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DEVELOPMENT OF AIRCRAFT GUN TURRETS IN THE AAF 1917-1944

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ARMY AIR FORCES HISTORICAL STUDIES: NO. 54

DEVELOPMENT OF AIRCRAFT GUN TURRETS IN THE AAF

1917-1944

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Air Historical Office
Headquarters, Army Air Forces
June 1947

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This study on the evolution of aircraft power-operated gun turrets surveys the major factors influencing the development of aircraft armament, the prevailing policies regarding armament, the basic assumptions concerning fire power, the organizations responsible for the development of aircraft armament, and the resources in men, funds, and experience available to those organizations. It is not an engineering study; rather it is an appraisal of the evolution of power turrets. The development of fire power policy was of crucial importance, for once the concept had been accepted, there was almost no limit on the refinements possible.

The following calendar should enable the reader to follow without confusion the shifting nomenclature of organizations which appear in the text:

- 1919 - 1926 Engineering Division, Air Service, at McCook Field with representative in Washington office.
- 15 October 1926 Materiel Division, Air Corps established at Wright Field; Liaison Section at Washington.
- 2 October 1939 Chief, Materiel Division moved to Washington; Assistant Chief established at Wright Field.
- 9 March 1942 Materiel Division, Washington redesignated Materiel Command; Wright Field office redesignated Materiel Center.
- 29 March 1943 Washington office became Assistant Chief of Air Staff, Materiel, Maintenance, & Distribution (AC/AS, MM&D); Materiel Center at Wright Field redesignated Materiel Command.
- 17-19 July 1944 AC/AS, MM&D redesignated AC/AS, M&S; Office of Director, Materiel & Services established with headquarters at Patterson Field. The Director, M&S was responsible to AC/AS, M&S, Washington, and he had jurisdiction over Air Service Command, Patterson Field and Materiel Command, Wright Field.
- 31 August 1944 Materiel Command, Wright Field and Air Service Command, Patterson Field combined and redesignated as Air Technical Service Command (ATSC) with headquarters at Wright Field.

Since this study is concerned primarily with the evolution of the basic principles and earliest working models of aircraft turrets, the contributions of the Proving Ground Command to subsequent engineering

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refinements are not reflected here. The directive of 1 April 1942 establishing the Proving Ground Command at Eglin Field required that agency "within the limits of available facilities and priorities" to undertake such tests "as may be requested by the Commanding General, Air Forces Materiel Command." Yet its primary concern was with tests from the point of view of the combat crews who would ultimately use the equipment rather than from the technical viewpoint of the Materiel Command, and it sought repeatedly to avoid experimental and developmental work. Consequently its influence in the initial research phase was minor in comparison with that of the Materiel Command.

It might be noted, however, that of a total of 1,433 service tests activated at Eglin Field from 1940 to 1 July 1944 by the Proving Ground Command and its predecessors, 379 dealt with aircraft weapons and related equipment. A number of modifications which made the original equipment suitable for combat use--the Briggs retractable ball turret and Bell tail turret on the B-17 and the Emerson ball turret and Southern Aircraft Corporation tail turret on the B-24, for example--were recommended by the Proving Ground Command.

The chief emphasis in this monograph is on the research and development of those aircraft gun turrets which actually saw service in combat. Because of the inevitable time lag between the first experimental models and quantity production, most of the story deals with the years prior to 1943. By that date the basic problems of turret design had been solved.

The monograph was prepared in the ATSC Historical Office by Capt. Irving B. Holley, Jr. Readers familiar with the subject matter are invited to furnish the Air Historical Office with criticisms.

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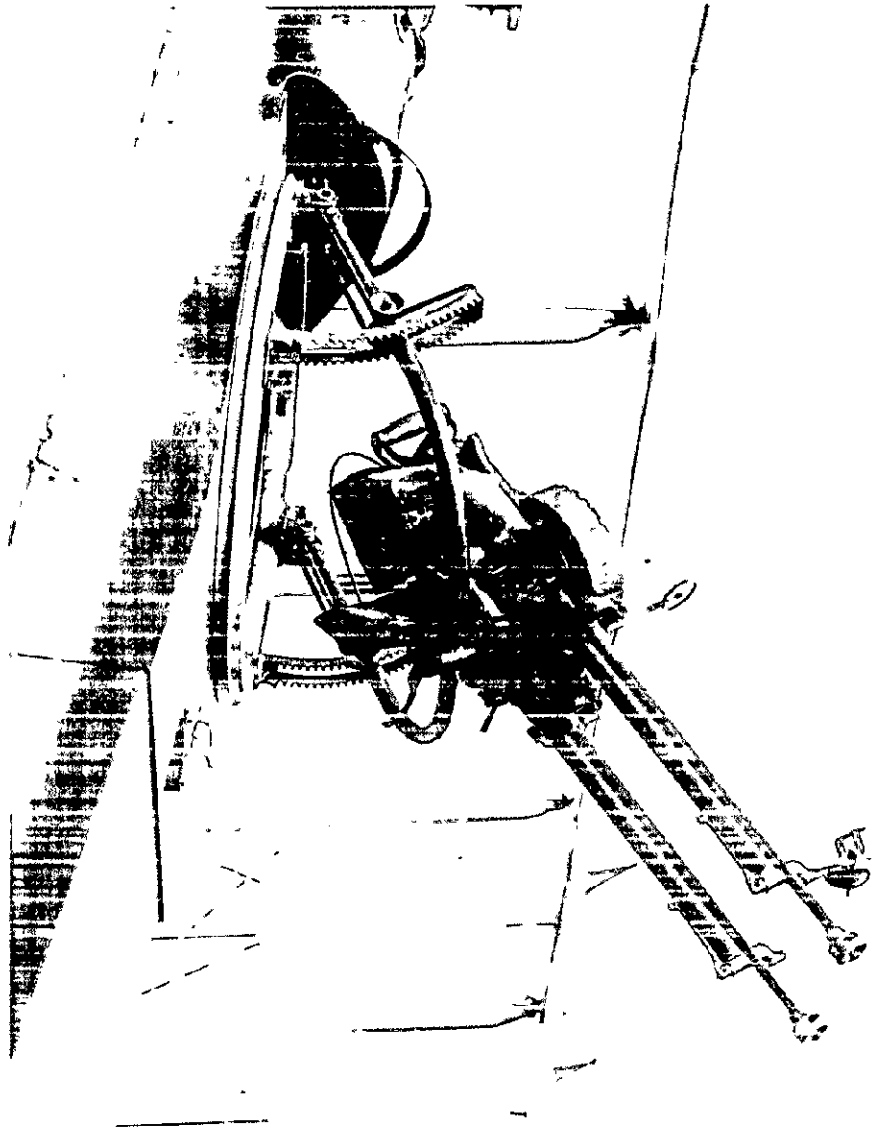
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Development of Aircraft Gun Turrets in the AAF, 1917-1944

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Modified Scarff ring installation mounting twin
Lewis guns. Note the elastic-cord elevation ad-
justment compensation device. 1920.

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Chapter I

TURRET ORIGINS, 1917-1939

The French called it a tourelle, the British called it a Scarff ring, and the Germans had still another name for it, but all were simply variations of the same thing, an ingenious ring mount perfected in England by Warrant Officer Scarff of the Royal Naval Air Service. By the end of World War I this ring, in one of its several modifications, was everywhere the accepted standard mounting for flexible aircraft machine guns, and increasingly the word "turret" came into general usage to describe it.

The earliest World War I turrets usually consisted of circular plywood tracks slotted to carry forked machine-gun adapters riding on hardwood casters. They were cumbersome and unmanageable; the wood warped and bound with every flexing of the aircraft fuselage: and manipulation, even at the laggard air speeds of that day, was complicated by the fact that the gunner never had enough hands to perform the many operations involved in training his guns. The major objection to these early turrets, however, grew out of the difficulties encountered in bringing guns to bear on elusive aerial targets. Attacks from above left the gunner kneeling in his cockpit, while attacks from below found him climbing to his seat to sight over the plane's edge.

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The Scarff mount, with its adjustable elevation attachment counter-balanced by elastic shock cord and its backrest rotation assistor, overcame many of these difficulties. By the end of the war Allied aircraft were using twin Lewis guns in Scarff rings perfected sufficiently to permit firing a single off-center gun without adverse slewing effect, and French manufacturers were turning out machined-aluminum turrets differentiated in type between nose and tail. But even these technical advances were recognized as unsatisfactory at the time of the Armistice, and commentators summing up the lessons of the war were specific in their warnings to the future. Officers with war experience repeatedly stressed two imperative requirements: first, to devise some means for overcoming the effects of high-speed slipstreams upon flexible guns; and second, to perfect a satisfactory method of covering the lower quartersphere behind the tail with protective gunfire.

From the end of the war onward, Army spokesmen declared that the high speeds of modern airplanes made manual operation of flexible guns almost an impossibility,¹ and as early as 1923 a French air officer from the Centre d'Études de l'Aéronautique predicted that the practical difficulties of constructing a mount to overcome the adverse effects of slipstream would lead eventually to electrically operated turrets.² These same analysts were equally emphatic in discussing the second problem, tail fire coverage. One said, "The experiences during the

-
1. Lecture by H. O. Russell, 23 May 1921, in AF Lib., D70/71.
 2. "Aircraft Armament," 22 Aug. 1923, by Capt. Dagnaux of the Centre d'Études de l'Aéronautique, France (translation; hereafter cited as Dagnaux, "Aircraft Armament"), in AF Lib., D70/18.

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latter part of the war have pressed home the need for another type of flexible gun installation to protect the region beneath the fuselage and under the tail. During the war this was the favorite region for the enemy to attack from."³ Others predicted that 1918 versions of lower guns sighted from the upper turret by means of tracers would be replaced with remote control systems for tail cone coverage.⁴

The patterns for future development had been well defined, but difficulties in the way of a practical realization of these goals were far from few. To begin with, American turret manufacturers had hurried off to a false start producing ring mounts designed on earlier single-gun versions which were obsolete by the end of the war. American mounts on DH-4 airplanes arriving in France were found to be inadequate, and French mounts had to be substituted for them. It was reported that there was nothing inherently wrong with the American products; they simply were not strong enough to bear the weight of twin Lewis guns.

The relatively unlimited productive capacity of American manufacturers was canceled out either by a lack of up-to-date technical intelligence or an inability to maintain a sufficiently flexible modification system.⁵ It is not surprising that aircraft armament development dropped back to a walk after the Armistice. The manufacturers most likely to produce innovations were turning out obsolete equipment at the end of the war, and exactly one year after the Armistice only two

3. Lecture by H. O. Russell, 23 May 1921.

4. Lagnaux, "Aircraft Armament."

5. Chief, Tech. Sec., LRF to Dir., AS, 18 Nov. 1918, in WF Lib., D72.11/33.

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commercial firms were working on government contracts in aircraft armament accessories. Consequently, the burden of development fell almost inevitably upon the Air Service's Engineering Division.⁶

With respect to the problem of slipstream, an AEF report of November 1918 which described the deficiencies of American ring mounts was accompanied by drawings of a French-designed wind compensator which was recommended for production, since only with great difficulty could an observer handle twin Lewis guns at high altitudes and high speeds. Although this recommendation came from the front and carried with it the moral authentication of combat service, the wind compensator was actually little more than an experimental model without adequate service testing to approve it.⁷ Acting on the recommendation, however, the Air Service spent most of the next 10 years perfecting a wind-compensating mounting ring.

Wind compensators took many forms, although all were but variations of two basic principles. One, the wind vane system, counterbalanced the effects of slipstream on the gun muzzles by mounting vanes or rudders projecting from the opposite side of the ring. The other system, an arrangement of springs within the structure of the ring, attempted to neutralize all drag on the guns by mechanical tension. Variations on these two themes were actively considered almost down to the very eve of World War II.

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6. List of manufacturers producing aircraft materiel on government orders, 21 Nov. 1919, in AF Lib., G13/7.
 7. Dagnaux, "Aircraft Armament."

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The preeminent factor adversely affecting aircraft armament in the early 1920's was the formal adoption in 1923 of aircraft type specifications, a move toward standardization which led a McCook Field armament lecturer to say: "By this means all design peculiarities incident to varied manufacturing sources have been eliminated."⁸ It is true that a large measure of standardization was achieved, but the policy of eliminating "design peculiarities" stultified creative development at its origin, and for a dozen years aircraft manufacturers showed little or no ingenuity in offering novel armament installations.

Innovations in flexible gunnery seemed anathema to the Air Service. A patented power drive submitted to the service by its inventor was rejected by the Chief of the Armament Section because it was excessively heavy, because it was difficult to maintain in view of its unusual number of parts, and because "It is power driven, which seems unnecessary in a device to carry machine guns for defensive purposes."⁹ The power turret seemed to be almost sedulously avoided.

To appreciate official skepticism of unusual ideas, however, it is important to realize that the Air Service was almost constantly besieged with a bizarre array of patented devices which the inventors confidently claimed as the source of certain salvation and the solution of all armament problems. For example, there was the fierce "converging-diverging" gun mount which, the inventor assured all comers, would trap an attacking

8. "Aircraft Development since the Armistice," lecture prepared for AS Reserve Officers, McCook Fld., rev. 6 June 1923, in AF Lib., C50.02/18.

9. Chief, Arm. Sec. to Chief, Eng. Div., AS, 2 May 1923, U.S. Patent 1,451,197, in AAG 473.5.

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plane in a circle of fire when a series of whirling machine guns were directed at it in ever lessening concentric circles. This ballistic monstrosity was brushed off by the Air Service after being given a fair test, but the Navy's Bureau of Ordnance, distrustful of the Air Service, requested the mechanism for further independent testing.¹⁰

The years immediately following the war produced a number of patents and inventions pertaining to flexible gunnery, but none was revolutionary. An Italian manufacturer offered a three-gun post mount with a compensating seating arrangement, a Frenchman patented a remote control system using pulleys and cables, and an American offered an improved wind vane compensator; but none represented really substantial changes over the technical advances achieved at the end of World War I.

The standard Air Service mount on postwar equipment was a 26-pound ring described as an "adaptation of the English Scarff type based upon previous French types." It had a compensator designed to counterbalance twin Lewis guns, holding them in equilibrium against the slipstream for all angular positions of the revolving ring throughout a speed range of 100 to 160 mph. Air Service tests demonstrated that a force of 52 pounds was necessary to move the guns broadside to the slipstream at 100 mph. At 160 mph, 106 pounds were required. The compensator spring and gear system was so arranged that it reached maximum compression when moving with the wind to the tail and utilized this tension to an advantage of

10. Chief, LuOrd to Chief, no, 2 March 1922, in ibid.

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some 80 pounds when moving in the opposite direction against the slip-stream.¹¹ The practical limitations of such a device were obvious; but as long as the problem of flexible gunnery was considered in terms of foot-pounds required for operation rather than essentially one of smooth tracking and sighting, the wind compensator promised to be an effective solution to the turret problem until airplane performance climbed considerably beyond air speeds then current.

Early in 1923 the Third Attack Group at Kelly Field, Texas, submitted a long, detailed equipment report to the Engineering Division proposing various improvements and suggesting lines of development inspired by the group's extensive operational training exercises. Among other items, the Third Attack Group reported that the service as a whole needed a turret mount which could be operated with speed and comfort inasmuch as the existing type required tremendous exertion on the part of the gunner even to move the turret slowly. The group further reported, confirming earlier opinions, that experiments clearly indicated that remote mounts depending upon tracer for sighting were a waste of ammunition.

The Engineering Division at McCook Field maintained that tracer-sighted, remotely mounted guns were practicable and revealed that it was currently considering a 125-lb., motor-driven mount for a flexible .50-cal. machine gun. No expenditure order was ever drawn for this installation, however, so apparently it remained in the discussion stage. Experiments of this nature were almost inevitably assured of shelving,

11. Armament, US Tactical School, Langley Fld. course outline, 1924-25, p. 41, in AF Lib., D70/32.

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not so much because of an unprogressive or conservative attitude on the part of the division, but rather as a result of the limitations of the day. Engines of 400 hp curtailed most armament developments to theoretical projections of installations "available for use should an airplane ever be evolved capable of carrying the load."

The Engineering Division was enthusiastic about the Third Attack Group's suggestions as a whole, however, pointing out to the Chief of the Air Service that such a report illustrated the "great value to the Engineering Division of the interchange of requirements and ideas made possible by reports of this nature," and complained that in the past there had been too few such reports from tactical organizations actually using the equipment developed by the division. "In fact," the division's indorsement continued, "there has always been a feeling . . . at the Engineering Division that it was rather difficult to find out exactly what the service desired in the way of equipment."¹²

The difficulties of correlating tactical requirements with Engineering Division activities were further complicated by the prevailing lack of skilled Air Service technicians whose detailed criticisms might be expected to provide the division with a working basis for perfecting existing equipment and planning novel installations. The Third Attack Group cited the need for trained armorers and armament officers and indicated the difficulties encountered in performing satisfactory service tests on armament equipment without them.

12. Chief, Eng. Div., McCook Fld., to Chief, AS, 30 Oct. 1923, with comments on Report of Operations of Third Attack Group, Kelly Fld., in AF Lib., 152.1/149.

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The whole problem of armament officers was discussed in the Langley Field Air Service Tactical School in 1924. The school's course outline held that a good armament officer "like a good engineer officer should be alert to anticipate and avoid breakages and failures" and should have a desire to investigate failures personally. "Too frequently," the outline candidly proclaimed, "this latter qualification is overlooked, and an officer is made an armament officer chiefly because there is nothing else he can do."¹³ If this blunt statement were entirely true, it would in itself explain the noticeable postwar slump in flexible gunnery as compared with fixed gunnery.

The primary interest in fixed gunnery, however, probably grew out of two more positive factors. To begin with, the prevailing custom of using commissioned pilots in fixed-gun pursuits and enlisted gunners at bombardment flexible-gun positions would almost undoubtedly place the emphasis of interest upon fixed gunnery. Beyond this, such attention to fixed gunnery was virtually assured by the accepted policy of requiring all armament officers at the group and squadron level to be rated pilots. The tactical school expressed the prevailing line of thought in saying, "Experience has proved that best results can be obtained only when this important staff officer has the flyer's point of view." This no one would dispute, but the argument continued: "For this reason it is held that the primary qualification for a squadron or Group Armament Officer is that he be a pilot." There was no widespread acceptance of the later practice of commissioning nonpilot flying

13. Armament, Air Tactical School course outline, 1924-25.

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personnel for bombardment duties, and the term "flyer" was accepted as synonymous with pilot. This apathy toward flexible gunnery is further substantiated by a report in 1927 of aerial activities at Fort Crockett, where "a very keen interest in fixed gun practice was displayed by the students of the School Group and only a mild interest in flexible gunnery."¹⁴

Another index to the trend of armament interest is found in the armament course at McCook Field, which devoted only 9 hours in 1926 to small arms, machine guns, flexible mounts, sights, and accessories, and 27 hours to fixed-gun installations.¹⁵ The Wright Field Engineering School armament course between 1928 and 1930 devoted three-fifths of the allotted time to bombs and bombing, one-fifth the time to the entire subject of machine guns and machine-gun mounts, and an equal time to pyrotechnics! The proclaimed object of the course was to instruct the class in standard aircraft armament and "to show the necessity, if any, of improving present standard equipment."¹⁶ Flexible gunnery seemed to have become the Air Service's stepchild despite the lessons of World War I.

However, it is important not to lose sight of the limitations of the day when considering the evolution of the turret. In 1928 the Bombardment Board recommended the procurement of a new experimental model twin-engine bomber capable of carrying a 1,200-lb. bomb load and a crew of three at a speed of 160 mph in a 150-mile operating radius.

14. Chief, Arm. Br. to Chief, DCS, 29 Nov. 1927, in AIG 473.5.

15. "Aircraft Armament," McCook Fld. course outline, 1926, in WF Lib., D70/80.

16. "Armament Course Outline," AC Eng. School, Wright Fld., 1928, in WF Lib., D70/90.

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Within the performance limitations of such an airplane, the contemporary armament development does not seem so retarded. The same board that made the recommendation mentioned above considered the existing service ring mount as "definitely unsatisfactory" and tending to become more unsatisfactory with increasing bomber speeds.

Two flexible mounts, the D-6 ring, a variation of the spring compensated type, and the A-3, a post mount with a ball and socket connection, were developed in the late 1920's for service testing; but the Bombardment Board's report did little more than repeat the old theme: "A more satisfactory flexible gun mount is necessary for the purpose of increasing maneuverability of the guns when operated in the slipstream."¹⁷ This annually reiterated plea had reverberations elsewhere.

In 1928 an Ordnance Department officer, Capt. H. C. Coupland, who was to become Air Ordnance Officer on General Arnold's staff in World War II, surveyed the aircraft armament problem in an unpublished magazine article which questioned the wisdom of the Air Service's over-all concept of fire power. After World War I, Coupland had been chief of the armament organization at McCook Field when aircraft armament was still an Ordnance responsibility. When the Air Corps took over this responsibility, Coupland stayed on as a liaison officer between the Air Corps and the Ordnance Department, and it was in this capacity that he prepared his article. "Bombardment policy," the article maintained, "gives secondary consideration to protective armament," which is the "truly

17. AC Tech. Rpt., "Armament Equipment on Bombardment Airplanes," 3 April 1928, in AF Lib., D70/88.

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military phase of aeronautics, and the actual personnel allotted to carry on the development of this work is extremely small; assistance from the commercial world is negligible; creative interest is needed."

The article was never published. The Chief of the Technical Data Branch at Wright Field, Ohio, felt that it was poor publicity for the Air Corps. "The subject is not treated in a sympathetic tone from the aircraft viewpoint; his treatment of Air Corps armament disposition is critical." Being critical was, of course, exactly what the author intended, and as a result, Maj. Leslie MacBill, Chief of the Experimental Engineering Section, ordered the article withheld from publication and retained for circulation within the office where, he said, the question of aircraft armament policy rightly centered.¹⁸

Throughout the early 1930's Wright Field personnel pressed the search for a satisfactory aerial gun mount. A number of solutions were proposed, some to be rejected immediately, others to be developed to the testing stage. Several truck and track rotary mounts were tried with varying success; the expedient of mounting a single gun on either side of an open cockpit was rejected on the basis of excessive weight, while center post mounts failed because they imposed such a restricted field of fire. A swivel arm mount which gave wide freedom of motion seemed to offer most promise and was marked for development.

In an attempt to overcome the evils of slipstream, a machine manufacturer submitted a working sample of a flexible gun mount driven

18. "Aircraft Armament; U.S. Army Developments," by Capt. R. C. Coupland, Jrd. Lept., Aug. 1928, unpublished article, with correspondence and inds., in AF Lib., D70/91.

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by two sets of manually operated worms and gears through a wide field of fire. The Armament Branch tested this apparatus in flight with an aerial camera which proved that the cumbersome gear train made it almost impossible for a gunner to track his target. The mount was returned to the manufacturer, and the Armament Branch recommended that "no further consideration be given the investigation of remotely controlled flexible guns."¹⁹

Armament Branch studies of possible power drives for turrets, including electric motors, wind turbines, and engine gear trains, led to the conclusion that a "design of such principle could easily be made" but "any action of a flexible gun depending upon movement of a train of gears would be slowed down, and would lose its flexibility to a measure that it would handicap the gunner, hampering him in what approaches almost instantaneous changes of position as required of the gunner in the present stage of aerial gunnery."²⁰

If a solution to the problem of overcoming slipstream was slow in coming, consideration of protective coverage in the area beneath the tail was equally troubled. Primarily, this was a question of aircraft design, and armament development in that respect could not progress apart from aircraft evolution. As early as 1923 the Handbook on Airplane Flexible Gun Mount and Accessories pointed out that "shooting through the floor of the cockpit is influenced greatly by the design

19. AC Tech. Rpt., "Test of flexible gun mount, remotely controlled," 11 Feb. 1931, in AF Lib., Doc 12 w/3405.

20. AC Tech. Rpt., "Study to determine possible advantages and development of mounting machine guns flexibly on various principles of mounts," 19 Nov. 1929, in AF Lib., Doc 12 w/3170.

of the airplane; hence it is practically impossible to obtain a mount of this type which can be used universally on airplanes of different design."²¹

The Bombardment Board, considering the Boeing XB-9 in June 1931, noted that the type specifications called for a floor gun, which had been taken into consideration by Boeing; but the board felt that since the under area could be "fairly well covered through depressed fire on account of the relatively narrow fuselage dimension together with the fact that serious structural difficulties would be encountered because of the monocoque design employed, this idea was dispensed with."²²

The floor gun mount of the 1930's generally took the form of a swivel clamp mounted on the edge of a rectangular opening constricting the field of fire to a relatively limited zone, but experimental work was under way at Wright Field projecting several lines of potential development. One version of a lower gun proposed a sliding seat mount hung below the fuselage and retracted by springs; while another, a rotating tank mount, extended a metallic cylinder below the fuselage by a system of springs as in the first version with the additional feature of shielding the gunner from the slipstream, but only so long as the gunner fired aft. It was proposed to assist the rotation of this mount by raising semaphore-shaped vanes on one side or the other.²³

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21. Handbook on Airplane Flexible Gun Mounts and Accessories, McCook Fld., Nov. 1923, in AF Lib., D72.11/25.
 22. TEC Memo Rpt., 24 June 1931, in Am. Lab. File, Boeing Y1B-9 Contract AC-4537.
 23. AC Tech. Rpt., "Study of method of mounting a floor gun in a bombardment airplane," 10 Dec. 1930, in AF Lib., Doc 12 w/3355.

