (Director), H. Whitney, H. Pollard (the two latter having had local office headquarters in the writer's office in Cambridge), I. Kaplansky, L. C. Hutchinson, and D. P. Ling. Particular operations thus valiantly served were rocket sights, toss-bombing equipment, and pilot's universal sighting systems; relating to Service projects NO-216 and NO-265. Certain other groups under AMP were similarly useful, though as it happened in less major connections.

In connection with researches on controls for guided bombs the differential analyzer at MIT has been made available for an extensive study of controlled trajectories in two and three dimensions. Engaged at first through the contractual machinery of Division 7, and later through that of Division 5, this facility made possible an articulate numerical treatment of a problem which could not otherwise have been handled without years of computation by a large staff expertly led at every point. The staff of this analyzer, as of the Center of Analysis itself at MIT, contributed mightily in this work.

Wherever, in the present report, the writer refers to "our laboratories," this impropriety should be interpreted as a manner of speaking, which has arisen out of habit, rather than in a precisely literal sense. The laboratories of The Franklin Institute contract are most likely thus to be connoted, and perhaps, even those at Columbia. The possessive pronoun is a consequence of the part the section has played in building up such facilities and in organizing the research which has been pursued.

FORM AND REFERENCES

The monographic form for this report, with its set of sub-monographs on the separate techniques and fields of endeavor, was chosen by the writer out of his personal preference for a unified literary entity. It should be possible, however, to separate, discard, or reassemble the various parts hereof in whatever manner appears desirable to suit a larger need. No details are here bodily reproduced which are available elsewhere, although brief outlines of such fuller material may be categorically included in reference to related topics.

Certain of the writer's own contributions, in either theoretical branches or concrete mechanism, may here be found discussed with an apparently unwarranted emphasis. In such cases the reason for such treatment is that documentation of these items is not likely to be found at other sources, or may there be but baldly referred to.

A serious attempt is made to give proper credit and to make equitable references to original enunciations and reductions to practice. If this is imperfectly achieved, it is without malice. Contractor's reports are referred to liberally, but more thorough search of these is indicated for the details of any given aspect which may later become significant. Writings of such collaborating mathematicians as H. Whitney and H. Pollard (of AMG-C) are voluminous and frequently contain definitive documentation of methods and components which we have been too eager to build and try, in contrast to the compulsions of our manifest duty to disseminate.