In 1931 the Materiel Division was concerned over the fact that no extended firing tests had been conducted to determine the effectiveness of floor gun mounts in covering the lower rear quartersphere. The division chief reported to the Chief of the Air Corps that with the exception of an experimental retractable platform designed and installed, no great amount of development work had been devoted to the project. A flurry of indorsements stirred up by a testing directive, issued after the Materiel Division's pessimistic report, revealed that the Service had comparatively little to offer the Materiel Division in the way of novel or useful suggestions.²⁴

Parallel with the trend of development in bombardment defensive fire, and actually a part of that development, was the question of transition from caliber-.30 to caliber-.50 machine guns. Plans to utilize the caliber-.50 were continuously active at Wright Field but received a low priority "because of the urgency of more important development work."²⁵ The quarterly test of airplanes with full military equipment, as required by the General Staff, was to be conducted in 1933 with bombardment airplanes carrying one flexible aircraft machine gun, caliber-.50, Browning, in the rear gunner's cockpit "for each third bombardment airplane," but at the time there were no available flexible mounts for flexible .50's and no .50's in stock.²⁶ In 1933 the Materiel Division listed as standard the D-6 ring mount with elevation clasp lock and azimuth crank and pinion. Similarly classified were all such old

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24. Chief, MD (WF) to J/AC, 6 July 1931, with inds., in ibid.
 25. Chief, MD (WF) to C/AC, with inds., 10 March 1933, in ibid.
 26. Memo, Chief, Materiel Liaison Sec. to Exec., AF, 15 Feb. 1933, in ibid.

Type A rings with elastic exerciser cord elevation counterbalances as remained in stock.²⁷ The art and practice of flexible gunnery had apparently advanced but little in the Air Corps from the time of the Armistice in 1918.

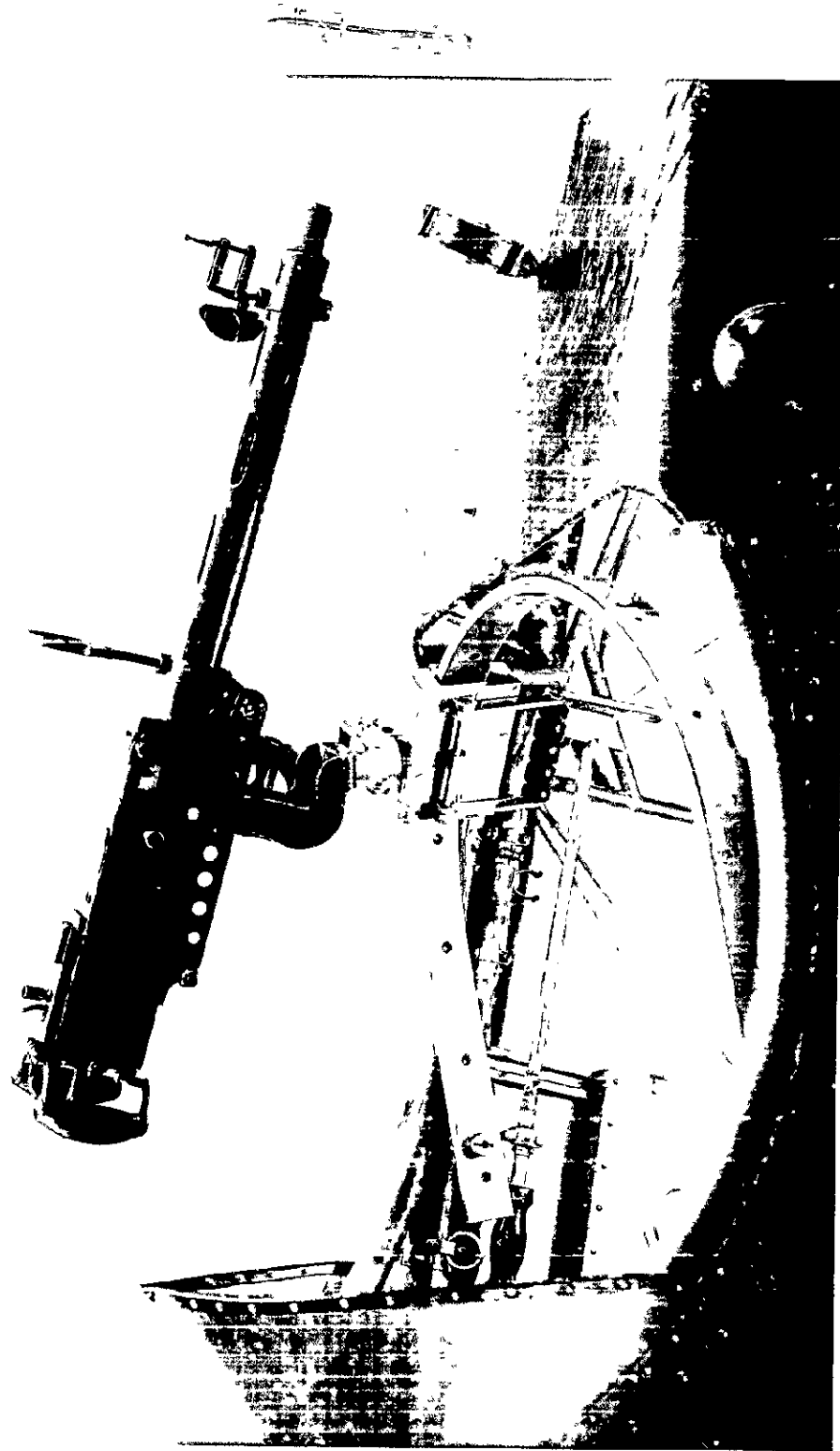
Any further consideration of Air Corps turret development would lack perspective without some indication of contemporary European policy and development of bombardment defensive fire power. A cursory survey of aircraft armament trends across the Atlantic reveals that bomber defense was the subject of much speculation by all the major powers, and in some cases extensive developments had been carried out with manufactured items.

In the Netherlands, Frederick Koolhoven, the aircraft manufacturer of Rijswijk, was quite certain that he had a revolutionary invention at his disposal when, in 1927, he filed a patent for an aircraft gun "rotatably mounted and revoluble by means of a source of mechanical energy controlled by the gunner," a turret said to be capable of rotation in azimuth speeds up to 130⁰ per second at an indicated airspeed of 160 mph. This confident inventor had not actually perfected his claim, but offered numerous solutions for the problem of a power drive, including a suggested propeller-driven flywheel equipped with a friction-clutch power take-off, a battery-supplied electric drive, a hydraulic drive operating from a hand-pumped accumulator pressure, and a whole series of pneumatic and gear train power systems.²⁸ Koolhoven's

27. LD, "Stocklist of Aircraft Combat Materials."

28. "Description of Koolhoven Mechanical Turret," by U. S. Military Attaché, France, Rpt. 13,122--., 14 Dec. 1927, in AF Lib., D72.11/57.

41026



A truck and track type flexible mount for a single cal. .30 machine gun. When the handle is pulled away from the box, a cam releases a locking mechanism, allowing the post mount to be re-positioned on the semicircular track. 1932.

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inventions quite obviously represented little more than drawing board wonders, but at the same time they did mark the trend of European interest. The 1927 Koolhoven patent conceived of the power turret as a rotating unit (guns, gunner, and mount), in contrast to the assisted motion flexible mount concept which persisted in many cases until the eve of the second World War.

In France turret development seemed to have progressed but little since World War I. Modified Scarff rings remained in use until the middle 1930's, when plastic domes appeared as windshields. Many experimental dome shapes were tried: the simple hemisphere such as that mounted on the Bloch-200, or the mushroom type of the Fotez-54, whose jutting edge permitted an increased downfire angle. Progress in dome development was delayed for a long time by the persistent use of twin Lewis guns, but the perfection of a reliable Browning permitted domes to develop with a single gun slot which could be sealed against the slipstream.

Early British experiments in sealing by Handley-Page favored zipper slot covers; but the trend of the future appeared with the Italian tri-motor bombers, which solved the problem by mounting twin guns on either side of the turret, with the gunner sighting through a panel between them. This, of course, raised the problem of optical distortions in sighting through the dome, but it offered a marked improvement over British unsealed dome slots, which required nose gunners to wear goggles and face masks for protection against the blast inside the dome.²⁹

29. "The Problem of Aircraft Armament," in L'Aerophile, translation by U.S. Military Attaché for Air, France, 23 Oct. 1936, in F Lib., D70/117.

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French aircraft armament in actual practice lagged far behind French invention. In the 1930's patents were issued by the French Government on a wide range of armament controls. In 1935 the French Hotchkiss Company patented some electric and hydraulic servo gun controls. In 1936 a L. Lincen patented an electrically driven lower ball turret with the gunner in an "embryo" position. The same patent covered the principles of a device to compensate for parallax in turrets remote from the sighting station.³⁰ In 1932 a French patent was issued on remote control systems employing vacuum tube circuits for position control by use of the balanced field principle utilized in Thyatron control systems; but despite the fact that such advanced principles of control were available, French bombers continued to appear with turrets little better than modifications of 1918 versions.

One representative French aviation publication, L'Aerophile, suggested in 1936: "We may some day see a lone gunner stationed in an isolated turret directing automatically and at long range" the fire of several guns. "Is it too premature to think of it," is it "really ridiculous as some have written"; the publication asked. This suggestion would seem to indicate, in the light of future developments, spectacularly long-range vision. The same publication suggested that turrets might eventually disappear entirely as the increasing speed of bombers restricted pursuit attack close to the bomber's axis of flight.³¹

30. French Patents: Hotchkiss, 789,778, 6 Nov. 1935; and Siemens, 800,959, 23 July 1936.

31. "The Problem of Aircraft Armament," in L'Aerophile, pp. 8, 11.

In Germany, the American Military Attaché for Air reported in 1935 that German flexible gun mounts followed the universal standard of hoop rings and spring compensators, but provided a web sling seat and wooden floor track to increase the gunner's maneuverability. The attaché even went so far as to suggest that the German Air Ministry might be approached in an effort to buy a sample for test at Wright Field.³²

A German writer, Fritz Hohm, reviewing the question of flexible gunnery up to 1935 in a lengthy study on aircraft armament, indicated a thorough understanding of the difficulties encountered in flexible gun operation under high combat aircraft accelerations³³ which made it next to impossible for a gunner to rise from his seat in a rapidly maneuvering plane.³⁴ Nevertheless, German aircraft designs reflected little interest in power turrets, although the Siemens Company procured a French patent in 1938 on an electric-drive nose turret.³⁵

In 1930 Gianni Caproni, the Italian aeronautical engineer, secured a British patent on the idea of defending bombers with a combination of top, tail, and lower retractable turrets.³⁶ This was no drawing board dream. The Italian Caproni Ca-73 and Ca-74 bombers were equipped with

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32. "Aircraft Armament and Accessories," by U.S. Military Attaché for Air, Germany, rpt. 14,384, 6 Dec. 1935, in AF Lib., G22.311/1.
33. "Acceleration" is a concept broader than "speed"; it covers not only mph, but also the implications of gravity loads, the bane of hand-held gunnery.
34. Die Laffen der Luftstreitkrafte, Fritz Hohm, 1935, translation by MD (AF), pp. 23-25, in AF Lib., D70/113.
35. French Patent: Siemens, 836,197, 5 April 1938. See also Deutscher Flugzeugbau Handbuch der Luftfahrttechnik, 1939, translation by MD (AF), 16 July 1940, pp. 259-75, in AF Lib., D70/142.
36. United Kingdom Patent: Caproni, 335,449, 25 Sep. 1930.

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upper and lower enclosed turrets, duralumin framework structures covered with celone sheets. The lower turrets were retractable and capable of azimuth rotation with a hand-crank chain and sprocket drive. The Breda L-20 and Caproni Ca-90 also sported manually operated turrets.³⁷

By 1937 the American Military Attaché for Air in Italy reported advanced models of power turrets in actual use on the majority of Italian aircraft. Earlier experiments with electrical drives gave way in favor of hydraulic systems with smoother tracking and an appreciable decrease in operating lag. Even the Caproni Ca-134 two-place observation plane carried a single-gun hydraulic turret, and experimental work was reported under way on hydraulic remote systems for position control of several guns from one sighting station.³⁸ Such developments, furthermore, were not confined to a single manufacturer. The Breda Ba-65 attack plane carried a hydraulic upper as did the Fiat B-11-20 bomber, which was reported as "in production" in December 1937. The Fiaggio P-32 and the Macchi Mc-99 were equipped with turrets providing hydraulic power for azimuth rotation only.³⁹ The imperial venture in Ethiopia had certainly not retarded Italian aircraft armament.

It would be a mistake, however, to assume that power turrets were being developed only in countries at war or under threat of war. As early as 1936 an American Naval Attaché reported from Sweden that

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37. "Free machine gun mounts used in Italy, etc.," by U.S. Naval Attaché, Italy, Rpt. 431, 31 Dec. 1930, in AF Lib., D72.11/71.
 38. "Brief Summary of Italian Aircraft Armament," by U.S. Military Attaché for Air, Italy, Rpt. 16,328, 23 Nov. 1937, in AF Lib., D70/123.
 39. "Detailed Report on Armament Installations in Italian Aircraft," by U.S. Military Attaché for Air, Italy, Rpt. 16,366, 14 Dec. 1937, in AF Lib., D70/124.

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Bofors had devised a turret which the attaché considered unique in that it moved both in azimuth and elevation under hydraulic pressure generated by a pump similar in principle to a Waterbury tool gear pump. A stick control on a four-way hydraulic valve gave simultaneous azimuth and elevation tracking.⁴⁰

In no country in Europe, perhaps, was so much activity displayed in the field of aircraft armament as in England. At the end of World War I the Scarff ring was in its sixth model, but far more important than the ring itself was the British application of flexible gunnery theory. Although the Russian Sikorsky bomber was the first to locate a Scarff mount behind the tail, the British soon adopted the plan on the Handley-Page V/1500 and laid the precedent for future British bomber armament trends. The 1922 Vickers Virginia and others, such as the Siddleley heavy bomber and the Kingston flying boat, tried various systems of nacelle gun mounts, but the Handley-Page precedent won out.

In 1930 the Bristol Aeroplane Company produced a bird-cage turret, a glass-enclosed upper dome mounting a single gun, manually rotated, and initiated the long course of turret development. In 1932 Bristol experimented with electric turret drives for nose and tail turrets but never perfected them because the friction-disc speed control incorporated in this design gave jerky tracking motion. The 1934 Bristol Army-Cooperation airplane was equipped with a hydraulic semiturret, or piston jack training assistor, which led the Bristol Company to utilize

40. "Development by Bofors Company," by U.S. Naval Attaché, Sweden, Rpt. R-725, 2 Dec. 1936, in AF Lib., D72.11/89. See also United Kingdom Patent: Bofors, 489,208, 21 July 1932.

hydraulic drives in the 1935 Bristol Bombay transport-bomber nose turret and in the 1936 Bristol Stenheim upper turret, in airplanes which introduced the succession of World War II Bristol aircraft.⁴¹

Early in the 1930's Vickers put twin Brownings in nose, tail, and upper positions on the original Wellington bomber, and Armstrong tried single gun turrets in the nose and tail of the Whitley, but neither proved satisfactory. In point of time, the British power turret appeared first on the 1934 twin-engine, biplane, Cverstrand bomber, which was equipped with a Doulton-Paul single Lewis-gun nose turret driven by compressed air, a system which permitted only limited periods of maneuvering with frequent rests for recharging the compressed air cylinders.⁴²

Power turret development appeared in England almost overnight. In 1933 Vickers obtained a United Kingdom patent on a retractable manual mount, a product scarcely divorced from the Scarff ring tradition, and the very next year a manufacturing concern, Petters, Ltd., took a United Kingdom patent on a hydraulic nose turret with a friction-disc speed control for use by a bombardier defending the nose position of a bomber.⁴³

Patent applications in the United States and Europe during the 10 years preceding the outbreak of World War II showed no end of fertile imagination in the conception of fire control systems; but while others

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41. United Kingdom Patents: Bristol, 545,459, 22 Feb. 1938, 510,538, 30 Oct. 1937, and 514,551, 9 Nov. 1936.
 42. H. S. Bourden, "Aircraft Gun Turrets, the Development of British Types for Aerial Ordnance," in Army Ordnance, March-April 1944, pp. 303ff.
 43. United Kingdom Patents: Vickers, 387,346, 1 Feb. 1933; and Petters, 436,071, 10 Sep. 1934.

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were patenting plans for projected mechanisms, British concerns were securing patents on basic units already in process of manufacture. In 1933 Boulton-Paul took a United Kingdom patent on a rotation axis bearing system for nose and tail turrets, avoiding the necessity of tooling the difficult and intricate ring gear utilized in most turrets. A combination hydraulic gland and slip ring assembly patent offered to interested inquirers a certain index of the trend in British turret development in 1934, when Boulton-Paul secured a patent perfecting a turret principle evolved earlier by Armstrong-Whitworth.

The Armstrong-Whitworth patent covered a turret ring which mounted a single flexible gun on a ring mount in a ball-shaped turret. The machine gun was so mounted that it was allowed a certain limit of free motion, movement beyond which closed an electric circuit and rotated the turret in the direction of training. A four-way switch made it possible to rotate in both directions for elevation as well as azimuth. Boulton-Paul utilized hydraulic valves instead of electric contacts. The valves were spring-loaded to return automatically to neutral with screw adjustment of the valve to "find" the correct neutral. In contrast to the electric version, the hydraulic turret provided speed variations which were simple functions of the degree of displacement in the control valve.⁴⁴

The contrast between British and American bomber defensive developments came into momentary focus in 1937 when the Air Ministry requested

44. United Kingdom Patents: Armstrong-Whitworth, 429,061, 29 Jan. 1934; Boulton-Paul, 431,714, 6 Feb. 1934, 436,069, 25 Jan. 1934, and 435,125, 23 Oct. 1934.

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detailed information of reported American turret developments in return for release of British technical information. The Materiel Division suggested an exchange in some other field inasmuch as no specific solution to the turret problem had been reached in the United States. When the British insisted, three drawings of the Glenn L. Martin B-10 manual nose turret were released.⁴⁵

Despite the fact that European development was generally far advanced over Air Corps practice in flexible gunnery equipment, the Air Corps repeatedly denied permission to aircraft manufacturers in the United States to export planes with near-standard ring or post mounts.⁴⁶ Apparently contemporary policy believed it wiser to prevent foreign nations from procuring obsolescent armament equipment than to favor and foster an aggressive and successful aircraft armament industry in the United States by encouraging sales abroad to warring nations.

In order to evaluate ^{the} Air Corps principles of fire power, it is necessary to visualize the trend of European development not only in terms of experimental projects in the turret field, but of the bombers actually developed as well. In 1935, according to a German survey of European bombardment aircraft, the six-engine Italian Caproni Ca-90 P carried six guns in five emplacements, including waist windows and lower turrets. The French Briquet 273 reconnaissance airplane perfected the slenderized fuselage technique so favored by the Germans to improve

45. Memo, Chief, Information Div., AG to Chief, MD (AF), 3 Aug. 1937, in Arm. Lab. File, Machine Gun Mounts 1937. See also AAG 473.5, reference 3 Sep. 1937.

46. AAG 473.5, 1926-37, passim.

tail cone fire coverage. The previously mentioned Loulton-Paul biplane, the Overstrand bomber, carried both an upper and a lower retractable turret. Twin-gun upper turrets with 1,000 rounds for each gun and twin-gun lowers with 800 rounds per gun were cited as acceptable installations.⁴⁷ Aircraft armament in the United States, evaluated against the background of the foreign developments represented by these installations, is discussed below.

47. Hohm, Die Waffen der Luftstreitkrafte, pp. 33-43, 298-301.

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Chapter II

BOMBARDMENT DEFENSE POLICY, 1932-1939

Any study of power-operated gun turrets for aircraft would be inadequate if it were limited to the purely technical aspects of the apparatus without reference to all those nonengineering factors which have been so important in the evolution of aircraft armament policy. Bombardment armament practice, the flight field organization and facilities, and the basic assumptions regarding fire power expressed officially in the years immediately preceding the outbreak of World War II in 1939—all these are matters of immediate concern in any attempt to understand the evolution of power turrets in the Army Air Forces.

In 1932 a forward-thinking Bombardment Board recommended that the entire bombardment directive be rewritten to bring bomber design into closer harmony with the realities of existing requirements. The board, including among its members such men as Maj. J. T. McFarney, Maj. Carl Spaatz, Maj. H. A. Dargue, and Lt. J. N. Walker, all of whom later became general officers in World War II, considered that any such revision would require a clear conception of the air force mission and the function of bombardment aviation in its relation to that mission. The board's report expressed itself emphatically: "Destruction of the

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enemy's means with which to wage war—primarily the mission of bombardment—is of paramount importance," and "the primary mission of the Air Force is to drive home the bombardment attack." This concept, relegating all other aerial functions to positions supplementary to bombardment, inevitably brought the question of defensive armament to the fore. The board's report initiated a questionnaire for circulation through the Air Corps to garner opinions to match the board's own suggestion that turrets be advised for twin guns fore and aft, each gun to carry 600 rounds of ammunition, while some form of lower turret or nacelle gun be devised to cover the sectors below and in the rear so that blind areas might be limited "as much as possible."¹

Questionnaires disseminated throughout the Air Corps on fields of fire, types of mounts, enclosures, and caliber of guns were returned to Wright Field with a variety of comments, the majority of which reiterated the need for turret enclosures. None, however, mentioned the need for power drives. A Langley Field officer even went so far as to favor abandoning the caliber-.50 entirely for some smaller caliber such as .25, believing that "clouds, bad weather, and darkness should offer the greatest protection."

The results of the opinion-sampling survey were so difficult to correlate that the Armament Branch at Wright Field preferred to depend upon a small board of competent officers rather than a general survey. It was recommended that the results of the armament questionnaire be

1. AC Board Proceedings on B-997, 1 Nov. 1932, in ATCS 334.7. See also Drum Board Rpt., 11 Oct. 1933, in AAG Bulk files.

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"held pending the issuance of new developments in machine gun mounts and accessories at which time a board be convened to adjudge their merits and render suggestions for future improvements."²

The difficulties attendant upon the development of aircraft armament were magnified by the fact that the structure of the organization charged with responsibility for the perfection of this armament was itself in a state of evolution. The exigencies of routine requirements coupled with a continuous turnover of personnel prevented or at least delayed the formulation of comprehensive policies regarding the procedure to be followed in correlating service needs with Wright Field experimental activity, and foreign developments with Air Corps practice.

In 1935 the Armament Branch was conscious of these limitations. Reviewing the current status of armament projects, the branch reported that development had been "restricted to improvement in design of specific items" and little attention had been given to whether or not the items of equipment, even in the improved condition, were "adequate to accomplish tactical functions" as revised by the performance of modern airplanes. The imperative need for a definite line of development and a clearer grasp of the necessity for evolving procedures within the Armament Branch had been recognized by the Materiel Division ever since General Arnold's reports from March Field in November and December 1934, when the whole subject of the tactical employment of bombardment aircraft was thrown open to question. However, any plans for extensive

2. AC Tech. Rpt., "Gun Mounting Arrangements," 10 April 1935, in AF Lib., Doc 12 w/4061.

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experimental programs which the Armament Branch may have entertained at the time were necessarily pared to suit the funds available.

In 1935 the budget prepared for the new fiscal year allocated \$45,000 to the entire experimental and service test armament program. The Armament Branch felt that \$100,000 would be required to carry out an adequate and aggressive experimental program. This serious restriction notwithstanding, the Materiel Division believed that substantial progress might be made "provided approval can be obtained to proceed along some definite line until experience . . . dictates revision."³ The Materiel Division as a whole realized that the lack of a clearly defined program of development had seriously impaired the normal evolution of aircraft armament.

A conference of Air Corps and Ordnance Department officials at Aberdeen Proving Ground in 1937 revealed that the Air Corps itself was far from satisfied with the status of armament development. An officer representing Langley Field expressed this opinion most forcefully. Since 1930, he pointed out, the airplane had roughly doubled its speed, its size, and its bomb load, but "the armament has remained the same. The point of view has been held that increased fire power is not only logical but exigent in this development. The feeling of the tactical units has been that the . . . installation of guns has not kept pace with the basic development." Even in the current model B-17 and B-18 bombers, the "fire control system is practically the same as it was at least ten years ago,"

3. AC Tech. Rpt., "An outline of prevailing circumstances in the field of aircraft armament and a recommended program of development," 11 Nov. 1935, in F Lib., Doc 12 w/4077.

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and only "comparatively recently several leading aircraft manufacturers realized the necessity for power operated turrets."⁴

The serious indictment of armament was not entirely ignored by those in authority. In April 1938 Brig. Gen. K. H. Arnold, then Assistant Chief of the Air Corps, initiated action to establish a committee composed of Air Corps, Ordnance Department, and Navy personnel to investigate the whole topic of ballistics effecting the development of fire control apparatus. Only a year before it had been noted that progress was seriously compromised by the prevailing lack of information on ballistic factors. "We are working considerably in the dark on the subject," said an official at Aberdeen in 1937, "because development and trial are just now starting."⁵

General Arnold's committee reported in July 1938 that the personnel available at the Materiel Division for fire control research were entirely inadequate for such an extensive subject and recommended that every effort be made to facilitate cooperation between the Armament Laboratory at Wright Field and the research staff at Aberdeen. Perhaps the most pointed comment of the whole report, however, was contained in a quoted letter from the Second Wing, GHQ Air Force, at Langley: "The present state of efficiency of flexible gunnery is worse than it was in 1918, the science of flexible gunnery having remained the same while the sights no longer fit the speed of the airplane."⁶

4. "Notes on Air Corps-Ordnance Dept. Conference," 18 June 1937, in Arr. Lab. file, Misc.

5. Ibid.

6. Rpt. of Navy, Air Corps, and Ordnance Dept. on Fire Control, 7 July 1938, p. 9, and Col. Robert Olds to CG, 2d Wing, GHQ AF, 29 April 1938, in ATCS 472.81, Fire Control 1941.

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In November 1938 General Arnold, who by that time had become Chief of the Air Corps, requested a report on the progress achieved in fire control equipment. Wright Field indicated that on the theoretical side ballistic computations were under way at Aberdeen and a tow-target mechanism had been perfected to facilitate the process of gathering information for ballistic studies, but a comparatively limited advance had been made in specific armament equipment because of the need for extended preliminary investigations and the serious shortage of qualified personnel.⁷

In December 1938 the Acting Chief of the Air Corps, Brig. Gen. W. G. Kilner, informed the Materiel Division:⁸

The Chief of the Air Corps is much concerned over the tardy development of much of our requisite fire control apparatus. He desires that the necessary steps be taken as soon as possible to insure the reorganization or reinforcement of the Armament Section in order to expedite the development of fire control apparatus and to make sure that this technical equipment will be ready for new types [of aircraft] now in production and to meet any increased expansion in procurement which may occur.

For years the Armament Laboratory had been neglected by those in authority, but if the Air Corps failed to develop fire control apparatus commensurate with European equipment, after 1938 it was not for want of support from the Chief, who, in the following year, June 1939, expressed himself even more emphatically:⁹

It is the opinion of the Chief of the Air Corps that there has been less advance and development made in aircraft armament

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7. Memo, C/AC to Chief, Supply Div., 3 Nov. 1938, and reply, Exec. (WF) to C/AC, 8 Nov. 1938, in *ibid.*
 8. Acting C/AC to Chief, MD (WF), 2 Dec. 1938, in *ibid.*
 9. C/AC to Chief, MD (WF), 9 June 1939, in ATSC 470, Armament Development.

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and ordnance accessories for aircraft than in any other branch of the art. It is also my opinion that the responsibility for this rests with the Materiel Division. It is quite apparent that some drastic steps must be taken by the Materiel Division to bring this development up to a par with the airplanes.

If progress had been slow, it should be remembered that only slight interest had been shown in armament from Washington throughout the previous decade or more, particularly in the allocation of funds. Nevertheless General Arnold requested that the Materiel Division prepare a definite developmental program in aircraft armament to be submitted without delay.

Parallel to the recommendations of the Chief of the Air Corps were those of the Air Board: "After a review of conditions as they exist today, the Board is impressed with the imperative need for a more definite, effective, and continuing War Department policy governing military aeronautical research and development." The board felt that any failure to anticipate developments would lead eventually to supplying the Air Corps with aircraft utterly ineffective against enemy weapons. Of peculiar importance to armament was the board's tenet that research and development in aircraft design must be paralleled in the field of accessories, particularly armament and communications equipment. Division designers were warned to give careful consideration to military objectives, "the specific needs for performance and fire power of combat airplanes based upon plans for their utilization in specific situations."¹⁰

Planning and long-range vision, conspicuously absent during the 19 years following World War I, appeared abruptly and changed the course of

10. LI No. 3, 18 Oct. 1939, in Arm. Lab. LI file.

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bombardment aircraft armament. The Kilner Board's recommendations for a five-year research program were carried out and reinforced by a system of priorities on research suggested by the Air Board. In order of importance emphasis was to place power plants first, fire control apparatus second, and pursuit aircraft third.¹¹ The Air Corps planned to implement this program with a substantial increase in funds. The proposed five-year research and development program for the years 1940 to 1944, inclusive, allocated in May 1939 the following sums to flexible gun accessories for aircraft:

	<u>Fire Controls</u>	<u>Power Turrets</u>
1940	\$10,000	\$20,000
1941	30,000	35,000
1942	50,000	50,000
1943	40,000	40,000
1944	30,000	35,000

These sums seemed modest in view of the magnitude of the task to be accomplished. The Materiel Division gave expression to a long-awaited policy in explaining how these funds were to be spent. In language which unconsciously reflected the theme of Air Corps flexible gunnery critics in the past two decades, the division's notation accompanying the proposed program declared: "To avoid loss of efficiency incidental to increased air speeds, it is necessary that development work be undertaken with a view to providing power operation for turrets and enclosed positions from which flexible machine guns are employed. . . . To date,

11. AC Board Final Report on Revision to the Five Year Experimental Program, 28 June 1939, in ATSC central files.

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little development work has been accomplished with reference to the provision of power operation."¹²

The precipitous transition to an enthusiastic support of power turrets very probably came as a direct result of the accumulated impact of foreign armament developments. Why this trend to turrets had not been undertaken earlier was revealed when, in July 1939, the Chief of the Materiel Division expressed concern over the system by which the division kept informed on foreign aircraft armament. The Chief of the Experimental Engineering Section cited the usual sources of technical information available to the Air Corps, such as publications, military attaché G-2 reports, MID reports, and data obtained by division and other representatives on tour, but noted that in general this category of information proved extremely difficult to obtain since foreign practice corresponded with current policy in the United States in retaining all aircraft armament equipment in a confidential status. Furthermore, the search for information concerning armament in particular was retarded by the fact that aviation observers, as a rule, are not armament conscious.

Even more serious than the information-gathering difficulties, the section chief reported, was the fact that while the information received on foreign aircraft armament was circulated through the section, no one was specifically charged with obtaining and disseminating such information in the various laboratories of the Materiel Division. It would be

12. Proposed Five Year Research and Development Program for Fiscal Years 1940-1944 Inclusive, 10 May 1939, in Arm. Lab. file, Research and Development.

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difficult to underestimate this organizational weakness in view of the fact that the section chief himself credited the influence of foreign equipment as largely responsible for such important modifications in Air Corps armament as the increase from two to four fixed guns on pursuit airplanes, the trend to tail guns in bombardment airplanes, and the interest in aerial ballistics inspired by French experiments at Cazeau.¹³

As far back as June 1938, the Materiel Division had prepared a questionnaire for military attachés including, among other items, a list of detailed questions concerning armament, particularly turrets.¹⁴ The information received from this survey as the reports came in during the following months left no doubt at the Materiel Division regarding the progress of European turret development.

It was not until a year later that the Chief of the Air Corps directed the Foreign Liaison Officer to instruct the Military Attaché for Air in London to investigate a hydraulic gun and turret control mechanism invented by a Mr. Frazer-Nash of Tolworth, Surrey, in England.¹⁵ In June 1939, Wing-Commander Anderson of the RAF visited Wright Field and off-handedly reported: "Mr. Frazer-Nash's hydraulic controls are regarded as a valuable means for the operation and maneuvering of guns and turrets." The Wing-Commander, who seemed anxious to establish closer coordination between the Air Corps and the RAF "with less emphasis on the barter exchange of ideas," promised to attempt to

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13. R&R, Chief, MD (WF) to Capt. C. S. Irvine, 1 July 1939, in ATSC 336, Foreign Developments, Armament.
 14. Memo, Chief, ES to branch chiefs, 28 June 1938, in Arm. Lab. file, Misc. Confidential Correspondence 1937.
 15. C/AC to Foreign Liaison Officer, 27 May 1939, in AAG 473.5.

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make arrangements for Ordnance and Air Corps attachés to fly in British airplanes equipped with multiple gun turrets. However promising this attitude may have been for improved relations, it would be well to remember that this was but a scant three months before the outbreak of hostilities.¹⁶

A few days after the second World War began in September 1939, the Materiel Division was directed to start at once to examine the tactics and techniques employed by the belligerents. To carry out this policy the division again circulated questionnaires amongst the attachés in foreign capitals. The Armament Laboratory at Wright Field compiled a list of questions regarding power turrets, computing sights, and range finders to obtain this specific technical information. Even more important, however, laboratory personnel displayed an unusual and hitherto neglected interest in the concept of fire power held by the several belligerents. The questionnaire sought to determine if it were the "general tendency in bombardment aircraft gun arrangements to attempt to defend the airplane from attack in all directions or to defend from attack from limited areas," and if in the case of the latter, what fields were assigned major importance.¹⁷ Apparently the Materiel Division had come to appreciate the importance of an integrated study of the fire power concept in conjunction with mere technological development.

16. Report of Visit of W/C Anderson, RAF, to Arm. Lab., 1 June 1939, in WF Lib., D70/129.

17. R&R, Chief, EES to Chief, Arm. Lab., 29 Sep. 1939, in ATSC 336, Foreign Development.

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In December 1939, three months after the Germans invaded Poland, the Chief of the Experimental Engineering Section expressed concern over the deficiencies of Air Corps bombardment fire power. "Information obtained from newspapers and other sources indicates that foreign bombers are extremely deficient in lower rear and directly to the rear gun defense. It is the opinion of this office that our bombers are in no better condition than the European bombers so far as defense is concerned." The chief directed that studies be initiated immediately and "prosecuted with utmost vigor" in an attempt to obtain increased volume of fire.¹⁸

The Chief of the Armament Laboratory, in answering this directive in January 1940, reported that the laboratory had exerted every effort to prepare drawing studies, mock-ups, and negotiations with commercial sources to make available "in the near future" experimental models of twin-.50 power-operated gun turrets, both upper and lower, "to establish designs" which might be "substituted for the existing manually operated emplacements for single machine guns should the Bombardment Board's decision favor the more complicated arrangements believed to be much more efficient."¹⁹ This report indicated the progress attained up to that time on power turrets developed by the Armament Laboratory, but it also raised an issue: Who was ultimately responsible for the creation of aircraft armament innovations, the Bombardment Board or the personnel of Wright Field's Armament Laboratory? Even though that responsibility was clearly defined by Army Regulations, the laboratory

18. IOM, Chief, EES to Chief, Arm. Lab., 20 Dec. 1939, in Arm. Lab. file, EO 553-1-315.

19. IOM, Chief, Arm. Lab. to Chief, EES, 9 Jan. 1940, in ibid.

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chief's reference to the decision of the Bombardment Board carries with it implications of an area of uncertainty in the pattern of the organization involved in perfecting Air Corps armament.

By the end of December 1939 the question of bomber defense had become so critical that General Arnold called a conference of representatives from every branch of the Service concerned with aircraft armament. This conference met in Washington on 27 December 1939 and discussed the problem at great length, finally reaching the conclusion, among others, that bombers needed all-around fire protection with fire power to the rear equal to that of a pursuit attacker. Since pursuit craft were currently appearing with eight fixed wing guns and most Air Corps bombers would do well in bringing more than a single gun to bear aft, this disparity left much to accomplish. The conference further concluded that multiple gun turrets were definitely desired even though the Martin B-26 was the only new aircraft appearing with a turret installed.²⁰

General Arnold implemented his desire to take immediate corrective action by instructing the Air Corps Board at Maxwell Field, the home of the Air Corps Tactical School, to prepare a study showing the fire power which the flexible guns on modern bombers, Air Corps as well as foreign bombers, could bring to bear on an attacking aircraft.²¹ Col. Carl Spaatz, Assistant to the Chief of the Air Corps, elaborated on General Arnold's decision on 18 December 1939:²²

As a result of all the reports which have been received by the War Department of air operations, commencing with those in

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20. Memo Rpt., MD (Wash.), re Armament Conference OCAC, held 27 Dec. 1939, dated 8 Feb. 1940, in ATSC Fire Control 1941.
 21. C/AC to CO, AC Tactical School, Maxwell Fld., 18 Dec. 1939, in Arm. Lab. file, Misc. Confidential Correspondence.
 22. Lt. Col. Carl Spaatz to AC Tactical School, 20 Dec. 1939, in ibid.

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China, continuing in Spain and the present operations there in Europe, there has been a growing feeling in the War Department that bombardment airplanes are helpless against pursuit attacks. This feeling has reached the point where there is considerable thought given to the inadvisability of procuring any more bombers.

He further intimated that even the new Air Corps bombers might not be provided with adequate fire power protection.

The Air Corps Board, in its subsequent extensive study on "Fire Power of Bombardment Formations," 3 January 1940, pointed out that among existing bomber types in most cases only one gun covered the tail cone area, and "in certain bombers, the field of observation in the rear hemisphere is so limited that it is perfectly feasible for pursuit to approach from the rear and attack without detection." Quite obviously, then, the project became one of reducing the disparity between the fire power of pursuits and the available fire power of bombers in a given area. But this project could not be accomplished merely by adding improvements to existing planes for, as the Handbook of Instructions for Airplane Designers had long preached, serious consideration must be given to fields of fire in the initial aircraft design, for once airplanes are built, improvements are limited.²³

The board concluded that Air Corps bombers, the B-17, B-24, B-25, and B-26, were superior to the foreign aircraft evaluated, and bomber losses in the current European war were the result of faulty employment and untrained gunners as well as inadequate defensive fire. The report recommended that the question of bomber defense be kept under continual

23. Rpt. No. 53, Maxwell Fld. AC Board, "Fire Power of Bombardment Formation," Annex V, 3 Jan. 1940, in Arm. Lab. file, Misc. Confidential Correspondence.

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study and specific attention be devoted to computing sights, range finders, and mechanical gun laying.²⁴ Bombardment defensive fire power policy had reached maturity in the United States.

24. Ibid.

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Chapter III

THE ARMAMENT LABORATORY AND FIRE POWER THEORY, 1934-1939

To understand the evolution of aircraft armament in the Air Corps, one must understand the Wright Field organization charged with responsibility for the actual technical development. This chapter will consider the Materiel Division's Armament Branch concerned with armament development at Wright Field, its personnel, finances, and administrative relationship to the Air Corps as a whole; the basic doctrines of the service regarding fire power expressed officially as well as unofficially; and the Air Corps' interpretation of those doctrines as expressed in terms of aircraft actually built and armed.

According to a War Department directive of 1921, the Air Service shared responsibility with the Ordnance Department for armament development. The 37-mm. cannon marked the dividing line of responsibility. All mounts for weapons larger than 37 mm. were to be the proper sphere of Ordnance and those of 37 mm. and smaller the Air Service's concern. The language of the directive was specific concerning gun mounts: "Mounts for all aircraft guns not exceeding 37 mm. caliber, when built integral with the aircraft or engine . . . but not including recoil systems unless integral with engines" were Air Service responsibilities. Then, lest there be any chance loophole, it was provided that the "Chief of the Air Service and Chief of Ordnance will report to the Adjutant

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General of the Army [i.e., the General Staff] any new item which they consider should be added to the list" or any new development which "necessitates reclassification of such items."¹

When Assistant Secretary of War H. H. Woodring and a committee visited Wright Field in 1934, the Armament Branch reported that "experimental developments which, due to the absence of supply sources, are, of necessity, conducted at Wright Field" included gunsights, bombsights, and the mechanisms and accessories for flexible .50-cal. guns.² This revelation of the restricted nature of development work in such critical fields carried with it implications of an inadequate interpretation of the threefold obligation inherent in the basic directive of 1921: experimental development of armament equipment at Wright Field; liaison with and education of potential manufacturing sources; and engineering supervision of actual development work under contract with commercial establishments. To surrender the second and third obligations would be tantamount to an unrealistic viewpoint regarding the role of Wright Field in its relation to ultimate wartime production.

Criticisms raised by the Baker Board report in 1934 led to a directive to revise the organization of the Materiel Division in 1935. New definitions of personnel and administrative functions were proposed. In the case of the Armament Branch, the chief was authorized to hold the rank of major and designated as responsible to the Chief of the Engineering Section for all theoretical studies and research work pertaining to

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1. WD GO #6, sec. VIII, 1921, quoted in "Aircraft Armament," McCook Fld. course outline, 1926, in WF Lib., D70/80.
 2. Memo Rpt., ES, 31 May 1934, in ATSC 334.8, Military Affairs Committee Investigation.

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aircraft armament, for testing and passing on equipment involved, for the preparation of specifications, and for proper coordination with industry. The branch chief was to be supported by at least one officer as an Engineering Specialist, authorized to hold the rank of first lieutenant. The Engineering Specialist was responsible for the development of armament equipment on all types of planes as well as flight testing that equipment.

The revision sought to improve the proficiency of the organization by enlarging on the educational and background requirements of responsible personnel in the Wright Field laboratories. All officers were required to have six years of service, with an engineering education desirable but not mandatory. Moreover, officers in key positions were required to have continuity of service in the engineering activities of the Materiel Division with exceptions made for short tours of duty in the Air Corps Tactical School, in the Army Industrial College, as well as in technological schools.³ By such provisions the Materiel Division hoped to insure an adequately aggressive engineering organization within the Air Corps.

The problem of procuring civilian personnel for the Armament Branch was parallel to the question of officer personnel, and in many respects even more important inasmuch as the civil service status of Armament's civilian employees imposed a continuity of service which almost inevitably surpassed officer assignments in stability. In 1937 the Chief of the

3. Memo Rpt., ES, 4 Feb. 1935, in ATSC 321.9, General, Eng. Div., folder 1.

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Armament Laboratory recognized the need for an enlarged organization to keep abreast of the constantly increasing demands of routine work and to "make possible a more thorough analysis of design and installation problems prior to the time that novel features must be incorporated." The chief's request for four draftsmen at \$2,300 a year was but a limited approach to the whole problem. Power-turret, gunsight, and bombsight projects required highly skilled technicians to analyze difficulties, to prepare and carry out service tests, and to coordinate with manufacturers. The chief suggested that a really adequate organization for attacking the bombsight project would consist of a team composed of two pilots with bombardiering experience, a mechanical engineer, and two engineering draftsmen--a development-team concept which might have proved of extraordinary utility if applied to other projects as well.⁴

When, in December 1938, the Materiel Division explained its delays in fulfilling General Arnold's recommendation for the development of fire control equipment, the Armament Laboratory noted a number of factors including: lack of personnel; lack of basic ballistic data; lack of flight experience with existing equipment; lack of an adequate number of interested manufacturers as sources of supply; and above all, the intrinsic nature of the project, "one of the most complex technological problems that can be envisioned."

Just how complex it was possible for fire control apparatus to become was pointedly illustrated somewhat later when the Chief of the

4. IOM, Chief, Arm. Lab. to Chief, ES, 17 April 1937, in ATSC 470, Armament Development.

Engineering Section, asked to be provided with texts on selsyn and amplidyne systems, vacuum tube theory and principle, introductory optics, ballistic definitions, and similar studies regarded as essential to an understanding of contemporary fire control equipment.⁵

Enlarging the civilian technical staff through civil service channels was no easy task. Personnel requisitions recommended in June 1938 were not authorized until October and even then the positions were not all filled by December because, in the case of two specialists, a physicist and an engineer, the "extraordinary qualifications" sought, together with the fact that an associate grade physicist and an assistant grade engineer each drew only \$2,600 a year in the civil service scale, would probably cause protracted delays in recruiting satisfactory personnel.⁶

By June 1939 there were 31 employees in the Armament Laboratory with a \$78,340 payroll, and the Chief of the Materiel Division proposed to increase this number to 48 with a total payroll of \$111,680. In July 1939 the Armament Laboratory was divided into six units: Shops, Bombsight, Bomb Racks, Synchronizer and Fixed Gun, Cannon and Flexible Gun, and Fire Control.⁷ By April 1940 this organization had been re-formed on more functional lines as the Administrative Unit, Fire Control Unit, Bombing Unit, Specifications Unit, Service Liaison Unit, and Shops Unit, a re-organization which, incidentally, reflected the growing problems of the time.

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5. List compiled for Chief, ES, by direction of Col. F. C. Wolfe, Jan. 1943, in Arm. Lab. file, EO 554-1-130, folder 2.
 6. Chief, MD (WF) to C/AC, 10 Dec. 1938, in ATSC 472.81, Fire Control 1941.
 7. Chief, Arm. Lab. to Chief, EES, 17 July 1939, in ATSC 321.9, General, Eng. Div., folder 1. See also 1st ind. (basic unknown), Chief, MD to C/AC, 21 June 1939, in ATSC 470, Armament Development.

The stated responsibilities of the Armament Laboratory included, along with engineering and procurement, liaison with Ordnance, Chemical Warfare, and Navy engineering research projects, and also a specific obligation in the preparation of annual experimental programs.⁸ This question of program planning became so critical as World War II drew near, that in August 1939 a system of priorities was established within the Armament Laboratory to single out items of equipment for completion within the fiscal year. It was stipulated that a brief plan of procedure be drawn up for each project under development, a requirement of sufficient merit to suggest that it might offer continued utility as an administrative tool.⁹

One of the many difficulties the Armament Laboratory had to face in prosecuting its experimental program was the inadequate number of aircraft available for realistic testing of armament equipment. In November 1938, of the 17 airplanes assigned to the Engineering Section, only 1 went to the Armament Laboratory, while 4 were assigned to the Administrative Branch, 4 to the Aircraft Laboratory, 5 to the Equipment Laboratory, 2 to the Power Plant Laboratory, and 1 to the Aircraft Radio Laboratory.¹⁰ By January 1939 the Armament Laboratory had secured the services of two planes, a 1936 model A-17A and a 1937 model B-18.¹¹ One month after the outbreak of war in Europe seven planes were made available

8. Chief, Arm. Lab. to Chief, EES, 19 April 1940, in ATSC 321.9, General, Eng. Div., folder 1.

9. ICM, Chief, EES to Chief, Tech. Staff, 7 Aug. 1939, in ATSC 470, Armament Development.

10. Memo, Chief, ES to Chiefs, all branches, 3 Nov. 1938, in Arm. Lab. file, Airplanes General 1938-1939.

11. Memo, Chief, ES to Chiefs, all branches, 6 Jan. 1939, in Arm. Lab. file, Misc. Correspondence 1939.

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to the Laboratory, but the most modern bombardment plane among these was only a B-18A.¹²

Insufficient appropriation for experiment^{a1} work was an even greater obstacle in the Armament Laboratory's path. Maj. Gen. Oscar Westover considered that the annual budget was the "biggest single task" confronting the Chief of the Air Corps, who was obliged to compile, submit, and defend the annual appropriation, a sum of approximately \$73,500,000 in 1938 when the Air Corps had but 13 B-17's in service and 26 on order, and the backbone of the U.S. bomber force consisted of 400 B-18's in service and on order. We "need not be surprised," General Westover remarked, "to find the United States surpassed and outstripped in the excellence of aeronautical equipment. . . . Germany, England, Italy, Russia and probably France . . . are now devoting more time, attention, and funds" to experimentation than the Air Corps had been able to devote to it.¹³ What this actually meant in specific terms may be seen in a brief summary of funds available to the Materiel Division and the Armament Laboratory. In 1929, for example, Experimental Engineering Section civilian payrolls were as follows:¹⁴

Office of the Chief	\$ 30,000
Aircraft Laboratory	140,000
Armament Laboratory	61,000
Equipment Laboratory	126,000
Power Plant Laboratory	148,000

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12. Memo, 3 Oct. 1939, in Arm. Lab. file, Airplanes General 1938-1939. See also IOM, Chief, Arm. Lab. to Chief, EES, 13 Oct. 1939, in Arm. Lab. file, Contract AC-9977, Douglas B-18A, B-23.
13. "Air Armament," lecture by Maj. Gen. Oscar Westover, 26 Sep. 1938, in WF Lib., A10/284.
14. Working Program; and Engineering & Research Program, C Funds Fiscal Year 1929, in Arm. Lab. file, Research and Development. For a fuller discussion of funds for AAF experimental work in general, see AAF Historical Study: No. 50, Materiel Research and Development in the Army Air Arm, 1914-1945.

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The budget estimates prepared for 1938, including something over \$2,500,000 for experimental and development work, are perhaps another index:

Planes	\$1,000,000
Tests, Designs, etc.	35,000
Propellers	100,000
Balloons, etc.	20,000
Power Plants	750,000
Armament	25,000

The sum of \$25,000 for armament, it must be recalled, was to cover the entire armament program, not merely power turrets. A breakdown of this total explains why the Armament Branch could not hope to keep pace with the urgent and belated directives arriving from Washington to stimulate development in fire control equipment:¹⁵

Synchronizers	\$ 1,000
Bomb Racks	3,500
Mounts	10,000
Gunsights	800
Bomb Handling Equipment	4,200
Miscellaneous	500

While direct purchases of armament equipment amounted to \$14,421 in 1938, in 1939 they accounted for \$215,000 in the Materiel Division's budget. A breakdown of estimated purchase expenditures for armament in 1940 marks the wartime shift of emphasis to armament:¹⁶

Bombsights	\$40,000
Cannon Fire Control	45,000
Remote Machine Guns	25,000
Bomb Racks	25,000
Mounts, etc.	10,000

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15. Abstract of Costs, Fiscal Year 1938, in Arm. Lab. file, Research and Development.
 16. Research and Development Program, Subtitle B, Fiscal Year 1940, in Arm. Lab. file, Research and Development.

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But even these sums were relatively small in view of the magnitude of the task imposed upon the Armament Branch of overtaking the time lost in the 20 impecunious between-war years. Subsequent appropriations and supplemental allocations increased these amounts greatly, but the estimates are important as indices to the thinking of the times. A Wright Field officer warned: "If General Arnold expects the same type answers from the Armament Branch that he is obtaining from the Power Plant Branch or the Aircraft Branch, we must have more money, more personnel, higher priority and more backing."¹⁷ Undoubtedly the annual lack of funds was the largest single detriment to experimentation at Wright Field; but even if ample funds had been available, developmental research would have encountered a number of other serious organizational problems.

General Arnold's joint Army-Navy-Ordnance committee on fire control raised so many issues in 1938 regarding the relationship of the Air Corps with Ordnance that in January 1939 the Chief of the Air Corps considered the possibility of transferring the entire responsibility for fire control apparatus to Ordnance, with its extensive body of experience with range finders and automatic computers used with artillery and antiaircraft equipment. The Chief of the Materiel Division rejected the idea; since fire control equipment had to be considered in the initial design of the aircraft and inasmuch as the incorporation of evolutionary features with reference to structure, aerodynamics, performance, etc., depended upon freedom from fixed design of accessory equipment, it was

17. Lt. P. G. Miller to Capt. C. S. Irvine, 12 July 1939, in Arm. Lab. file, Informal Notes, Bombsight Development.

essential to retain fire control responsibility within the Air Corps.¹⁸ The Chief of the Ordnance Department reported, furthermore, that he did not wish to take on the responsibility and the project was dropped.¹⁹ Whether this indecision with regard to organizational sponsorship delayed the development of fire control apparatus cannot be determined; but appearing as it did in the critical months before the outbreak of World War II, it served to focus attention on the importance of making early decisions regarding the precise definition of areas of responsibility.

On repeated occasions throughout the "Long Armistice" beginning in 1918, the Engineering Section complained of the difficulty encountered in obtaining service opinion on developmental trends. In order to remedy this, the Materiel Division conducted a conference at Wright Field in December 1938, including representatives from tactical organizations and the armament school at Lowry Field, to help in planning the research and development program in preparation for the next five-year period. The conference undoubtedly had merit in bringing the operational experience of tactical officers to the place where it could do most good, and the conference method proved so useful that it was suggested as an annual feature.²⁰ It was apparent, however, that a two-day conference could never substitute for an active, full-time testing organization devoted entirely to tactical application of Materiel Division developments.

18. Chief, MD to C/AC, 31 Jan. 1939, in Arm. Lab. file, Fire Control Miscellaneous 1940.

19. 1st ind. (basic unknown), 27 Jan. 1939, in *ibid.*

20. Exec., WF to C/AC, 13 Dec. 1938, in ATSC 470, Armament Development.

In January 1939 the 2d Bombardment Group of the GHQ Air Force proposed a special gunnery test unit. The group commander pointed out that "the technique of flexible aerial gunnery has not improved since the World War," and that a two- or four-plane unit solely devoted to flexible gunnery could, if equipped with modern aircraft and unlimited ammunition, make substantial improvements in gunnery techniques which tactical units were unable to do for want of time. His proposal suggested a year-around base near the shore line where unlimited air range facilities would be available for firing tests which would yield experience to perfect training systems and training literature, provide a realistic service test for new equipment, and form an experienced nucleus for a yearly conference of group armament officers.²¹ The group commander's proposal, furthermore, contained a most pointed explanation of the difficulties encountered at Wright Field in securing the benefits of service experience. Since no bombardment unit had sufficient time, after completing training directives, to do "more than a bare minimum of the experimental bombing and gunnery work which is so necessary to attain the desired ultimate efficiency," and since "there are many aspects of both gunnery and bombing which have either been incompletely investigated or not investigated at all," a testing unit devoting its entire time and energy to these problems would "undoubtedly lead to a rapid improvement in the technique of both gunnery and bombing."²² The suggestion materialized six months later, when an expenditure order

21. CO, 2d Bomb Group, GHQ AF to CG, 2d Wing, GHQ AF, 26 Jan. 1939, in Arm. Lab. file, Fire Control Miscellaneous 1940.

22. Ibid.

was prepared by the Armament Branch for the Air Corps Proving Ground at Eglin Field, Valparaiso, Fla.²³

To understand the evolution of aircraft armament and evaluate the bombardment defense program it is necessary to understand the basic assumptions regarding fire power policy maintained by the personnel responsible for Air Corps bombardment armaments. In 1937 the Chief of the Engineering Section, replying to a French criticism of Air Corps aircraft charging that U.S. aircraft had excessively "limited fields of fire" available for defense, declared that the charge afforded "grounds for speculation as to the up-to-dateness of the French conception of modern combat requirement." The chief expressed himself emphatically:²⁴

Certainly present day aircraft will not have to deal with a type of pursuit attack which "flies circles around" the slow observation or bombardment airplanes as in wartime [World War I] days. With the exception of surprise meetings, modern pursuit attacks on "slower" aircraft will presumably be matters of long straightaway chases and the approach of the attacker will be from long, flat angles to the rear. American defensive armament takes into consideration the changes in relative speed which have taken place since the war.

Speed, then, had changed the picture since the first World War, and the Air Corps was credited with having based its armament practice upon the assumption that most attacks would come from the rear. The Engineering Section chief suggested that the new B-17 and B-18 airplanes

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23. Chief, Arm. Br. to Chief, EES, 7 July 1939, in ATSC 470, Armament Development. In April 1939 a board headed by Lt. Col. Douglas B. Netherwood, Director of the Air Corps Board, had selected the site of Eglin Field. See Proving Ground Command Historical Branch, "Historical Outline . . .," p. v.
24. Chief, ES to Chief, Materiel Liaison Sec., OCAC, 15 May 1937, in ATSC 333, Foreign Development.

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should overcome the objections raised by the French, whose "point of view regarding the accentuation of armament and utility even at the expense of performance is well brought out in their own bombardment types." But the British, too, were sacrificing performance to armament and utility.

In June 1939 an Intelligence officer, reviewing the lessons of the Sino-Japanese conflict, pointed out that at the beginning of hostilities the "Japanese showed a tendency to follow American tactics and policies in the air, namely, that bombardment is invincible and that pursuit is growing obsolete." Pursuing this doctrine in action, the Japanese were contemptuous about obsolete Chinese pursuit, and as a result their formations were shot up in short order.

The Materiel Division reply to this report denied the validity of the expression of Air Corps doctrine. "The U.S. Army Air Corps does not claim that bombardment is invincible and pursuit is growing obsolete" but rather that "formations adequately manned, of proper strength, disposition, training, and armament protection, can operate effectively without accompanying pursuits." This self-sufficiency of bombardment formations, the division said, was shown in the many Japanese pursuits shot down by Russian tail gunners when the Japanese attacked from the rear.

The Chief of the Armament Laboratory studied the Sino-Japanese report and drew several pertinent conclusions from it: multiple gun turrets were necessary for bomber defense; fire power could be achieved by following the British example in turrets; and the Russian experience

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proved the utility of flexible tail guns against pursuit attack.²⁵ All the elements for a definite course of action were present: an expression of doctrine; a proof of utility in a combat report; and a foreign precedent in mechanical design. But two critical years were to pass before these elements were formulated into a definite policy and applied to aircraft design and production.

General Arnold visualized pursuit attacks on bombers from all angles and instigated a study to consider the feasibility of various methods of attack. Subsequent tests conducted at Wright Field led to the conclusion that the head-on attack was of little utility. With a P-36 attacking a B-10 under ideal conditions, nose to nose, along a predetermined ground course, the pursuit reported that barely enough time remained after recognition of the oncoming plane to get out of the way. The best chance for successful pursuit attack, it was said, lay in striking within a 0° to 20° cone along the tail axis where structural interference to defensive fire would be greatest.²⁶

The problem of areas for attack was discussed by Maj. R. C. Coupland, Ordnance officer:²⁷

It is theoretically possible to attack a bombardment airplane from any angle . . . , [but] the practical difficulties involved and the loss of effectiveness in any zone, except that circumscribed by a 20° to 30° angle from the line of flight of the objective airplane, place such attacks in the category of a threat rather than an effective method of employing fire power.

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25. "Aerial Warfare in China," G-2 Report 2657-H-439/1051, 14 Dec. 1938; Comments by Chief, MD, 10 June 1939 and Chief, Arm. Br., 29 May 1939, in ATSC 336, Foreign Reports.
26. Memo, Maj. R. C. Coupland, Ord. Dept. to C/AC, 9 Feb. 1940, in Arm. Lab. file, Airplanes Miscellaneous 1940.
27. Ibid.

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From this it might be concluded, Major Coupland suggested, that it had become necessary to redesign bombers to afford fire power from the rear at least "equal or better than can be brought to bear by the attacker in the rear cone of vulnerability." This conviction was rapidly gaining adherents, but for many years the logic of this conclusion had been ignored.

The Armament Laboratory generally assumed that 80 per cent of all attacks on bombardment airplanes by pursuit would fall within a 45° cone to the rear,²⁸ but until the introduction of remote controls no extensive attempts had been made to place a gunner in the tail because of the weight and balance problems caused by such an installation, not to mention the space limitations imposed by conventional designs.²⁹ Wright Field assumed that tail gun positions would be impractical because of the high acceleration to which a gunner stationed there would be subjected.³⁰ To a like extent it was assumed that the pitch and yaw at the tail position would make sighting difficult if not impossible.³¹ While the Air Corps assumed the impracticality of the tail gun, the British were building four-gun tail turrets for heavy bombers.

Changes in airplane design to reflect changes in bombardment defense doctrine were necessary, but a policy of standardized design was a barrier to such change. Thus the Materiel Division's Handbook of Instructions for

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- 28. Memo, Capt. P. E. Shanahan to Lt. Col. O. P. Echols, 19 Feb. 1940, in Arm. Lab. file, E. O. 554-1-123.
 - 29. Notes on visit of M. E. Goll to fire control manufacturers, Feb. 1940, by Capt. P. E. Shanahan, in *ibid.*
 - 30. Record of conversation: W. G. McNeill, Arm. Lab. and Lt. Irving B. Holley, Jr., ATSC Historical Office, 11 Oct. 1944.
 - 31. Record of conversation: H. L. Anderson, Aircraft Lab. and Lt. Irving B. Holley, Jr., ATSC Historical Office, 11 Oct. 1944.

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Airplane Designers, 1925 edition, declared: "At the time of writing, this Handbook represents the most satisfactory solution of design problems, hence should be used as a guide for all airplane designs submitted to the Engineering Division for approval." Standing alone, this statement would seem to indicate an attitude of complete conviction and positive assurance of the division's leadership in design concept. On the other hand the Handbook did encourage originality: "Manufacturers are urged to propose variations leading to improvement," and "deviations will always be granted upon request to effect better solutions of problems."³² Nonetheless, it is difficult to escape the implication that stultification is inherent in any system of minimum standards unless an unusually aggressive policy for continual improvement is pursued in modifying the standards.

The number of points for a figure of merit assessed by an aircraft evaluation board were predicated upon an aircraft that met all the requirements of the general specifications and the current edition of the Handbook. The 1935 Handbook pointed out that its contents were "mandatory unless specifically excepted in the contract."³³ In design competitions tremendous importance was attached to the Handbook and the precise requirements of the general specifications accompanying the contract. Only so long as these two systems of standardization were revised to keep ahead of service requirements could they escape the responsibility for stultification.

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32. Handbook of Instructions for Airplane Designers (hereafter cited as Handbook), 4th ed., 1925, Foreword.
 33. Handbook, 7th ed., 1932, Foreword.

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There were contradictions in the Handbook affecting armament. The 1925 edition suggested that a floor gun could be installed for tracer sighting in conjunction with a manually operated remote chain and sprocket drive, even though such a device had been condemned by tactical units in 1923. The Handbook, however, stipulated a minimum 30° cone of allowable area to be blanked out to gun fire by the tail assembly, and showed a progressive spirit by pointing out that this provision would not apply in the case of a gunner located behind the tail surfaces.³⁴ Such a stipulation certainly did not discourage the use of tail guns.

The Handbook's 1936 edition introduced a new feature in the Armament section, emphasizing the importance of designing armament functionally with the airplane inasmuch as armament was, after all, part and parcel of the primary purpose of military aircraft. Experience showed, the Handbook pointed out, that it was impossible to make subsequent satisfactory provision for armament after it had been subordinated in the original design. For aircraft manufacturers who had been 18 years away from the realities of war, this was an important reorientation and a reiteration of the fundamental role of armament.

The 1936 Handbook, furthermore, specified fields of fire for bombardment aircraft covering the "greatest possible portion" of the forward hemisphere, complete protection in the upper rear quartersphere, and in the zone below and to the rear, all stipulations of undefined generality qualified only by the requirement that intersecting fire from at least two guns should meet at 100 yards in every direction. This

34. Handbook, 4th ed., 1925, sec. V, Armament, pt. III.

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was the first Handbook edition to mention turrets for providing the gunner with complete protection from the slipstream. This edition also contained a progressive note suggesting that "In the event that turrets cannot be manually operated at top speed, some means of power drive shall be supplied in addition to manual emergency operation." On the other hand, the Handbook's concept of fire power was still limited in requiring turrets to be equipped with "a device to lock them in any desired position while firing the guns."³⁵

The first revision of the 1937 Handbook required protective gun fire for the "greatest possible portion" of the entire sphere about the bombardment plane and complete coverage by aimed fire for the specified field of each gun position. The introduction of "aimed fire" was necessary, for planes had appeared with guns whose axis of bore satisfied the minimum requirements even though the marginal areas of the defined field were in such a position as to defy accurate sighting.³⁶ However, turrets remained optional with manufacturers, who were required to provide flexible gunnery arrangements sufficient to permit "rapid maneuvering throughout the entire field of fire without undue exertion on the part of the gunner," an objective which was sufficiently open to varied interpretation to allow almost any latitude of opinion in solving the problem.³⁷

By 1939 the specifications for power drives in gun mounts were somewhat more precise. The Handbook stated that "The selection of manual or

35. Handbook, 8th ed., 1936, sec. V, Armament.

36. Memo Rpt., ES, 18 March 1936, in Arm. Lab. Spec. file, Boeing XB-15.

37. Handbook, 8th ed., 1st rev., 1937, sec. V.

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power means of operating flexibly mounted guns is dependent upon the combined drag of the exposed portions of the gun and the moving portions of the gun mount and enclosure." If the total drag exceeded 35 pounds, measured at the gun butts at the highest attainable airplane speed, power drives were necessary.³⁸ Apparently the Handbook did not attempt to establish standards for smoothness in tracking and for the other factors affecting the efficiency of bombardment defense.

Because of the rush of war work which pressed upon the Armament Branch, no revision in the section on armament appeared in the critical edition of ^{the} Handbook in July 1940, but the edition of the following year presented a completely rewritten armament section with a concept of fire power entirely in line with current wartime practice, involving adequate standards covering the number of guns employed, sighting dependent upon smooth tracking, provision for scanning, and gunner's comfort. That the power turret had at last come of age was implied in the announcement that "Manually operated flexible guns are no longer considered for the principal defense of aircraft. They may be considered as a means of providing supplementary fire for limited areas when crew members other than gunners are available for protection for short periods of time."³⁹

While the Handbook of Instructions for Airplane Designers from 1925 to 1940 showed the trend of official policy regarding bombardment defense, the armament installations in the bombers themselves showed the actual application of policy in the Air Corps. The following

38. Handbook, 8th ed., 3d rev., 1939, sec. V.

39. Handbook, 8th ed., 5th rev., 1941, sec. V, pt. V, p. 1245.

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armament installations were standard in Army bombardment aircraft in September 1939:⁴⁰

B-10 Martin (contract March 1931; first production article, July 1934)

- 1 nose .30-cal. manual turret machine gun
- 1 upper .30-cal. hand-held machine gun
- 1 lower " " " " " "

B-17A Boeing (contract Oct. 1935; first production article, Nov. 1938)

- 1 nose .30-cal. hand-held machine gun
- 1 upper .30-cal. hand-held machine gun
- 1 lower " " " " " "
- 2 waist " " " " " "

B-18 Douglas (contract Jan. 1936; first production article, June 1937)

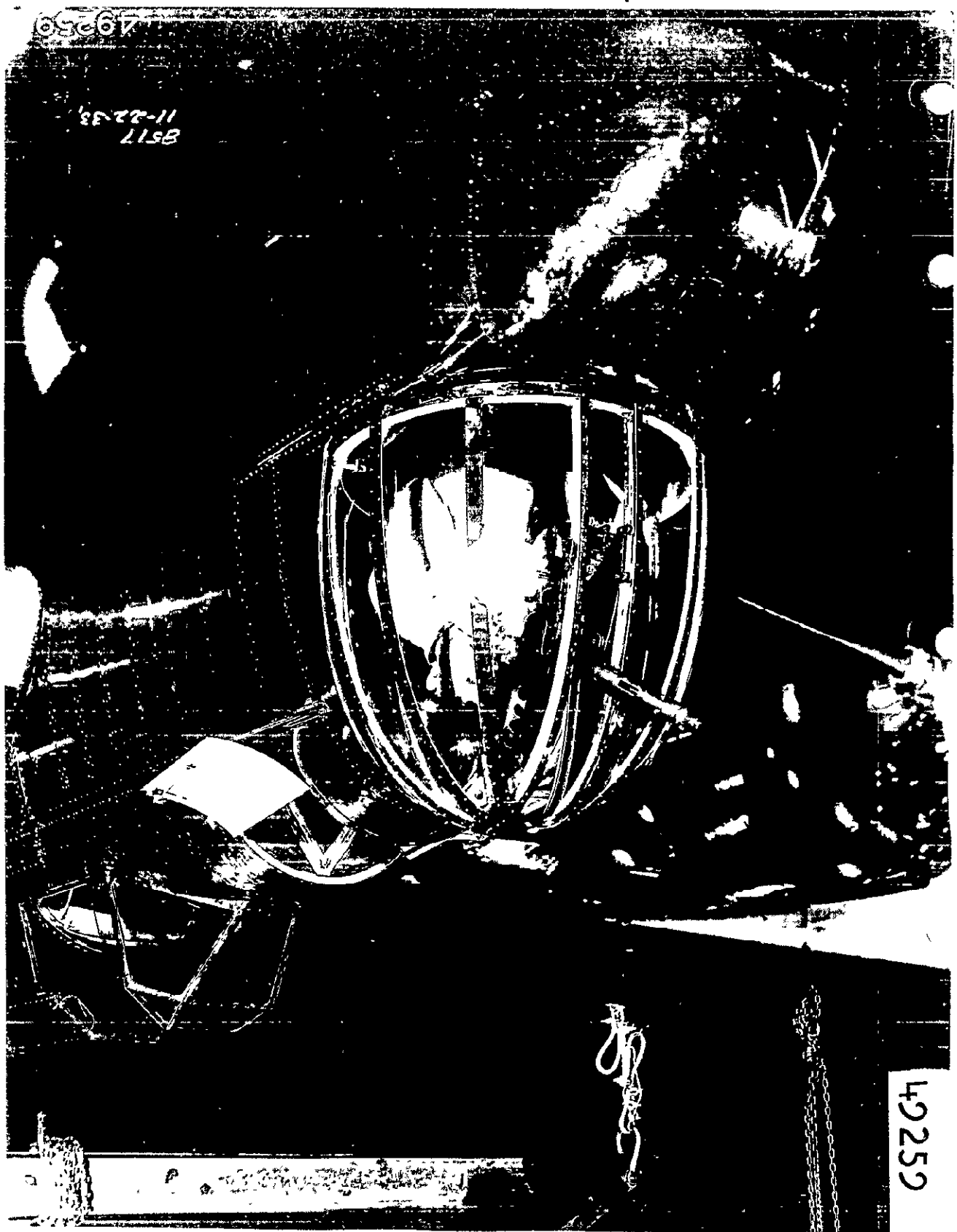
- 1 nose .30-cal. manual turret machine gun
- 1 upper .30-cal. manual turret machine gun
- 1 lower .30-cal. hand-held machine gun

B-23 Douglas (contract June 1937; first production article, Nov. 1937)

- 1 nose .30-cal. hand-held machine gun
- 1 upper .30-cal. hand-held machine gun
- 1 lower " " " " " "
- 1 tail .50-cal. hand-held machine gun

40. Tabular data from specifications in ATSC Contract files.

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Martin B-10 manually operated nose turret mounting
a single cal. .30 machine gun. 1933.

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Chapter IV

BOMBARDMENT ARMAMENT: TRANSITIONAL PHASE, 1934-1939

The Glenn L. Martin Company's B-10 bomber of 1934 was noteworthy in the record of armament development as the first Air Corps bomber to appear with an enclosed turret. The B-10 carried a four-man crew and bristled with three .30-cal. machine guns—one nose, one upper, and one lower or floor position. Of these three emplacements, the nose turret was significant because it represented a revolutionary departure from earlier practice. In the position formerly occupied by a ring mount, Martin installed a single gun in a rotating dome 36 inches in diameter and 35 inches high at the apex, the whole a welded steel framework sheathed with gore-shaped sections of "plastacelle."

The manually operated dome or turret retained many of the features of the ring mount from which it evolved, and typical of the evolutionary process, its design was retarded by an attempt to modify existing equipment rather than to solve as directly as possible the problem encountered. The gun mount within the turret utilized the old system of shock-cord compensation, and the turret track was designed to lock in any one of 36 different positions for firing.

The Martin turret marked a long step forward in the contest against slipstream, but as a solution of the tracking and sighting problem it

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left much to be desired. A B-10 service test in 1934 revealed that the nose gun did not cover the stipulated field of fire, was uncomfortable for the gunner, and was not correctly proportioned to provide the gunner with ample head room. Despite all these shortcomings, however, it was reported as easy to manipulate at high speeds.¹

The perfection of armament inevitably is costly in terms of airplane weight, and it is necessary in evaluating the Martin turret to appreciate that this entire installation weighed only 80 pounds. In view of the Air Corps requirement that the contractor guarantee the estimated aircraft "weight empty" to within 1 per cent, it is not difficult to understand why airplane manufacturers were loath to devote any unusual effort to perfecting armament installations.²

The type specifications for multi-engine bombardment airplanes, revised in 1935, called for the installation of a minimum of three positions, all mounting .30-cal. guns. The nose gun, arranged to cover the "maximum portion" of the foresphere, the upper midship gun to cover the upper rear quartersphere, and the lower or floor gun to cover the lower rear quartersphere were all required to be capable of rapid operation at maximum airplane speeds. The disposition of any additional guns was optional with the airplane manufacturer. In view of the weight penalty involved, it seemed unlikely that manufacturers would seek more than the minimum requirements, a situation which suggests that the

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1. Service Test Requirements Manual on armament equipment installed in B-10, B-12 series airplanes, 13 Aug. 1934, in Arm. Lab. Evaluation file.
 2. Glenn L. Martin Specifications for YB-10, 24 July 1934, in Spec. Br. file (obsolete).

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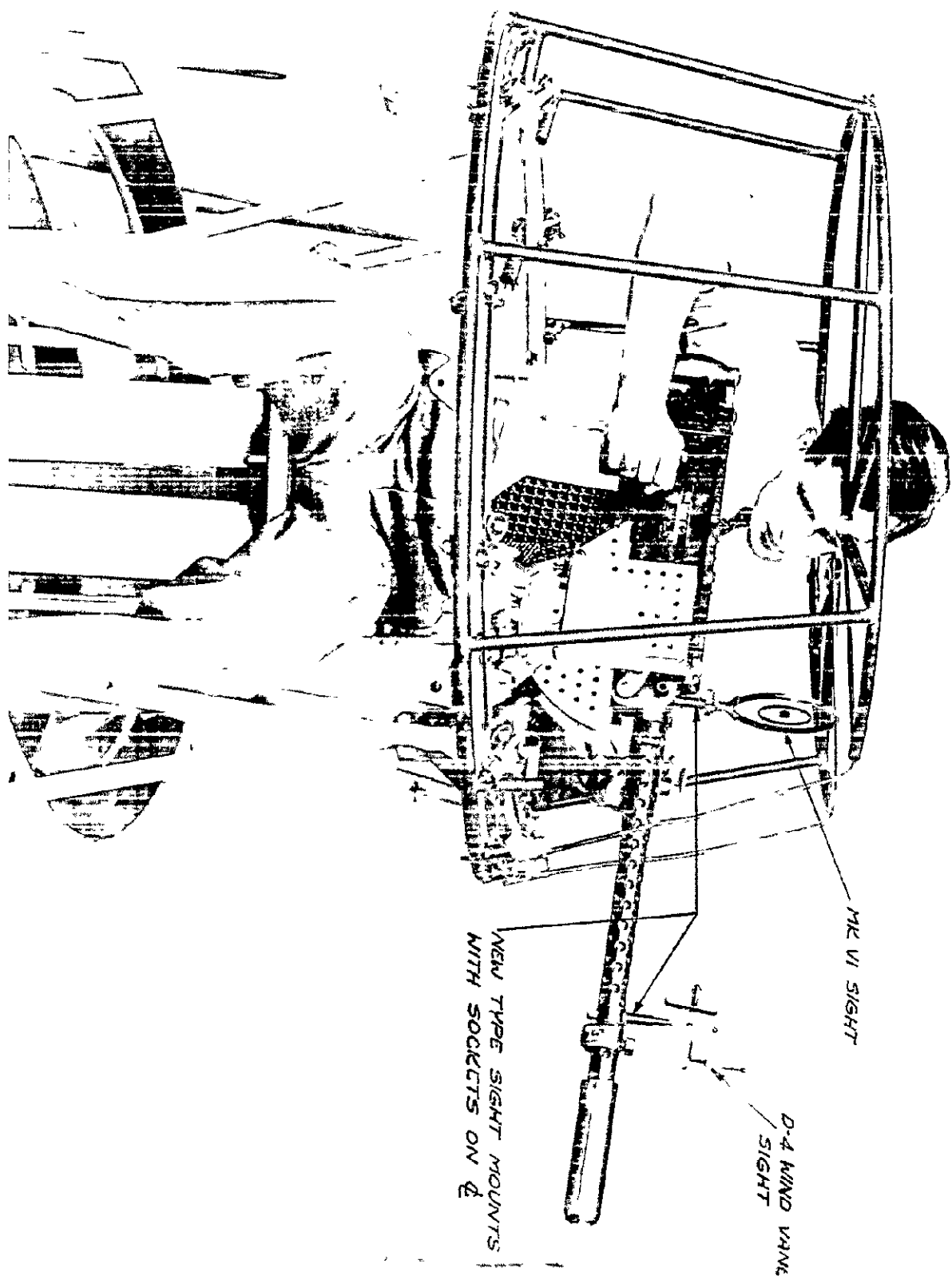
minimum standards should have been raised to insure an ample margin of performance in terms of fire power. Similarly, such loosely defined zones as the "maximum portion" of the foresphere field of fire appear to have offered a considerable latitude to the manufacturer in the selection of armament installations.

One requirement of the revised type specifications, however, gave promise for the future. The manufacturer was required to provide an enclosure for the upper rear emplacement in order to give complete protection from the slipstream and visibility "in all directions," rendering the position a lookout for the airplane.³ A lookout implied a protuberance, and a protuberance represented a victory in the contest against the aircraft designers who placed streamlining and airplane performance over armament utility. So strong was the feeling of designers and manufacturers against aerodynamically poor armament protuberances that the Armament Branch at Wright Field felt it necessary to develop a turret independently and without regard for any particular bomber.

In January 1935 the Curtiss Aeroplane and Motor Company informed Wright Field that the Navy was negotiating for a Curtiss manually operated gun turret. The Chief of the Engineering Section, anxious to avoid needless duplication of effort, questioned the Navy on the project; but the correspondence lagged until a year later when Curtiss submitted rough drawings of the turret, an enclosed ring mount 40 inches in diameter and capable of 360° azimuth rotation and 90° to -30° elevation

3. Memo Rpt., ES, 9 Oct. 1935, in Arm. Lab. Circular Proposal file, Bombardment Multi-engine Airplane Spec. 98-201-A&B, C.P. 36-545.

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Further experimental work local, manually operated
turret mounting a single cal. .30 machine gun.
Transparent dome removed. 1937.

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movement. Curtiss asked \$4,255 for this turret, which mounted a .30-cal. gun and contained an azimuth hand-crank system, making rotation possible in airspeeds as high as 200 mph.⁴

Calculations at Wright Field indicated that the Curtiss turret would result in an 18 per cent speed reduction when mounted on a B-18, that is, reduction from a top speed of 220 mph to 186 mph, and that the turret would cost 18 per cent of range and 2 per cent of service ceiling. The conclusion was, therefore, that such turret installations must be retractable to reduce the drag as much as possible.

In October 1936 Curtiss offered a new and improved turret to the Materiel Division for \$5,847.75; and after protracted negotiations concerning unrestricted patent and design rights in the contract, a turret was delivered to Wright Field in May 1937. The purchase proved of little value, however, for as late as July 1938 the Armament Laboratory reported: "Repeated efforts to secure a B-18 airplane for the short period necessary to install and test this turret have met with no success and the development has now lost importance due to later designs."⁵ In an organization already starved for funds, blind alleys were more than merely costly.

While Wright Field was negotiating the Curtiss contract, the Douglas Aircraft Company built the first DB-1, the Air Corps B-18, which complied with the minimum type specification requirements for three

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4. Chief, ES to Inspector of Naval Aircraft, WF, 23 Jan. 1935; Memo Rpts., EES, 5 Feb. 1935, 12 May 1936, 3 Aug. 1936, and 22 Aug. 1936; and Chief, EES to Curtiss, 18 May 1936, and Curtiss to Chief, MD (WF), 10 June 1936, in WF Arm. Lab. file, E.O. 553-1-261 Curtiss.
 5. Note by M. E. Goll, Arm. Lab., 15 July 1938, in ibid.

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flexible gun positions. The nose and floor guns were more or less conventional, but, as a "689" inspection board reported in August 1935, the bidder elected to diverge from the requirements in the case of the upper rear gun, "with the result that an arrangement superior to that required has been provided." The term "689" refers to the blank form used in making final acceptance tests. The term lingered on long after the form disappeared.

The manually operated turret of the B-18 included many novel features. It was retractable, although the board suggested that a crank and cable retracting mechanism replace the existing elastic shock-cord system, which was certain to prove inadequate in service use. Furthermore, the board considered the gun aperture slot closers as "an excellent idea well worked out." The inferior quality of the transparent "paraline" plastic sheets was criticized, thus focusing attention upon the difficulties encountered in gun turret development before the appearance of "plexiglas."⁶ The B-18 turret was primarily important in making a start on the practical problems facing all turret designers: retraction, slot closure, dome contour, and the selection of transparent sheathing, all considerations which had far to go before attaining even a semblance of design stabilization.

6. Airplane Evaluation Board Report, Armament Inspection, 30 Aug. 1935, in Arm. Lab. file, Airplane Evaluation Folder 1 C.P. 39-800, 38-385, Airplanes A-17 to B-26. The technological lag in transparent acetates and the slow evolution of an easy-to-cast, durable, shatter-proof plastic was to delay the development of other airplane components as well, such as bombardier compartments and bubble canopies.

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The importance of the Douglas B-18 turret was amplified far beyond the actual stage of technological development it represented when in June 1937 the Air Corps contracted for 177 B-18A's at a cost of something less than \$12,000,000.⁷ This represented quantity production on a scale unknown since the last war, and as such exemplified the Air Corps' interpretation of a modern bomber. As finally revised in February 1940, the B-18A carried three .30-cal. machine guns as it had in 1937; and no provision was made for additional guns or alternate installation of .50-cal. weapons.⁸

As early as April 1935 Douglas was thinking in terms of power turrets, and drawings for an improved version of the B-18 contained tentative outlines for power-driven nose and upper midship turrets. The nose was a pear-shaped compartment driven about its vertical axis by a worm and gear drive powered from a Vickers hydraulic unit. The Engineering Section suggested that the power turret idea contained sufficient merit to be procured "at additional cost to the Government," but added, somewhat pessimistically, that "although a power driven turret is desired, it is believed that this proposal is too incomplete to evaluate."⁹ Despite the fact that this installation never actually passed the experimental stage, it was significant in that it utilized a Vickers hydraulic power drive unit which contributed to the development of the contemporary Vickers drive unit.

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7. Contract W535 ac 9977, 23 June 1937, (DB-5) B-18A, in ATSC Contract files.
 8. Contract W535 ac 9977, 23 June 1937, with revisions to 29 Feb. 1940, in Arm. Lab. file, Douglas B-18A Contract ac 9977, folder 2.
 9. Change Order #7, 19 Oct. 1938; and Memo Rpt., ES, 10 March 1939, and UR correspondence, in ibid.

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The efforts of the Armament Branch to improve the original B-18 brought the whole problem of turret development into focus. So long as single .30-cal. Brownings were employed in bomber defense, there was comparatively less need for power turrets, but the trend toward .50-cal. weapons made power training imperative. The use of .50-cal. guns actually decreased defensive efficiency before the appearance of power turrets, for not only were the heavier guns more difficult to maneuver in the slipstream, but their bulk made internal structural interference an appreciably greater factor. To overcome the first objection, at least in part, wind vanes were ordered for the B-18A upper turret, but nothing short of redesign could overcome the latter objection. As the Handbook of Instructions for Airplane Designers had pointed out, armament installations not an integral part of the original aircraft design were inevitably unsatisfactory.

The Armament Branch, in evaluating the DB-4 (B-18A) drawings, dismissed the floor gun position as "of little value" because of its limited visibility; but even more serious was the limitation on fire in the upper foresphere imposed by the underslung position of the nose mount. Various attempts at Wright Field to devise a small "upper nose" turret led only to better understanding that the exact requirements for turrets seemed to develop only from actual construction experience.

When pressed for information to fulfil its obligation to revise the Handbook, the Armament Branch retorted, "No definite steps can be attempted at present to supply exact requirements for flexible machine gun positions," and concluded that large expenditures of time

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and funds would be necessary before flexible machine gun emplacements could be considered adequate for modern high-speed aircraft, a deduction that could have been made in 1918. It was pointed out, however, that progress in turrets depended upon prior solution of a number of specific problems: computing sights to replace wind-vane sights, ballistic data for machine gun fire, the perfection of recoil adapters, and the arrangement of feeds and magazines.¹⁰

In 1936 the Materiel Division initiated two experimental long-range bomber projects, XBLR-2 with Douglas and XBLR-3 with Sikorsky. The Sikorsky drawings called for an imposing array of armament including a 37-mm. cannon and six .50-cal. machine guns. The cannon was to be mounted in a manually operated upper turret. A lower rear single .50-cal. gun turret design provided electric retraction and azimuth rotation, but only manual elevation. When these proposals were considered at Wright Field, the 37-mm. manual turret was viewed with reasonable alarm, but nothing ever came of the project, since the Douglas XBLR-2 proposal eventually won the competition as the better of the two proposals and a contract was negotiated for the airplane, later to be designated XB-19.¹¹

The Douglas XB-19 specification called for two 37-mm. cannon, four .30-cal. and four .50-cal. weapons, disposed in various forms of turrets and mounts about the aircraft, but no provision appeared in

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10. AC Tech. Rpt., "Flexible machine gun equipment for enclosed positions," 21 Jan. 1937, in Arm. Lab. file, E.O. 553-1-261.
 11. Memo Rpt., ES, 12 March 1936, Sikorsky Aviation Corp. Project M5-35, in Arm. Lab. Spec. file.

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the original 1936 specifications for a tail gun.¹² When the Air Corps accepted the XB-19 in 1941, the armament was almost exactly as originally planned save for the addition of a single .50-cal. tail gun mounted much like the gun in the B-23 tail.¹³

The XB-19 turrets were logical developments of the experimental work done in connection with the Douglas airplane series DB-1 through the DB-4. The nose turret was a simple combination of hydraulic pistons or jacks, sometimes referred to as struts, driving the turret through a limited arc in both azimuth and elevation. The upper turret utilized the hydraulic piston principle for elevation operation, but employed a Vickers unit and V-belt drive for azimuth rotation. Hydraulic pressure entered the turret through a rotating gland not unlike the Boulton-Paul patent, and a four-way valve controlled the Vickers unit in speeds ranging from 3° to 60° per second in azimuth. Elevation speeds were more positive, running from 0° to 60° per second.¹⁴

As originally conceived, the XB-19 turrets were a normal step in the evolution of power turrets, but the actual process of manufacture consumed such an exceptionally long time that other and more promising turret designs had taken the field when the Douglas turrets appeared. Whether or not the XB-19 turrets ever reached production becomes a matter of small concern, however, if the lessons inherent in the designs were extracted for future applications. It is impossible to evaluate the importance of Douglas experimental work with the Vickers unit; but in

12. Douglas Project M4-35, in ibid.

13. Memo Rpt., EES, 13 May 1941, in ibid.

14. Ibid.

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the light of its subsequent critical role in turret development, the experience derived in using the rudimentary Vickers unit would seem to have justified the entire expense of the XB-19 armament installation.

It was perhaps unfortunate that Douglas attempted to jump from manual .30-cal. turrets to 37-mm. cannon turrets without first having perfected .50-cal. turrets, for there were many problems encountered with the 37-mm. cannon which were essentially cannon rather than turret difficulties. In principle the Douglas turret called for a .30-cal. machine gun mounted rigidly with the 37-mm. cannon, the former to serve as a sighting guide for the latter. This installation erroneously assumed that ballistic qualities were similar. This was not surprising inasmuch as only one 37-mm. cannon was available to the Air Corps as late as 1937, and that one dated back to 1921.¹⁵ Even more important, perhaps, than the lack of available ballistic data was the fact that the lack of information regarding the 37-mm. cannon delayed Douglas in designing the whole fuselage.¹⁶

As late as December 1939, Douglas asked the Materiel Division for the information accumulated as a result of service testing the DB-2's experimental, power-driven nose turret. In order to design the XB-19 turrets efficiently, Douglas was anxious to extract every lesson possible from the earlier experiments and, lacking adequate range facilities, wanted Wright Field to make official test findings available. In addition to information regarding total running time, unsatisfactory reports,

15. "Notes on Air Corps Ordnance Conference," 18 June 1937, in Arm. Lab. file, Misc. Confidential.

16. Douglas to MD (WF), 24 Feb. 1938, in Arm. Lab. Contract file ac 8132 Douglas XB-19.

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and overhaul periods, the Douglas designers were especially interested in Wright Field opinions on the turret's acceleration rates, minimum as well as maximum, an important consideration which was later neglected by many turret manufacturers during the initial development period.¹⁷

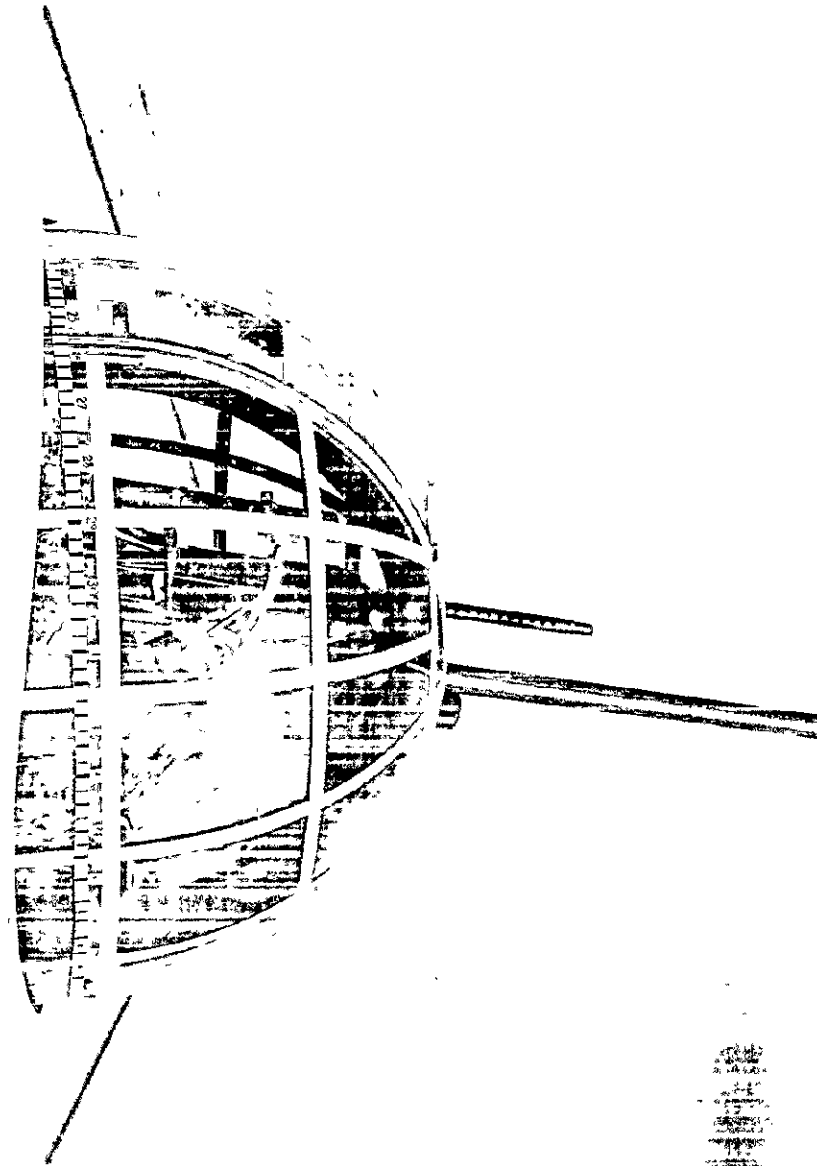
When no letter arrived from Wright Field, Douglas reiterated the request in March 1940. The Experimental Engineering Section's reply stated that the tests conducted on the Douglas nose turret were insufficient to warrant comparison with other equipment. In view of the meager funds available to the Armament Branch, it would seem advisable to have pursued a policy of extracting every possible value from experimental items.

Limited procurement implies a necessity for intensive testing to insure maximum results from a scanty budget. The complaint of inadequate funds becomes invalid if the equipment procured with the money available is not exploited to the utmost. Even more unfortunate, perhaps, the Experimental Engineering Section's reply brushed off the Douglas request by suggesting that Douglas apply for any further information to the Bendix Corporation, which was then interested in the turret problem.¹⁸ It cannot be said whether or not this action killed off a potential turret source, but, significantly perhaps, no Douglas turret developments appeared after that date. In contrast to this unwillingness to utilize available equipment was the aggressive, sales-conscious attitude of the Martin Company, which wrote to the Materiel Division: "During

17. Douglas to MD (WF), 28 Dec. 1939, in Arm. Lab. file, E. O. 554-1-123.

18. Douglas to MD (WF), 20 March 1940; and Chief, EES to Douglas, 29 March 1940, in ibid.

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Douglas B-19 hydraulically operated upper turret.
This locally controlled turret mounts a single
cal. .30 machine gun directly over a 37-mm. cannon.
Note especially the hatch dome contour. 1947.

our present production of front gun turret assemblies . . . we have made numerous improvements. Desiring that the Division may benefit from such improvement . . . one drawing . . . is being forwarded."¹⁹

North American Aviation specifications in 1937 for a twin-engine bomber, the XB-21, called for an armament array of five cal.-30 guns, a hydraulic nose turret carrying one .30, a .30 in either waist, and one in the conventional floor position.²⁰ Tests conducted on the XB-21 by the Armament Branch indicated that the Vickers unit power-drive system, utilizing a valve system not unlike the Boulton-Paul patent version, was improperly engineered, since the motors became "unoperable during inspection," apparently because they were underpowered. Despite the novelty of the drive feature, the all-important detail of slot closure for protection from blast had been completely neglected.²¹

The experimental contract negotiated for a single XB-21 in May 1938 called for hydraulic turret installations. Like the Douglas turrets developing at the same time, North American's experiments were valuable only in so far as they contributed to the slowly accumulating fund of armament information in the Materiel Division.²²

Parallel in time with Douglas and Curtiss developments were those of the Boeing Aircraft Company. In 1935 Boeing's B-15 design, lineal ancestor of the heavy bomber of World War II, proposed two flexible

19. Martin to MD (WF), 12 Aug. 1938, in ATSC 473.5, General.

20. North American Spec. NA-21, 13 Jan. 1937, rev. to Oct. 1938, in ATSC Spec. Br. file, Obsolete.

21. Memo Rpt., ES, 14 April 1937; and Memo Rpt., ES, 9 April 1937, and revision, 13 July 1937, in Arm. Lab. file, Evaluation Folder 1, C.P. 39-800, 38-385, Airplanes A-17 to B-26.

22. Contract AC 11070, 14 May 1938, in Arm. Lab. file, North American XB-21 Contract AC 1070.

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.50-cal. and four flexible .30-cal. weapons, all in plastacelle blisters or panels in conventional nose, upper, and lower positions; but not a single gun was contemplated in the tail. The XB-20, another Boeing product, carried essentially the same armament as the XB-15.

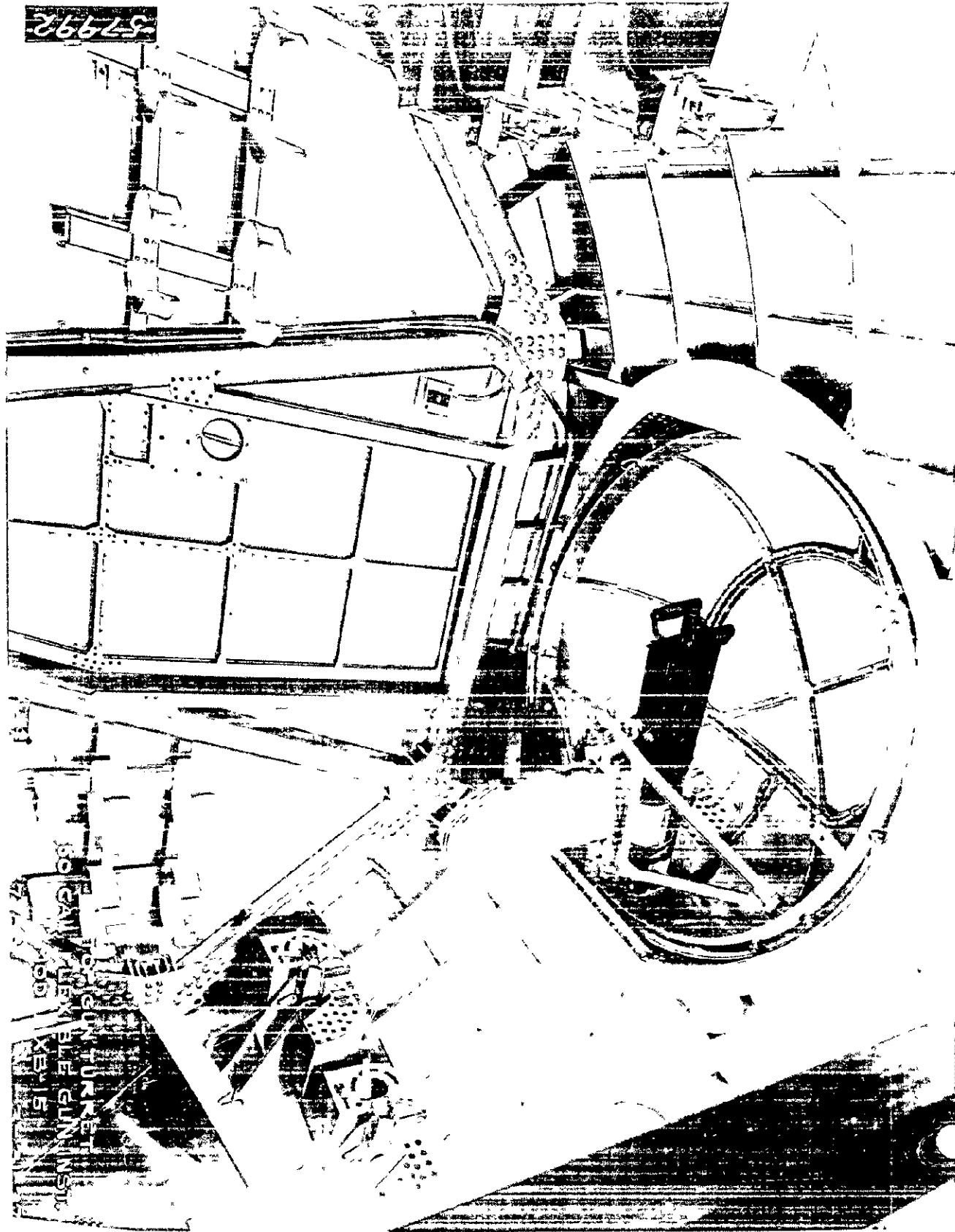
Tests conducted at Wright Field in February 1938 to determine the suitability of the XB-15's armament revealed that the manual nose turret, a small transparent semisphere not unlike the nose mount of the B-18, was extremely difficult to operate, requiring 80 pounds exertion when at 90° azimuth and at 250 mph airspeed. A Wright Field report recommended the installation of a power drive and additional pick-up windows to improve scanning. Moreover, the report continued, "it is important that the area directly to the rear be amply protected by a directly or remotely controlled gun."²³ The distance between a Wright Field recommendation and the actual execution of a design change by a manufacturer was amply demonstrated in General Arnold's fire control conference in December 1939, when Boeing was reported as saying that the manufacturer "could not possibly" put a tail gun on a B-17 since that would require them to "redesign the whole tail."²⁴ The evolution of the B-17's armament installations provides even better evidence of the difficulties facing the Materiel Division in the attempt to get aircraft manufacturers to install turrets.

The Armament Branch studied Boeing's model 299, the future B-17, submitted in 1935 in reply to Circular Proposal 35-26. In place of the

23. Memo Rpt., ES, 10 Feb. 1938, XB-15, in Am. Lab. Spec. file; see also Boeing Y1B-20 and XB-15 Specs.

24. See p. 38, footnote 20, this study.

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Being XB-15 manually operated upper shaft turret
mounting a single set. 50 machine gun. 1937.

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minimum three .30-cal. gun positions stipulated in the type specifications, the bidder elected to install five positions, two waist guns in addition to the conventional emplacements. At Wright Field this proposal seemed unsatisfactory:²⁵

Although the combined area covered by the three upper guns is undoubtedly greater than that which could be allocated to one retractable turret, it would require three gunners constantly stationed at these positions during an engagement. This number, in addition to the nose and floor gunners, would be in excess of those who could be allotted for defense out of the crew of five.

It was pointed out that visibility was actually reduced in using three positions, for the time required to pick up a target leaving one field to enter another might be so great as to reduce the total field of fire below that of a rotating turret manned by a single gunner.

Despite the opinions of the Armament Branch, the XB-17 appeared with five flexible machine guns in the five positions initially planned. No substantial changes in this arrangement appeared down through April 1937, when the Y1B-17A specifications were prepared. Firing tests conducted at Langley Field revealed that the waist guns were restricted to a 20° angle of down fire, a zone somewhat less than that prescribed by the contractor's own specifications, and the lack of scanning windows coupled with the area blanked out by the tail assembly effectively reduced the aircraft's over-all armament efficiency. The Armament Branch concluded that the guns did not defend the airplane satisfactorily and declared that "further procurement of large airplanes should be accompanied

25. Memo Rpt., ES, 1 Oct. 1935, in Arm. Lab. file, Evaluation Folder 1, C.F. 39-800, 38-385, Airplanes A-17 to B-26.

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By the requirement that one well designed power driven turret located in the upper rear position provide the principal defense of the airplane."²⁶

In the summer of 1937 the Armament Branch reported that major changes were essential in the B-17 to overcome "unsafe conditions" and "improper functioning of armament equipment." The "existing limitations" would be "greatly magnified at increased speeds," and power operation of the nose turret was mandatory. An improved upper turret would not only provide a lookout, relieving crew members at the waist positions for other duties until an emergency appeared, but would greatly increase the field of fire.²⁷ These criticisms notwithstanding, the B-17B appeared with one flexible .30-cal. in the nose, another in a streamlined blister upper position, a similar lower position, and two .30-cal. waist guns.

Some indication of the contest between armament and aerodynamic interests appeared in the B-17B specifications, which listed "deviations and exceptions" to requirements, including a "streamline turret without downward angle of fire used to improve the aerodynamic characteristics of the plane."²⁸ These compromises imposed by aircraft design were unsatisfactory. A Wright Field Evaluation Board reported in July 1939 that the Boeing blisters were of unclear design and did not meet the specification requirements. Moreover, the single nose gun offered

26. Memo Rpt., ES, 24 April 1937, in Arm. Lab. file, E.O. 553-274.

27. Memo Rpt., ES, 7 July 1937, in Arm. Lab. File, Bombardment Multi-engine Airplane Spec. 98-201-B, C.P. 36-545.

28. USAAF Spec. B-17B, (Model 98-201-B-1B), 3 Aug. 1937, in ATSC Spec. Br. file, Obsolete. [Underscoring added.]

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unsatisfactory coverage in the foresphere, while the upper and waist gun combination were unsuitable for covering the area blanked out by the tail assembly.²⁹ Apparently the lessons inherent in the B-15 design had not been applied in the B-17.

The Materiel Division recommended in October 1939 that the side blisters be removed from the B-17B,³⁰ but the Boeing specifications of March 1940 for the B-17C reported "protuberances and gunfire substantially the same as B-17B." The Boeing B-17D specifications revised to July 1940 remained the same as the B-17B, with the exception of modifications replacing the lower blister with an elongated "bathtub" and the installation of six "strategically located" ball and socket mounts for interchangeable use of the single .30-cal. nose gun.³¹ Not until the appearance of the B-17E in 1941 were turrets added and the tail modified to mount twin .50's.

Bomber manufacturers for the Air Corps were not the sole source of power turret promotion. By the end of September 1939 the Navy was circulating tentative specifications for patrol bomber power turrets.³² The Materiel Division learned in February 1940 that the Navy regarded turret development as advanced enough to warrant their installation in the new Consolidated PBV. The Bureau of Ordnance specifications were

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29. Evaluation Work Sheet, Boeing 299M, 29 July 1939, in Arm. Lab. file, Evaluation Folder 1, C.P. 39-800, 38-385, Airplanes A-17 to B-26.
 30. TWX, MD (VF) to MD (Wash.), 26 Oct. 1939, in Arm. Lab. Contract file, B-17B, Boeing ac 10155.
 31. Boeing Spec. 299R, 11 March 1940, B-17C, in ATSC Spec. Lab. file, Obsolete; see also B-17D Specs. (Model C-212-4)
 32. Chief, Arm. Lab. to Navy Liaison Officer, 29 Sep. 1939, in ATSC 473.5, General.

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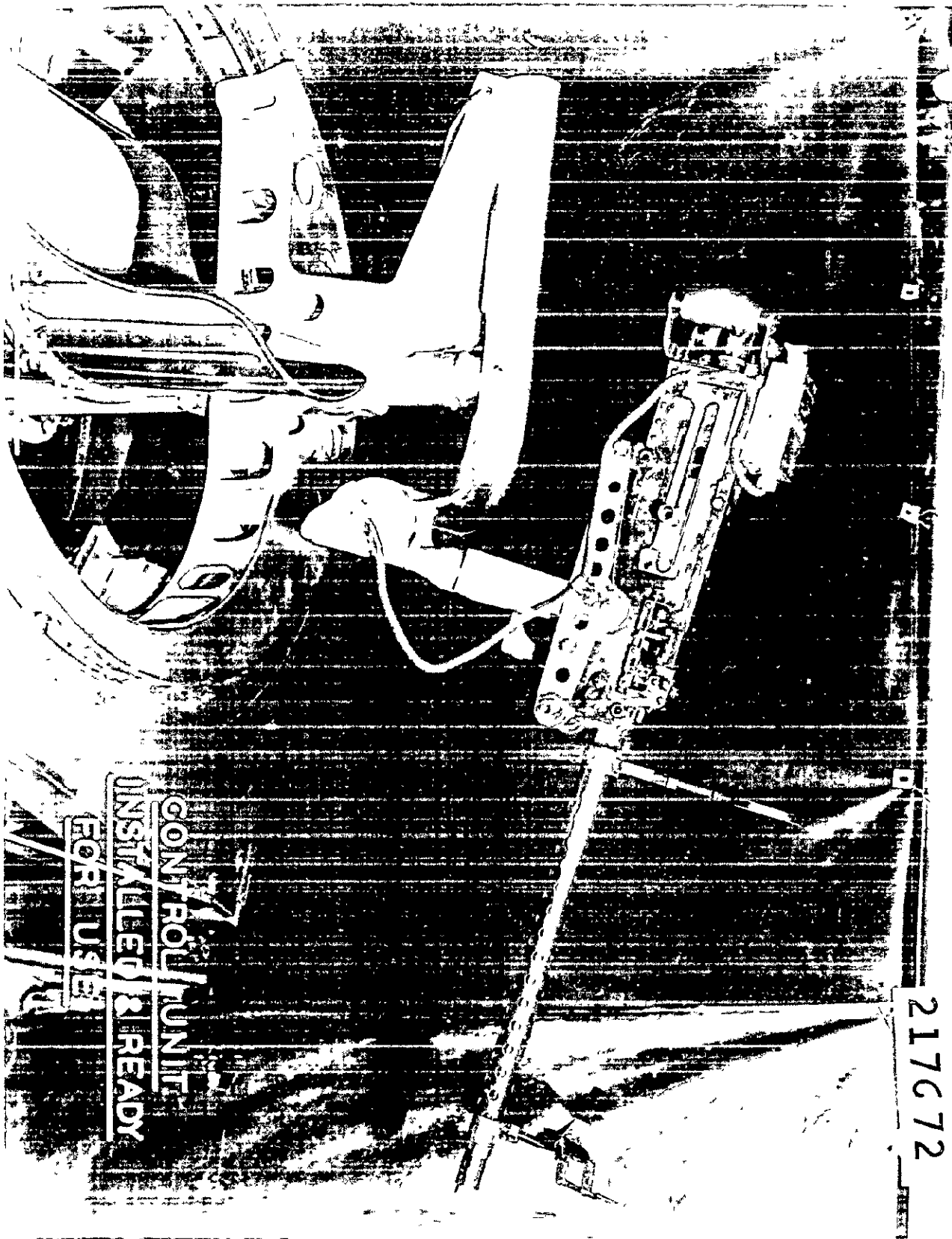
considerably more specific than any contemporary project of the Materiel Division, stipulating azimuth speeds up to 90° per second, standard ring sizes, and provision for "in flight" cleaning of scanning domes.³³

In May 1939, Vultee Aircraft, Inc., offered the Materiel Division an electrically powered flexible gun mount. The division's Technical Executive instructed the Armament Branch to investigate the Vultee project "very carefully" with a view toward possible application on several types of planes if it proved feasible. The Chief of the Experimental Engineering Section later reported that the Vultee mount had merit, then added (rather inexplicably, in view of the trend toward power mounts) that "There are, however, serious objections in that power operation is required." An appreciation of this objection is possible only if one recalls the seriously low capacity of existing aircraft generators, which made the addition of any electrical accessories a critical decision. It is difficult to determine just how much the low capacity of standard aircraft generators retarded the development of power turrets, but undoubtedly the influence was appreciable. Vultee offered an experimental model to the division at \$22,139.22 including a 12 per cent profit, and a mount was secured for testing at the Armament Laboratory.³⁴

The Vultee mount was not a turret but an assisted motion flexible mount, which the Armament Laboratory rejected for a number of reasons.

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33. Memo, B. W. Chidlaw, Capt. A C, to Chief, EES, 29 Sep. 1939, in Arm. Lab. file, Secret Correspondence, folder 2, 1940.
 34. Vultee to MD (WF), 27 May 1939; R&R, 27 May 1939 and 1 June 1939; and Vultee to MD (WF), 12 July 1939, in Arm. Lab. file, Machine Gun Mounts 1938-1939.

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CONTROL UNIT
INSTALLED & READY
FOR USE

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Vulsee experimental power mount. Note the obsolete
wind vane front sight and thumb switch controls. 1939.

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Its dispersion pattern was twice the normal size for comparable mounts, its current consumption without wind load was excessively high, and its spade-grip, electric-button drive control provided directional rotation but no speed control.³⁵ The Armament Laboratory felt that a modification was neither practical nor justified as to expense because of the mount's "inherent fallacy in fundamental design," but concluded that the manufacturer had acquired a "much better conception" of the power mount problem in the course of fabricating the experimental model.³⁶ By slow stages the Armament Branch was acquiring the practical experience necessary to undertake the task of equipping bombers with power turrets.

By 1938 the Materiel Division and the Air Corps in general had begun to acquire a "much better conception" of the fire power problem in bombardment aircraft. The GHQ Air Force had raised some interesting questions regarding rear-firing guns: Would the advantage of a tail gun offset the loss in speed and performance? Could a tail position be so constructed as to insure comfort and firing efficiency for the tail gunner? And finally, Has practical experience in this country proven the desirability of the adoption of such installations in Army bombardment airplanes?³⁷

At the Materiel Division it was believed that even the B-18A was inadequately armed, and a better tail gun could be installed if the necessary space requirements were established during the initial design stage of the airplane. However, since no physical tail gun installations

35. Memo Rpt., EES, 16 Sep. 1939, in Arm. Lab. file, E. O. 553-1-300.

36. Memo Rpt., EES, 2 Nov. 1939, in *ibid.*

37. CG, GHQ AF to MD (WF), 14 July 1938, and 2d ind., MD (WF), 23 Aug. 1938, in Arm. Lab. file, E.O. 553-283.

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from which experience could be derived had been made in the Air Corps, it was the opinion of the division that there was no specific answer to the problem.

The Navy was mounting tail guns in the XPBS-1 and the XPB-2Y1, but information concerning these installations had not been made available to Wright Field where the prevailing opinion had hitherto held that the excessive pitch and roll and yaw of the extreme tail position would prevent accurate firing from the tail even if a gun could be installed there.³⁸

The Armament Laboratory reported in July 1938 that a fixed gun in the B-18A tail could not adequately defend the large area blanked out by the tail assembly, but a remotely controlled gun sighted from the upper turret might prove satisfactory. The laboratory recommended that designs including this idea be solicited from interested manufacturers.³⁹

As an interim measure, the Materiel Division procured the Douglas B-23, a major modification of the B-18A. The new bomber carried four guns, three conventionally placed .30-cal. guns and a single .50-cal. in the tail; but unfortunately it represented a retrogression, since, with the addition of a tail gun, apparently less attention was devoted to the upper midship gun. The turret of the B-18 had been removed and in its stead, as the specifications pointed out, firing could be accomplished through removable windows.⁴⁰

38. Ibid.

39. Memo Rpt., ES, 13 Aug. 1938, in ibid.

40. Douglas Spec. B-23, 5 Dec. 1938, rev. to 15 May 1941, in ATSC Spec. Br. file, B-23, Obsolete.

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The Armament Branch was far from satisfied with the B-23. Tests revealed that the nose gun was "decidedly unsatisfactory." It was designed without reference to the realities of combat, for the gun had to be stowed to use the bombsight and stowing was virtually a two-man job. Furthermore, the newly conceived tail gun was given but scant recognition as "satisfactory within the limits of its design," leaving the gunner cramped and with inadequate scanning. Moreover, it was impossible to crawl from the waist to the tail while wearing a parachute.⁴¹

Shortly after the outbreak of the European war in September 1939, an RAF Air Vice Marshal colorfully divided all German fighter pilots into two general categories, "Gladiators" and "Scum." The majority, he declared, belonged to the latter class; for they were extremely "reluctant to close" with bombers equipped with tail turrets.⁴²

In the United States there were no tail turrets. The backbone of the Air Corps bomber strength consisted of B-18's, of which a tactical officer reported, "It is believed that the present defense armament is inadequate and not tactically sound."⁴³ The 7th Bomber Group at Hamilton Field complained in an Unsatisfactory Report that it could not finish the prescribed course of training because the B-18 nose gun was so designed as to make it "practically impossible to assume the proper sighting position." This deplorable situation was common knowledge at the Materiel Division, but the report contained a single comment which probably accounted

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41. Memo Rpt., EES, 21 Oct. 1939, in Arm. Lab. file, Douglas B-18A, B-23 Contract ac 9977, folder 2.
42. Advantages of tail turrets for machine guns, by U. S. Military Attaché for Air, England, Rpt. 41007, 21 March 1940, in WF Lib., D72.11/94.
43. Memo Rpt., ES, 10 March 1939, and 1st ind., 31 Jan. 1939, on 7th Bomb Gp. UR, 30 Jan. 1939, in ATSC 473.5, General.

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for the whole state of affairs when it asserted that no previous Unsatisfactory Report had been filed on the subject.⁴⁴ It would be unthinkable to expect the Materiel Division to operate in a vacuum. Only so long as a constant stream of critical reports from the service arrived to shape plans and policy could the division hope to move along progressive lines. If this critical element was lacking in the peacetime years, the impetus of war brought an entirely different measure of activity and enabled the division to demonstrate its latent capacity to develop armament equipment.

The Martin B-10, the Douglas B-18 and its lineal descendant the B-23, the Douglas B-19, the whole Boeing family (B-15, B-17, and B-20), the North American Aviation's B-21, and the individual turret development projects undertaken independently by manufacturers working in conjunction with Wright Field all illustrate the transition from hand-held guns to power-operated turrets. The next step in the evolution was the perfection of the mechanisms employed in fire control. Although the concept of fire power had reached maturity, the mechanisms conceived to implement that concept were a long way from completion.

44. Ibid.

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Chapter V

EVOLUTION OF POWER TURRETS: EXPERIMENTAL PHASE, 1938-1940

The evolution of a remotely controlled gun for the B-18 tail gun position is of peculiar interest not only because it marks an important step in the rise of a large-scale turret industry, but also because it explains just how the Armament Branch went about the task of steering an important manufacturing source into a novel production field. It is necessary to examine this steering process in detail in view of the fact that a large proportion of Armament Laboratory activity was devoted to monitoring manufacturers' projects.

As early as July 1938 representatives from Wright Field, visiting the General Electric Company's plant at Fort Wayne, reported the development of an electric variable-speed drive, called metadyne, which might be applicable to gun control units.¹ The "obvious necessity" of remote control guns in supercharged cabins and tail positions led Wright Field to open discussions with the General Electric (G.E.) Schenectady plant, already familiar with gun controls on Navy contracts, for the various electric drives available. The metadyne and pliodyne systems seemed to hold most promise; each represented variations of the shorted-armature,

1. Memo Rpt., ES, 6 July 1938, in Arm. Lab. file, Misc. Correspondence, 1938.

controlled-field drive used extensively with heavy industrial equipment requiring constant speed under varying torque loads.² A short time later the Equipment Laboratory independently obtained the same information and forwarded it to the Armament Laboratory with the suggestion that the Armament Branch establish torque and speed requirements for such controls to permit allocation of funds by the Equipment Branch for development purposes.³

In November 1938 representatives of the Navy, the Materiel Division, and G.E. held a conference in Schenectady to reach a decision on the drive to be installed in a tail gun installation proposed for the B-18. A multiple contact control, the Bowman system, devised for Navy searchlights, was rejected as inadequate, and the conference decided in favor of the metadyne system originally designed for Navy five-inch shipboard gun controls. The engineers at G.E. asked the Materiel Division representatives for all available information which would facilitate the preparation of their initial proposal.⁴ When these design data were received, G.E. promised a proposal in two weeks.⁵ Not until 3 March 1939, however, were a final proposal and detailed specification ready for Wright Field.

The G.E. remote tail gun, offered to the government complete with compensating sight at \$25,000, contained a number of novel features. The

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2. Memo, Capt. G. S. Irvine to Chief, ES, 28 July 1938, in Arm. Lab. file, E.O. 554-2-96.
 3. R&R, Chief, Equip. Br. to Chief, Arm. Br., 13 Aug. 1938, in *ibid.*
 4. Rpt. of MD representatives on conference at G.E., Schenectady, 3 Nov. 1938, in Arm. Lab. file, Secret Misc. Correspondence, folder 2, 1940.
 5. G.E. to MD (WF), 2 Sep. 1938, in Arm. Lab. file, E.O. 554-2-96.

single .30-cal. gun was controlled through a 40° cone of fire by an amplidyne drive, a modification of the earlier metadyne system. The installation was to be capable of a 30^o-per-second maximum speed within a 75- to 350-watt range of power consumption. The compensating sight was to correct for ballistics and parallax, but range, air speed, and relative target speed were entered as constants. The gunner, stationed in the upper B-18 turret, sighted through either one of a pair of standard collimator, illuminated reticle, parallax reducing sights designed to give a relatively unobstructed line of vision past the tail assembly. The original specifications called for bicycle-pedal turret rotation, but this innovation was never perfected. The gunner charged the gun by a system of cable and pulleys. The magazine carried only 185 rounds.⁶

The tail gun project gave ample evidence of the difficulties inevitably attending the development of a novel item of equipment by a manufacturer not entirely familiar with the problems of aircraft design. The limitations arising from this inexperience on both sides were nowhere more cogently illustrated than in the negotiations between Wright Field and G.E. which resulted in this aberrant directive from the Contract Section at Wright Field: "Any electrical connections which may be required between the turret and tail gun installation shall withstand rotation of the turret throughout 360° . No provisions are required, however, to permit turret rotation in excess of 360° in either direction."⁷ Despite the obvious handicaps of working in the dark, an experimental

6. G.E. to MD (WF), 3 March 1939, in ibid.

7. Contract Sec. (WF) to G.E., 30 June 1939, in ibid.

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tail gun was ready for firing tests at Aberdeen Proving Grounds in November 1939.⁸

Even before G.E. undertook to develop a tail gun, the Materiel Division displayed an interest in power-operated turrets. As early as 1936 a board of officers appointed to evaluate multi-seater fighter designs recommended "power operation for all large caliber gun turrets" as well as provision for future incorporation of remote control systems permitting a "considerable saving in personnel complement" and improved fire power in airplanes. The division concurred in these recommendations, but unfortunately in the fiscal year 1936 there were no available funds for fire control projects.⁹

The lack of funds was a particular handicap because the Sperry Gyroscope Company of New York had a fire control experimental project ready to push into the actual construction stage. In August 1936 a special committee, appointed to study the Sperry proposal for a twin 37-mm. cannon fire control system for use in the as yet undeveloped Bell Aircraft Company fighter (XFM-1), reported: "According to the present state of development of the art, it appears that an exact theoretical solution of fire control with a free gun and a free target is improbable." The committee noted, among others, the following limitations in the Sperry proposal: the mounts and gear drives were drawings only and not yet perfected in detail; the system presupposed an accurate

8. Chief, Arm. Lab. to Capt. C. S. Irvine, 2 Nov. 1939, in Arm. Lab. file, Misc. Fire Control 1940. See also Memo Rpt., EES, 10 Oct. 1940, in Arm. Lab. file, E.O. 554-2-96; and G.E. Tail-gun Manual, 19 Nov. 1939.

9. Chief, MD to C/AC, 21 July 1936, in Arm. Lab. file, E.O. 554-1-79.

external range finder to apply a range rate input; the technical problems of synchronizing the hydraulic valves to coordinate the movement of two remote guns were not perfected in detail; and, moreover, "there is some doubt as to the advisability of installing flexible forward guns in a 300 mph airplane" of the XFM-1 fighter type.

The Materiel Division objected strenuously to the committee's conservative report, pointing out that the very purpose of purchasing such an installation as that considered in the Sperry proposal was to seek experience in an unexplored field through experimental expenditure. General Arnold supported the Materiel Division; and after accumulating 11 indorsements, the project was approved by the Secretary of War for procurement during the 1937 fiscal period, at an estimated cost of \$93,000.¹⁰

The Sperry fire control project for the XFM-1 consisted of a computing unit and a telescopic sight arranged to lay twin 37-mm. cannon by means of a joy-stick-controlled hydraulic drive actuated by Vickers units. The system was unique in that the sight followed the guns instead of the reverse, which was conventional in gun control systems. The real importance of the Sperry project, however, lay not in any unique mechanical feature but rather in the experience that Sperry was acquiring in the field of fire control. The XFM-1 computer unit contained ball carriage speed controls, adding and subtracting differentials, and precision-cut, three-dimensional ballistic cams. All of these elements were to contribute to the success of the later K-series sights in the

10. Memo, Lt. Col. H. S. Burwell, Chairman of Special Committee on Sperry Central Fire Control for XFM-1 to C/AC, 1 Aug. 1936, in Arm. Lab. file, E.O. 554-1-79.

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coming war and to establish the soundness of the Materiel Division's insistence upon the educational value of experimental contracts.

The importance of carefully planned coordination between Air Corps and Ordnance Department research programs was never more apparent than in the case of the Sperry project, which depended entirely upon Ordnance for the basic ballistic information which went into the Sperry computer cams. Without realistic ballistic information, the best drive system in the world was of little value. Both the Sperry and Douglas 37-mm. projects were seriously impaired by the fact that as late as 1937 Ordnance had but inadequate ballistic data on 37-mm. cannon fire.

In January 1939 Wright Field representatives studying progress of the XFM-1 project at the factory indicated the trend in Materiel Division thinking by asking whether Sperry or any of the Sperry subsidiaries had "available or under consideration" drive units, smaller and simpler than the XFM-1 unit, for use in connection with machine-gun turrets. The XFM-1 fire control mechanism became an important link in the chain of Sperry developments, despite the fact that the XFM-1 itself was destined to be short-lived.¹¹ The frankly experimental nature of the Sperry project became evident in June 1938 when a conference of Bell, Sperry, and Wright Field representatives surveyed the entire power-drive problem and considered the possibility of converting the project to an all-electric system "in line with the general trend toward the use of electric systems throughout the airplane."¹² Sperry considered the all-electric system to be a second phase in the evolution of fire control equipment.

11. Memo Rpt., EES, 26 Jan. 1938, in ibid.

12. Sperry to MD (WF), 23 June 1938, in Arm. Lab. file, Fire Control Contract.

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The original XFM-1 computer was based upon the assumption that the relative positions of the target and attacker would change but little, and the computer was capable of but small angular rates of prediction. With the change from hydraulic to electric, Sperry hoped to achieve angular rates of 3° per second. This prediction rate was established as a goal, in Sperry's terms, as "the minimum that should be attempted if we are to keep pace with the rapid development that must take place in the art."¹³ Actually the goal was raised to 6° per second in the specifications accompanying the Air Corps contract signed 9 December 1938 for 13 Sperry fire controls at \$27,400, after the experimental model had been tested in a B-18.¹⁴

The fact that the XFM-1 limped along to a limited and tardy production undoubtedly influenced unfavorably the development of the Sperry fire control apparatus. A test of the equipment in a YFM-1 at Bell's Buffalo plant elicited only a guarded official opinion of "satisfactory for the purpose intended"; for at that time there was no way of evaluating the importance of the educational contracts in strengthening the Sperry organization.¹⁵

The XFM-1 fire control project lingered on at Wright Field long after it had outgrown its usefulness, although as late as 1942 some consideration was given to converting the project for use as a cannon installation in the B-24 tail.¹⁶ Nevertheless, the project was of

13. Sperry to MD (WF), 17 Oct. 1938, in ibid.

14. Phone transcript, Frederick Vose, Sperry and Lt. P. E. Shanahan, WF, 7 Nov. 1938; Chief, ES to Sperry, 1 Sep. 1938; and Contract AG 11745, 9 Dec. 1938, in ibid.

15. Memo Rpt., EES, 5 April 1940, in Arm. Lab. file, E.O. 554-1-106.

16. Memo Rpt., EES, 28 Feb. 1942, in Arm. Lab. file, Fire Control Contract. See also Chief, Arm. Lab. to Chief, EES, 7 June 1940, in Arm. Lab. file, E.O. 554-1-129.

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primary importance in adding to the working procedure and engineering experience accumulated by Wright Field and Sperry.

An interesting sidelight to the Sperry project appeared when the Materiel Division was informed that "the Navy states that they spent \$9,000.00 with Sperry" for fire control apparatus and received "absolutely nothing for it," a condition which led to a Navy recommendation not to contact Sperry on the matter.¹⁷ Exactly six days later, the Chief of the Navy's Bureau of Ordnance requested detailed information from the Materiel Division on the Sperry project; and, when this information was not dispatched immediately, the Navy brought pressure to bear through the Chief of the Air Corps to secure the report desired. The Materiel Division had to fight not only to raise funds for experimental work but to maintain entrée with manufacturing sources as well.¹⁸

In January 1939 the Materiel Division had acquired sufficient experience in the field of power-driven gun turrets to prepare a circular letter for several manufacturers who had displayed an interest in the subject. The letter contained working drawings of the B-18 and the .30-cal. machine gun, a copy of the armament section of the Handbook of Instructions for Airplane Designers, and the reports containing all available data from wind tunnel tests of machine-gun drag.¹⁹

The problem of creating fire control apparatus presented enormous difficulties. To begin with, the whole field was relatively unexplored.

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17. Phone transcript, Capt. Moore, WF Arm. Lab. and Maj. Whitehead, OCAC, 5 Aug. 1938, in Arm. Lab. file, E.O. 554-1-79.
 18. Memo, Chief, Navy BuOrd to C/AC, 11 Aug. 1937, and related correspondence, in Arm. Lab. file, E.O. 554-1-79.
 19. MD (AF) to Bendix, Maxson, and Sperry, 20 Jan. 1939, in Arm. Lab. file, Misc. Fire Control 1940.

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The progress achieved to date consisted of the independent projects of several different manufacturers working separately along parallel lines. Moreover, the very nature of the problem required the utmost in engineering liaison and coordination. Fire control involved sights, turrets, and aircraft. Sights required ballistic data which were the responsibility of Ordnance. Sights required optical components demanding the best of liaison between the computer producer and the optical manufacturer. The turret producer had to correlate with the sight builder, and both had to coordinate with the aircraft designer and manufacturer.

At Wright Field it became apparent that no rapid solution of the fire control project would ever be possible so long as manufacturers continued to attack the problem individually. Without actually enunciating a formal policy, the Armament Laboratory by 1939 began to pursue a program of cooperative enterprise utilizing the best products of several staffs of industrial engineers. The branch was finally fulfilling its wartime role of monitor and engineering liaison center for the developmental projects of the manufacturers. The success of this policy is attested by the report of an Armament Laboratory engineer returning from a survey of such cooperative fire control projects of a number of manufacturers:²⁰

Things never looked so good. We are slowly getting the right connections, and the farm principle we initiated for ideas and real talent is producing wonderful results. When all things are finally sifted down, we shall be well in advance of what any single organization could develop regardless of time.

By the end of 1939 six manufacturers were actively engaged in power turret projects, but before considering these individual companies in

20. M. E. Goll, Arm. Lab. to W. G. MacNeill, Arm. Lab., 18 March 1939, in ibid.

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detail, two other factors affecting turret production in the United States should be studied: first, aircraft delivery schedules, and second, the influence of foreign turret developments. A tabular representation of aircraft production schedules anticipated for parts of 1940-1941 is sufficient to provide a background of information about delivery schedules against which to judge the degree of urgency motivating turret production.²¹

Date B-17C B-17D XB-24 B-24 B-24A B-23 B-25 B-26 A-20B

1940

April			1			8			
May				1		12			
June				3		14	1		
July	2			3		2			
Aug.	1				1				5
Sep.	2				1		2	1	6
Oct.	2				2		6		7
Nov.	2				2		11		8
Dec.	2				2		20	2	9

1941

Jan.	3				4		24	7	48
Feb.	4				4		24	10	53
March	5	1			5		24	19	66
April	5	7			5		24	21	102
May	5	9			5		24	21	104
June	5	7			6		24	21	98
July		7							28
Aug.		7						78	85

21. Memo Rpt., EES, 17 May 1940, in *ibid.*

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As to foreign developments, early in 1940 General Arnold directed that a search be made of all the Information Division's intelligence reports for information concerning British power turrets for use by the Materiel Division. The search revealed that Frazer-Nash turrets manufactured by Parnall Aircraft, Ltd., were installed in the Hawker Demon, the Handley-Page Harrow, the Armstrong-Whitworth Whitley, and the Short Sunderland.²² In addition, anyone who chanced to read the popular British aviation magazine Flight in October 1936 would have known that Boulton-Paul turrets were also being installed on the Blackburn Roc and Blackburn Skua as well as on the Boulton-Paul Defiant.

The RAF was "secretly perfecting" machine-gun and cannon turrets in addition to computing sights, according to intelligence reports from Britain. As early as July 1939 the Air Ministry requested the Admiralty Research Laboratory to undertake a control project for "guns heavier than .303 mounted in turrets," and by the spring of 1940 the original "straight and level flight" assumptions were being questioned in favor of gyroscopically stabilized sights.²³

The full impact of British turret development, however, did not strike the Materiel Division until July 1940 when two officers, long associated with the work of the Armament Branch, submitted a report

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22. R&R, MD (Wash.) to MD (WF), 8 March 1940, in Arm. Lab. file, Misc. Secret Correspondence Folder 2, 1940.
 23. Development of Remote Control Aircraft Machine Gun and Cannon Turrets, by U. S. Military Attaché for Air, England, Rpt. 40982, 18 March 1940, in WF Lib., D72.11/93; and "Minutes of the Seventh Meeting of the Gun Sub-Committee Held at the Air Ministry, 7 May 1940," by U. S. Military Attaché for Air, England, Rpt. 42277, in WF Lib., D70/158.

covering the British turret program in minute detail. The officers, Lt. Col. Grandison Gardner and Maj. F. O. Carroll, sailed to Italy in March 1940 and traveled overland through France to England, where they discussed turret production with Air Ministry officials, RAF officers, and aircraft manufacturers, as well as turret manufacturers themselves. The two Air Corps observers reported the application of power turrets to bombardment aircraft as the "outstanding development of the British." Even more important, the observers noted, "The installation of these turrets on some of their bombers had caused such losses to the enemy attacking airplanes that the British now claim that attacks directly aft have been discontinued on these installations," forcing the Germans to make beam approaches with little success. Their report concluded, "It is imperative that our heavy and long range bombers be equipped with at least four turrets," fore, aft, top, and bottom. Admittedly such armament would reduce bomber speed and performance, but British practice seemed to have proved the merit of subordinating every bombardment airplane function to its defense, even at the cost of aerodynamic efficiency.²⁴

Of the three largest turret manufacturers in the United Kingdom--Bristol, Frazer-Nash, and Boulton-Paul--the latter two accounted for the greater part of the total production. The importance of all the models lay in their ease of tracking and the "positive control at very low rates of movement" possible with hydraulic systems almost entirely

24. "Report on Trip Abroad," by Lt. Col. Grandison Gardner and Maj. F. O. Carroll, 1 July 1940, p. 4, in WF Lib., Doc/232.

free from overtravel, the objection which had induced the British to reject electric systems several years before the war.

Frazer-Nash turrets, built by Parnall Aircraft, Ltd., reached an estimated production of 16 or 20 turrets per day in May 1940 if the output of subsidiary factories is included. This figure represented the total of four different types including a quadruple .303 nose and tail turret, a twin .303 nose and tail turret with servo-fed ammunition belts running to magazine reels amidship where expenditure of cartridges would not affect the aircraft's balance adversely, and finally a twin .303 retractable lower turret called a "dust bin."

Boulton-Paul Aircraft, Ltd., manufacturers of the Boulton-Paul turret, estimated a production of 65 turrets per day in May 1940, but the Air Corps observers did not find evidence to corroborate this claim. Boulton-Paul produced four types similar to the turrets found at Parnall except that the power drive consisted of a self-contained electro-hydraulic unit rather than a simple hydraulic turret drawing pressure through a hydraulic gland from the ship's system. The Boulton-Paul system, employing a ladder electrical power lead, greatly reduced its vulnerability to enemy fire in contrast to the long, exposed hydraulic feed lines required by Frazer-Nash. Perhaps the most important difference between the two types of turret lay in the fact that the Frazer-Nash system required varied angular displacement of the control handles as the torque load varied, while the Boulton-Paul system compensated for torque, and equal control displacement gave equal angular movement under all conditions of loading.

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"The British have shown the way and the method together with the results to be obtained in the installation of machine gun turrets," noted the Gardner-Carroll report, and "no effort must be spared to apply this type of mechanism to our own advantage."²⁵ The remaining question for the Air Corps, therefore, was whether to take over British turrets in their entirety for manufacture in the United States or to produce independent designs for local production. The critical element of time favored the former course, but a greater number of factors weighed in the opposite balance.

Despite the fact that Col. E. A. Deeds, representing Pratt & Whitney, was reported to be negotiating with the British for turret manufacturing rights, high British officials had suggested informally that the Air Ministry might be willing to trade turret designs in exchange for America's Norden bombsight. Any such exchange would inevitably involve a delay.²⁶ Furthermore, the Gardner-Carroll report held that British turrets were heavy and cumbersome and ill-suited for use with Air Corps bombardment aircraft.²⁷

American naval air officers who had an opportunity to operate British turrets in various aircraft (including the Manchester, Halifax, Stirling, Sunderland, Whitley, Wellington, Defiant, Beaufort, Botha, Anson, and Hudson) were of the opinion that turret development in England far surpassed the progress made in the United States and that "every effort should be made" to assist the British manufacturers to

25. Ibid., p. 7.
26. Ibid., p. 54.
27. Ibid., p. 24.

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establish facilities in the United States.²⁸ The question was not settled for many months, and as British production increased and manufacturers in the United States devoted larger amounts of time and money to turret development projects, the likelihood of manufacturing British turrets in the United States diminished proportionally.

By the end of November 1940, Parnall, Ltd., and a combination of 30 subsidiaries were employing 4,500 men in the parent plant and a total of 30,000 men directly and indirectly to achieve an output of 600 turrets a month with an estimated goal of 1,000 turrets a month. An organization of this scale lent weight to three axiomatic contentions made by Boulton-Paul as well as Frazer-Nash: (1) turret production should be separate from aircraft production, that is, turrets should be treated as government-furnished equipment; (2) each turret manufacturer should produce one type of turret, that is, hydraulic turret manufacturers should stay in the hydraulic field and electric turret manufacturers, in the electric field; and (3) turret manufacturers should not attempt to modify until production was rolling and modification could be carried out without detriment to production output.²⁹ That this latter axiom was learned from bitter experience was inferred by the Assistant Secretary of War in August 1940. "It has been reported that one of the factors contributing to the present desperate position of the British is the failure to freeze designs," he warned the Army procurement

28. "Information on Frazer-Nash and Boulton-Paul Aircraft Machine Gun Turrets," by U. S. Naval Attaché, England, Rpt. 1569, 29 Nov. 1940, in WF Lib., D72.11/102.

29. Ibid.

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services:³⁰

The Technical Services are never satisfied with anything less than a perfection which is always unobtainable. The best is the enemy of the good. If we are to avoid the catastrophe of "too late and too little", there must be a decision as to production types. Germany has demonstrated that thousands of imperfect tanks on the battlefield are better than scores of perfect tanks on the testing ground.

In the fall of 1940 the Materiel Division requested the British Air Commission to secure working drawings of the two major British turrets and physical samples as soon as shipment could be arranged.³¹ Meanwhile, intelligence reports from Britain were reiterating that "more and more evidence is piling up that mechanical turrets are absolutely essential to the success of airplanes whose size permits their installation."³² The French apparently believed in the necessity of power turrets, for attaché reports commented on a hydraulic turret designed by the Société Duplication de Machines Motrices. The Germans, however, gave no evidence of faith in the power turret doctrine. Flexible gun installations examined on captured German aircraft lacked power drives and were considered "extremely crude" by RAF observers.³³ As to the United States, the chapter below discusses the progress made by six interested manufacturers through 1940, when contracts for quantity production began to appear.

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- 30. Memo, ASN to C/AC, 26 Aug. 1940, in CTI-96, 7 Sep. 1940, in Arm. Lab. CTI file.
 - 31. TWX, EES to ES, MD (Wash.), 7 Oct. 1940, in Arm. Lab. file, Machine Gun Mounts, 1940.
 - 32. MID, Britain, Confidential Rpt. 336, in MID, United Kingdom, Rpt. 41,368, 3 Sep. 1940. See also CTI-92, in ATSC 473.5, General.
 - 33. "French Airplane Armament and Armor Protection," by U. S. Naval Attaché, France, Rpt. 49, 31 Jan. 1940, in WF Lib., D70/136; and Examination of gun mounts on He-111 airplane, British rpt. forwarded by U. S. Military Attaché, England, Rpt. 42514, June 1940, in WF Lib., D72.11/108 and 109.

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Chapter VI

POWER TURRET DEVELOPMENT: FIRST INDUSTRIAL PHASE, 1939-1940

The European war brought the Air Corps to a difficult decision. The United States had no air force, generally speaking, in 1939, so it became necessary to gamble on a "paper" air force--gamble to the extent of projecting a series of new airplanes for development in the hope that they would reach production before the United States became involved in the war. This gamble applied as well to accessories and armament. In the hectic early days of the war in Europe, the Materiel Division sought to accelerate experimental work on fire control equipment by breaking the whole problem into separate components, each to be a project within itself. Tentatively, and as a point of departure, the major industrial concerns interested in turret development were assigned specific airplanes to arm. In this way it came about that Sperry designed equipment for the B-17, Bendix for the B-25, Martin for the B-26, and General Electric for the A-20. All these and several other projects were under way simultaneously, but each manufacturer's turret development will be discussed individually.

Sperry Gyroscope Company

As far back as 1936 the Materiel Division was acutely aware of the need for fire control apparatus. As the caliber of aircraft guns increased, the number of rounds of potential fire per minute decreased,

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and this decrease made greater sighting accuracy mandatory. It was logical to invite Sperry representatives to attend a fire control project conference at Wright Field, for Sperry had already accumulated considerable experience in designing naval and antiaircraft gun directors.¹ The Sperry engineers who visited Wright Field discussed computers, power drives, and fire control systems with Armament Branch personnel and sketched tentative plans for future Sperry projects, but the original idea of fire control devices for guns of larger caliber was subverted by the fact that it had proved necessary to base all considerations on .30-cal. ballistic tables, "inasmuch as no information had been available on trajectories of 20 and 37 mm ammunition."²

Out of the conversations held at Wright Field came the XFM-1 project as an immediate objective in 1936, delaying the .30-cal. fire control project until the Sperry proposal of March 1939, which covered a computing sight for use in connection with hand-held flexible .30-cal. machine guns. The proposal specified a reflex or collimator sight unit to mount above the machine gun spade grips, where it could be fed azimuth and elevation rates by flexible shafts and data on relative lateral velocity, slant range, and indicated airspeed by manual input dials.

At the same time that the sight proposal appeared, Sperry drew up tentative specifications for a "means for laying one or two indirectly controlled caliber .30 flexible machine guns from a central station," including flexible cables up to eight feet long for transmitting sighting

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1. Chief, ES to Sperry, 20 May 1936, in Arm. Lab. file, E.O. 553-1-79.
 2. Memo Rpt., EES, 4 June 1936, in ibid.

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station rates to a power-operated gun mount by means of Maxson torque-converters.³ Something of the urgency and pressure of the times is apparent in the record of Sperry projects. Seven days after the Sperry proposals were prepared, an Armament Branch officer visiting the Sperry plant in New York telegraphed Wright Field recommending that the division delay approval on the flexible gunsight project since other projects looked more promising.⁴ Fire control projects were slow in gathering momentum, but once under way the novel ideas came in fast.

In June 1939 Sperry reported that its research engineers were preparing a comprehensive treatise attempting to outline every phase of the fire control problem. Sperry expected that an all-inclusive solution or system would cost about \$150,000, and Sperry officials were anxious to sound out Wright Field on the possibility of a fire control system contract. However anxious the Armament Laboratory may have been to enter promising new lines of development in 1939, it was necessary to wait for the next fiscal year's appropriation before any extensive expenditure could be undertaken. Nevertheless, an Authority for Purchase was prepared for a .30-cal. computing sight at \$24,000, and an expenditure of \$8,000 was authorized for beginning work on a central-station fire control system of .30-cal. machine guns.⁵

The central-station fire control project (CFC) grew logically out of the original Sperry .30-cal. flexible gun sight, which had centered

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3. Sperry Specs. and Proposals, 10 March 1937, in Arm. Lab. file, E.O. 554-2-97.
 4. TTX, Shanahan to Moore, 17 March 1939, in ibid.
 5. Phone transcript, Fred Vose, Sperry and M. E. Goll, Arm. Lab., 23 June 1939, in ibid.

REF ID: A66872

attention on the whole fire power problem and indicated the necessity of a composite system of sight, computer, and remote-control power-driven gun mount. The negotiations with Sperry over the .30-cal. sight project led the Materiel Division to conclude, "Consideration of fire control in its broader phases cannot be longer delayed." The very act of compiling adequate working drawings for Sperry engineers to use as a point of departure brought the problem of bombardment defense into focus, particularly when the Armament Laboratory felt it necessary to sound out tactical pursuit units for information to use in preparing studies on the modes of pursuit attack for Sperry's benefit.⁶

The search for information on angles of attack delayed the fire control project somewhat but not nearly so much as the cumulative delays imposed by the restrictions of the secrecy agreements surrounding all projects of this nature. It was typical of this limitation that the Materiel Division retained its dossier of information on aircraft designs, machine-gun dimensions and performance, and pursuit attack until a contract was actually negotiated with Sperry, when the material was forwarded for use.⁷ The effects of this policy on the course of development raise a question. Would the interests of the Materiel Division have been better served by the restrictions and limitations of secrecy, or by a policy of providing reliable manufacturers with every scrap of available information even before a contract of any sort was contemplated, to the end that the manufacturer's engineers could have become thoroughly versed

6. Memo Rpt., ES, 18 April 1939, in Arm. Lab. file, Misc. Fire Control 1940.

7. Chief, EES to Sperry, 1 May 1939, in ibid.

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in the broader aspect of the problem in hand? Specifically, would it not have been far more productive if Sperry, G.E., Bendix, and Westinghouse, to name but a few, had been supplied with all the available information necessary to project a fire control system long before funds became available for such an enterprise?

When at last the necessary information was made available, Sperry engineers prepared a treatise on the fire power problem, evaluating a wide range of factors including volume of fire, dispersion, encounter duration, weight limitations, size limitations, personnel requirements, ease of maintenance, reliability, and cost. This evaluation was materially improved because of Sperry's experience with the XFM-1 Bell fighter project.

Sperry concluded that a fire control system should contain a minimum of two sighting stations and computers, each a combination of upper and lower periscopes with a 36° scanning cone. Stereoscopic and coincidence range-finder systems having proved unsatisfactory in experimental tests, Sperry favored a stadimeter range finder. After an extensive survey of a large number of drive units (electric, external hydraulic, and internal or self-contained hydraulic), Sperry selected the last as best suited for handling excessive torque loads in certain positions, wide temperature and pressure variations dependent upon altitude changes, and difficulties incident to unbalanced torque loadings arising with one gun firing.⁸

8. Central Station Fire Control System, a treatise on defensive armament for bombardment type airplanes, prepared by the aircraft armament department of Sperry Gyroscope Co., 29 March 1940, in Arm. Lab. file, E.O. 554-1-129.

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Sperry proposed to build an experimental, remote, retractable turret mounting twin .50's and a computing sight for \$116,325, or, in quantity, at \$59,835 each.⁹ The plans called for construction of the computer and drive-control combination, but the turrets themselves were considered to be "integral parts of the airplane structure and therefore appropriately part of the airplane manufacturer's contract."¹⁰

The problem of dividing responsibility for the various components was no more confusing than the rapid changes in plan and design. Proposal followed proposal in rapid succession, and no system or program reached completion in its original form. Hardly had Sperry received an Authority for Purchase for two computers and three controls at \$79,277 when the Materiel Division requested a proposal on a complete central-station fire control system.¹¹

In order to cope with changing concepts, designs, and contract status, Sperry adopted a policy of planning all component units for interchangeable use as nearly as possible. The proposed CFG system was to utilize the hydraulic controls perfected for the .30-cal. turret and the computing sight designed for hand-held gun use. Sperry wanted all units to be "salvageable," each unit sufficiently flexible to be adaptable to a combination of problems.¹²

Throughout the early months of 1940 Sperry and the Materiel Division groped for a solution to the bombardment armament problem. The hand-held

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9. Sperry to MD (WF), 28 March 1940, in Arm. Lab. file, E.O. 554-1-141.
 10. Sperry to MD (WF), 29 March 1940, in Arm. Lab. file, E.O. 554-1-129.
 11. Sperry to MD (WF), 15 April 1940, in Arm. Lab. file, E.O. 554-1-123.
 12. Phone transcript, Fred Vose, Sperry and Chief, Arm. Lab., 30 April 1940, in ibid., see also memo, EES, 17 May 1940, in Arm. Lab. file, Misc. Fire Control 1940.

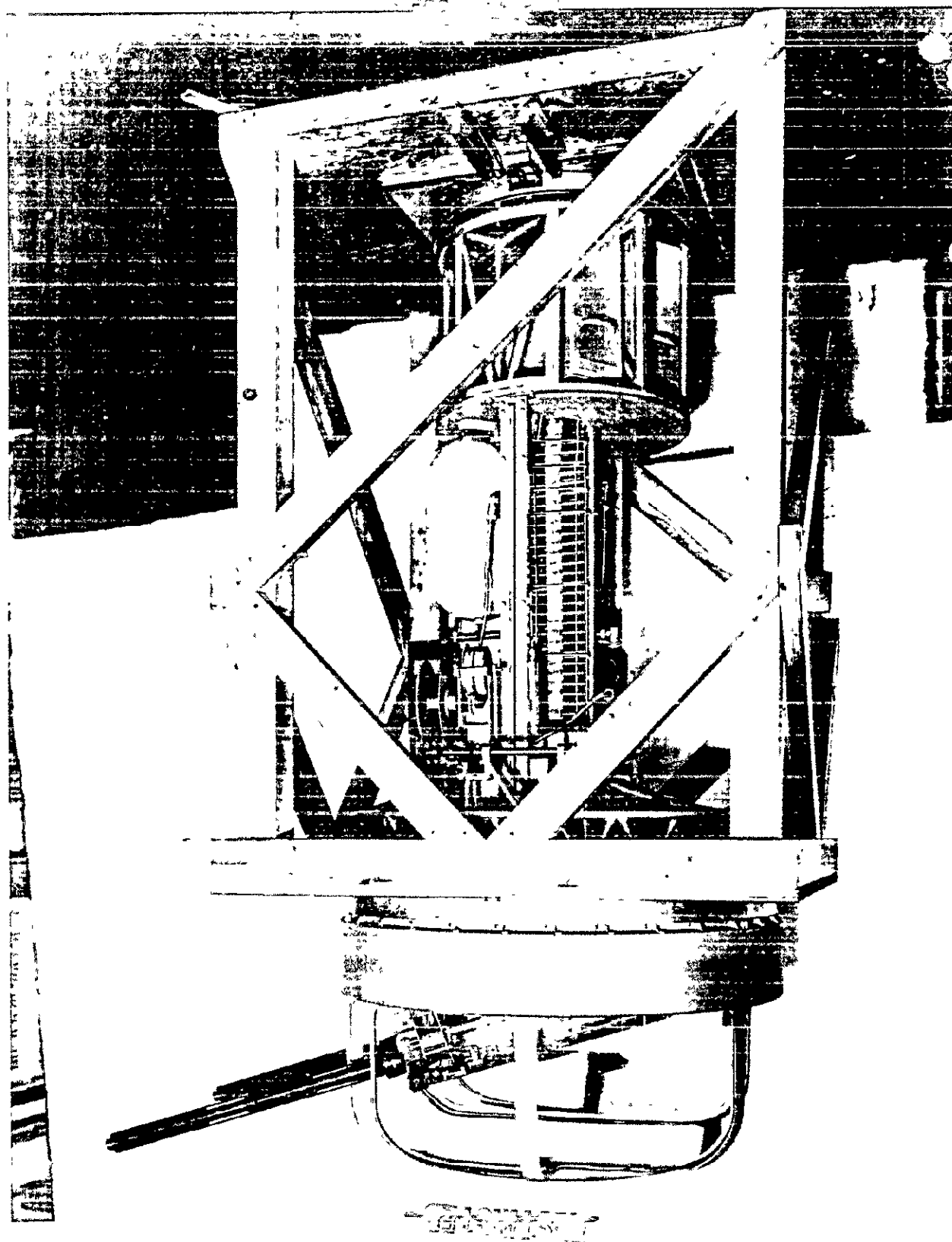
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gunsight gave way to the turret system, but efforts to put a computing sight into a locally controlled turret filled the turret with apparatus and left the gunner off center. This led Sperry to visualize a sighting station remote from the gun turret with mechanical linkage by flexible shafts or electric linkage by control circuits to orient the sight with the guns. Whatever solution might win ultimate approval, Sperry was anxious to build the CFC system out of locally controlled turret components and to create a standard design and a measure of insurance against complete frustration should any single installation prove unserviceable.

In May 1940 the Boeing Aircraft Company expected to equip the B-17C with a twin-.50 upper retractable turret coupled to a remote sighting station containing a computer, and a similar lower remote using a Keuffel and Esser driftmeter noncompensating sight within the structure of the turret itself. When an Air Corps Board rejected the idea of using a modified driftmeter lower sight, Boeing warned the Materiel Division that delays involved in replacing the sight "will kill the whole turret program for all B-17C airplanes." Boeing was unwilling to plan on any basis of "mythical anticipated development."¹³

The program of the moment was to arm the B-17C with two waist hand-held .50's mounting computing sights, the upper remote, and the lower with a modified driftmeter sight. Sperry was to provide the sight, computers, flexible shafts, power units, and controls; Boeing was to build the turret dome or enclosure, the ring gear mounting, gun mounts, and gear trains. This division of responsibility, however, was considered

13. Boeing to MD (WF), 17 May 1940; and TWX, Boeing to MD (WF), 7 June 1940, in Arm. Lab. file, E.O. 554-1-129.



First experimental Sperry upper local twin cal. .50
gun turret. Note the welded tubing framework,
the fabric ammunition belt, and ammunition drawers
below the revolving gunner's platform. 1940.

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far from satisfactory. Boeing, as the aircraft manufacturer, preferred to be provided with ready-built turret units as "Government Furnished Equipment" (GFE).¹⁴

The initial delays encountered in settling upon a satisfactory bomber defense system and the delays encountered in dividing responsibility between Sperry and Boeing were but minor compared with the engineering difficulties and delays that appeared as the project neared completion. The Sperry system operated on 24 volts DC, while the B-17C contained a 12-volt DC system. Temporary power packs were necessary to test the apparatus, and a makeshift installation impaired the validity of the tests. More important, perhaps, were the inadequate facilities for realistic service testing. The Materiel Division tried to secure a B-23 to replace the B-18 for tow-target testing of the installation against a speed "approaching that of the B-17C."¹⁵ It would be difficult to estimate just how seriously Sperry development was retarded by the discrepancy between the relative speeds of a B-18 or a B-23 and a modern fighter attacking along a pursuit curve.

By July 1940 the plan for a complete fire control system for the B-17 was abandoned in favor of a more immediate solution to the armament problem, so that the threatened delays in armament development would not endanger B-17 production. At a conference of Armament Branch and Sperry representatives in July 1940, it was decided that Sperry would build a locally controlled upper turret mounting twin .50's, each with 400 rounds of ammunition. The turret was to accommodate a compensating sight when

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14. Chief, PES to Boeing, 23 May 1940; and TNX, AC Res. Rep., Boeing to MD (WF), 18 June 1940, in *ibid.*
 15. TNX, Chief, EES (WF) to Chief, Arm. Sec. (Wash.), 5 Dec. 1940, in Arm. Lab. file, E.O. 554-1-141.

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one became available. This decision proved the utility of the Sperry "salvageable" principle, for the interim equipment was fabricated almost entirely from components planned for the other more complex systems. As to quantity production, the delivery schedule planned for the upper local turret was as follows:¹⁶

<u>Month</u>	<u>Year</u>	<u>No. Turrets</u>
November	1941	1
December	1941	11
January	1942	20
February	1942	20
March	1942	20
April	1942	40

The Armament Branch, meanwhile, had been conducting extensive tests to determine the best form of installation for turrets. Lower turrets, especially, presented a problem, since no satisfactory solution had as yet been offered to overcome the difficulties of sighting below the fuselage level. In August 1940 a Work Order was prepared "to cover all work in connection with the development of a retractable type flexible gun turret for installation in the floor of a bombardment type airplane." In September this was modified "to cover extension of the investigation to include consideration of a spherical, non-retractable turret."¹⁷

The spherical lower or ball turret idea proved so satisfactory that the Materiel Division sent rough drawings of the installation for Sperry to elaborate on, and authorized production of the ball turret for use on the B-17E in lieu of the originally contemplated lower remotes.¹⁸

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- 16. Memo Rpt., PLS, 9 July 1940, in ATCJ 473.5, General.
 - 17. Work Authorization Sheet, 13 Aug. 1940, in Arm. Lab. file, E.O. 553-1-337.
 - 18. TRX, MD (WF) to Sperry, 20 Sep. 1940, in Arm. Lab. file, E.O. 554-1-141.

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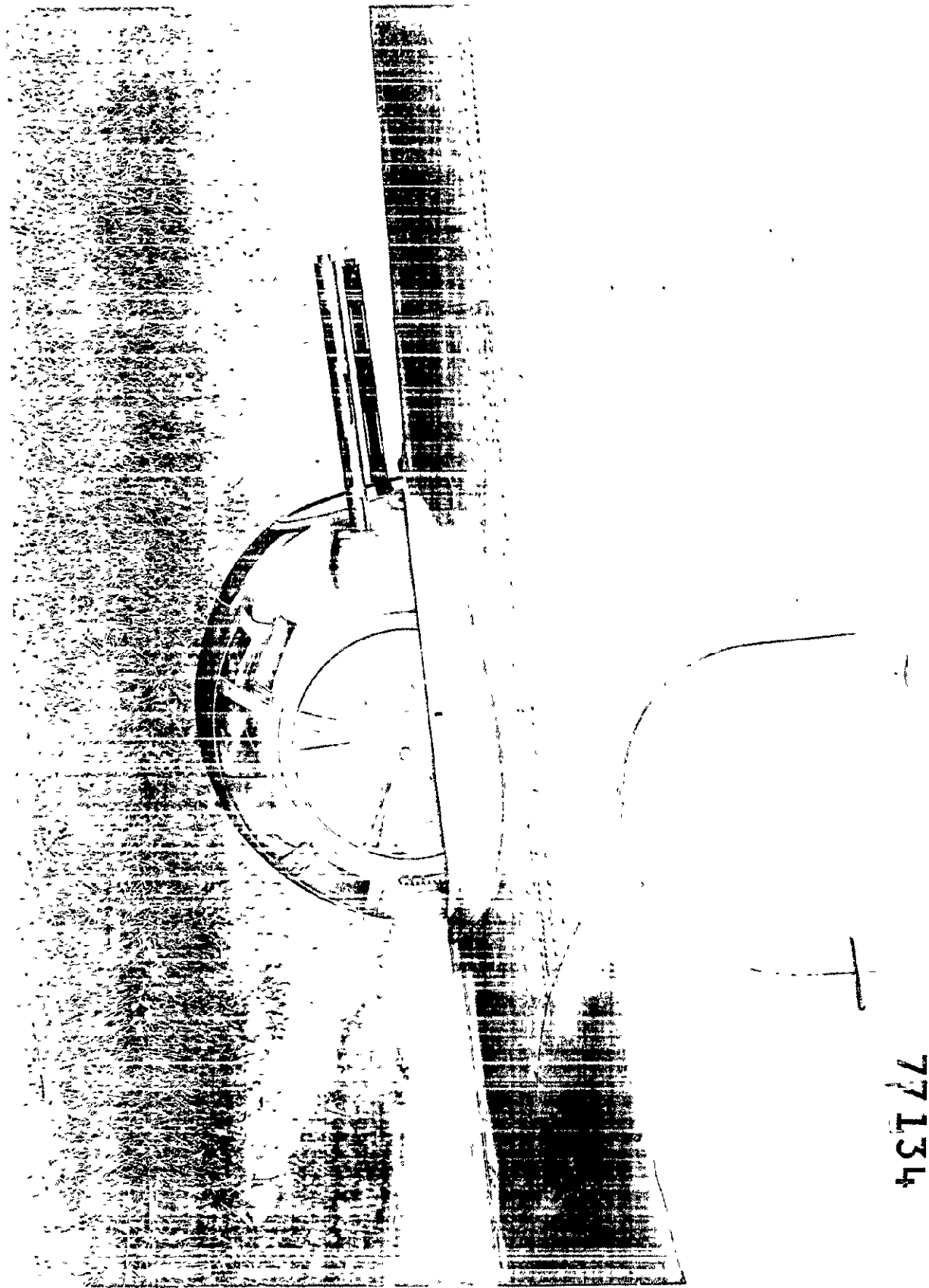
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When the Materiel Division negotiated a contract in December 1940, Sperry turrets were finally approaching the production phase. This contract called for 540 upper local turrets at \$7,185 each (totaling \$3,879,900) and 113 lower remote turrets at \$11,275 each (totaling \$1,274,075). The lower remotes were to equip B-17's until the 113th article, when it was expected that the newly conceived ball turret would be in production.¹⁹

After it had been decided to supply turrets as GFE rather than as integral parts of the airplane, Sperry was forced to seek a manufacturer to perform the heavy casting and machine work which the Sperry facility was not prepared to handle. The contract for 540 upper turrets made this step most imperative, and Sperry selected the Steel Products Engineering Company of Springfield, Ohio, as a suitable subcontractor.²⁰ As to other subcontractors, in November 1940 the Materiel Division invited Sperry to display its experimental models at the proposed Air Corps aircraft equipment exhibit in Detroit, an exhibit to induce automobile manufacturers to undertake contracts for military aircraft components. Sperry declined, however, reporting that a Detroit subcontractor, the Briggs Manufacturing Company, had been engaged to take over the actual assembly and heavy tooling work on the Sperry lower turret.²¹

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19. Contract W535 ac 16235, 27 Dec. 1940, and supplementary A for P, 29 Jan. 1941, in ibid.
 20. TWX, MD (WF) to Sperry, 21 June 1940, in Arm. Lab. file, E.O. 554-1-129.
 21. Phone transcript, Mr. Lee, Sperry and Maj. Early, MD (WF), 6 Nov. 1940, in PES Arm. Unit File, Sperry General to Dec. 1941.

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The Sperry lower ball mounting twin cal. .50 machine
guns. Installed in a B-17. 1941.

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Sperry's difficulties in turret production were summarized by one company official as follows: "Instead of having about three years to get things ready, the whole thing has to be done simultaneously, that is, developing and getting into production at the same time. This is what has caused the delay." If upper turret production was two months behind B-17 deliveries and lower turrets were four or five months in arrears, the delay was understandable in view of the fact that production dogged the heels of experimentation, but even so there could be no escaping the fact that aircraft delivered without armament would be useless in combat.²²

Tucker Manufacturing Company

In July 1939 the Chief of the Air Corps informed the Materiel Division of an "ingenious electrically controlled gun turret" built by Preston Tucker of Ypsilanti, Mich.²³ Wright Field representatives visited the Tucker Manufacturing Company to inspect a 37-mm. cannon mounted on an armored car. The Tucker turret proved to be slow-moving but offered some promise for possible conversion to aircraft use, especially with respect to an unusually favorable feature, a commutator which did not arc under rapid reversals. Another novel feature in the Tucker drive motor was the use of glass-impregnated coils as burn-out deterrents. A lever-action, carbon-disc variable rheostat controlled the field current for speed variations in the fixed-armature current

22. Ibid.

23. G/AC to Chief, MD, 13 July 1939, in AAG 473.5.

motor. Despite the fact that the drive showed no tendency to hunt and produced an adequately high torque at low speeds, the low or minimal tracking speeds were definitely unsatisfactory.²⁴

Tucker attended the turret conference held at Wright Field shortly after the outbreak of hostilities in September 1939 and proposed to build an electric power drive for incorporation within the existing B-18 manual turret. This twin-.30 turret was to achieve a 45° per second azimuth speed with a 12-volt DC drive motor, the whole to be equipped with a fire cut-out or interrupter, electric or dynamic brakes to prevent structural interference with the gun muzzles, and provision for emergency manual operation.²⁵ The Tucker proposal asked for \$10,000 for an experimental model.²⁶

Five months passed before work actually began on the installation. An extended delay was encountered in securing a B-18 to send to Tucker, and the Armament Laboratory had to ask Selfridge Field for some solenoids when none could be found at Wright Field to satisfy Tucker's request.²⁷ The confusion of the war-born acceleration of activity and the critical lack of standard equipment items such as machine-gun solenoids at Wright Field tended to impair the progress of turret development.

Delays in negotiation may have been detrimental to Tucker, but almost from the very beginning a turret designed around the already obsolescent B-18 was doomed to failure. In December 1940 the Materiel

24. Memo Rpt., EES, 24 Aug. 1939, in Arm. Lab. file, E.O. 553-1-303.

25. Memo Rpt., EES, 25 Sep. 1939, in ibid.

26. Tucker to MD (WF), 29 Sep. 1939, in ibid.

27. IOM, EES to PES, 30 Nov. 1939, in ibid.

Division concluded that the Tucker turret was "not representative of the assemblies contemplated for possible future procurement."²⁸

Even if the Tucker turret did not represent a production type, the problems encountered in its evolution were valuable experience for the Armament Laboratory, where tests on the Tucker experimental model revealed the necessity of preparing specifications which would include minimum slewing speeds. British practice had revealed the necessity of such a step long before, but apparently each new designer had to learn the hard way. As a starting point, it was proposed to establish 10 mils or something more than $1/2^{\circ}$ per second as a satisfactory minimum.²⁹

The Armament Branch considered Tucker as a possible source for turrets to arm the first 100 B-17 airplanes equipped only with hand-held machine guns. Although no contract was signed, Tucker prepared to build a model turret improving on the original experimental installation sold to the Materiel Division. The modified turret carried twin .50's in place of the .30's of the original version and added a hydraulic power drive to secure smooth, low-speed tracking characteristics.³⁰

The Armament Laboratory prepared an Authority for Purchase to procure a laboratory test model of the revised turret.³¹ The design, however, proved sufficiently unsatisfactory to warrant its rejection, and the Chief of the Air Corps informed the Ordnance Department, which had plant cognizance over the firm, that there was "no probably production

28. TWX, EES (WF) to Arm. Sec. (Wash.), 4 Dec. 1940, in *ibid.*

29. Memo, Capt. P. E. Shanahan to Lt. Col. Grandison Gardner, 28 June 1940, in Arm. Lab. file, E.O. 554-1-130.

30. Memo Rpt., ES, 1 Aug. 1940, in Arm. Lab. file, Tucker Aircraft Corp. Caliber-.50 Gun Turret.

31. A for P 175577, 3 Dec. 1940, in Arm. Lab. file, Machine Gun Mounts 1940.

requirement" for the Tucker turret capacity which could be utilized for armored-car and surface-craft turret construction.³² As a producer, Tucker's capacity was not entirely inconsiderable. The manufacturer claimed to represent not only his own facility but three others as well; Graham Paige Motors, the Excel Foundry and Machine Company, and the Crocker-Wheeler Electric Manufacturing Company, all at Detroit.³³

The fate of Tucker's project pointedly demonstrated the inadvisability of turret development without adequate financial resources. To perfect a turret and carry it successfully through the experimental stage to the threshold of production required either a government-financed experimental contract or a corporate organization of sufficient scale to absorb the unproductive immediate costs of the period of research and experimentation. From that point on, if adequate information was available in the form of combat experience, the evolution of a power turret would become little more than a matter of applying sufficient engineering ability to specific technical problems.

Bendix Aviation Corporation

When the Armament Laboratory began casting about in the winter of 1939 to find manufacturers interested in fire control apparatus, the Bendix Aviation Corporation in South Bend seemed to offer ideal facilities for the project, in view of the corporation's interest in aircraft accessories. This facility, however, was temporarily denied as a potential source by a directive from the Chief of the Air Corps, who stated that

32. G/AC to Chief, Ord. Dept., 6 Dec. 1940, in AAG 473.5.
33. Tucker to MD (Wash.), 3 June 1941, in ibid.

"Pending completion of negotiations between the Bureau of Ordnance, Navy Department, and the Bendix Corporation concerning this development, it is desired that no further contacts be made with that Corporation with reference to this project."³⁴ Apparently no cooperation between Air Corps and Navy personnel was anticipated from the very beginning.

In spite of this injunction, a Bendix engineer, J. H. White, attended the Wright Field turret conference in September 1940 and, in company with Armament Branch personnel, made a flight in a B-18 which was "attacked" by a pursuit plane simulating combat approaches, in order to help White become "thoroughly familiar with the problem and have a comprehensive knowledge of the solutions desired." The idea was undoubtedly an excellent one, well worth frequent repetition with other manufacturers' engineers; but just how anyone could become "thoroughly familiar" with the problem of bombardment defense in a single flight is rather difficult to understand. ^{However,} White's visit to Wright Field was not without result.

Late in September 1940 Bendix began preparing studies on various solutions to the turret problem, uppers as well as lowers. On the basis of available B-18 turret drawings, Bendix undertook to design a hydraulic turret with a gear pump drive unit constructed with a mesh sufficiently fine to avoid all line pulsations.³⁵ In an attempt to visualize a spherical lower turret, Bendix prepared a photographic report of the problems involved in fitting men of varying weights and sizes into spheres of

34. Chief, MD (VF) to C/AC, 31 March 1939, and 1st ind., 17 April 1939, in Arm. Lab. file, Misc. Fire Control file 1940.

35. Memo Rpt., ES, 20 Sep. 1939, in Arm. Lab. file, E.O. 553-1-119.

different diameters, but the complications encountered led finally to a decision favoring a periscopic sight solution.³⁶ This remotely controlled lower turret was to contain twin .30's in a truncated cylindrical projection or a hemispherical under-dome, manually retracted. In October 1939 Bendix plans called for a turret capable of 360° azimuth rotation and a possible plus 10° to minus 90° elevation arc. The gunner was to be within the aircraft fuselage in a "stationary trough upholstered for reasonable comfort." All the details of the hydraulic drive had not been worked out, but Bendix expected to achieve azimuth rates ranging from $1/4^{\circ}$ per second to 45° per second.³⁷

Two months after the hydraulic version was discussed, Bendix submitted a formal proposal to the Materiel Division offering an all-electric turret drive for application with both an upper and lower turret. The upper, mounting twin .50's, was to operate through a speed range of 3° to 60° per second on a one horsepower motor. Variable speed adjustment was based on DC pulsating control field current derived from positioning a wobble-stick control handle which determined the speed of pulsation by moving a brush across an eccentrically segmented commutator running at a constant speed. The proposed specifications apparently neglected the all-important consideration of minimum tracking rates and gave no indication of anticipating any difficulties with excessive arcing at the pulsator control. The lower was to utilize a system similar to that of the proposed upper, mounting twin .30's instead of .50's.

36. Bendix to Lt. Donicht, WF, 22 Sep. 1939, in ibid.

37. Memo Rpt., EES, 31 Oct. 1939, in ibid. See also Change Order No. 1, 9 Oct., 1940.

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The Bendix proposal offered an experimental upper turret complete with a compensating sight for \$30,075, an experimental lower turret with compensating sight for \$31,675, a compensating sight alone for \$19,050, or a combination of all three for \$75,645, to be delivered within nine to 12 months. These figures represented the outcome of a six-month experimental period during which two groups of Bendix engineers, one in New York and another in South Bend, sought a suitable turret drive. The New York group worked in electric drives, the South Bend group, with considerably less success, in hydraulic drives.³⁸

The two Bendix research groups set out to develop a power turret using the Navy specifications of May 1939 as a point of departure. In a treatise prepared on hydraulic turrets, the South Bend group established some basic assumptions: the ultimate objective was to increase fire power; this could be done by more or heavier guns; improved turret design to give more power with less weight and drag; or improved sighting and turret design, specifically by building a continuous rotation turret capable of training without effort and so constructed that the gunner would remain always in a fixed relation to the guns and gunsight.

By attacking the project with a definition of principles, Bendix seemed to indicate a correct approach to a most difficult engineering problem, but the proposals following this initial expression of policy apparently bogged down because of failure to secure an adequate "appreciation of situation." Both Bendix research groups demonstrated a palpable lack of familiarity with airplanes in general and aircraft armament in particular.

38. Bendix to MD (WF), 19 Dec. 1939, in Arm. Lab. file, (Oversize) 553 Bendix.

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In drawing up tentative turret designs around the B-18 turret, Bendix engineers visualized a gunner sitting behind a gun rather than between twin guns, and on this premise declared it structurally impossible to swing the gunner in a fixed relation to his guns through an adequate field of fire. Similarly, in exploring the utility of a standard follow-up valve, such as the hydraulic valve manufactured by the Clark Equipment Company for steering gear booster installations requiring torques up to 6,000 pounds, the Bendix engineers seemed unable to visualize the application of a follow-up control valve to continuous rotation turrets. The pursuit of position control apparently blinded Bendix to the possibilities of speed control. Nothing indicates more pointedly how important the Armament Branch policy of farming out ideas had become. Working independently, industrial engineers were delayed by specific problems which had been solved elsewhere. Adequate coordination from Wright Field made it possible to select the best ideas from each manufacturer and add to them a wide range of practical experience with bombardment aircraft.³⁹

When Bendix finally decided upon an electric turret drive, the Materiel Division prepared a contract for an experimental lower turret at \$45,600. The vague and generalized nature of the specifications accompanying this contract indicated the relatively undeveloped status of the project. The lower turret was to drive twin .50's electrically, 360° in azimuth and 100° in elevation through a speed range of 3° to 60° per second. The circuit was to be provided with a fire cut-out device,

39. Bendix Proposal, 19 Dec. 1939, in ibid.

dynamic-brake structural interrupters, and limit stops. The plan called for two novel features, a hydraulic gun charger and a periscopic sight with a 20° cone of vision. The whole turret was to be retractable and so designed as to be suitable for installation in the B-17.⁴⁰

The lower periscopic sight was novel, but from its very inception not all Bendix designers were convinced of its utility for combat use. While one Bendix research worker questioned its use, another supported it, claiming that the image on ground glass enabled a gunner to find a plane more easily than with the naked eye despite the reduction in size. The theory supporting this claim maintained that the area of acuity of the average retina is fairly narrow. Objects with little relative motion outside this area are hard to see. If the whole area is reduced, the effective area of acute vision is increased.⁴¹ The theory was perhaps sound enough for limited-area scanning, but quite obviously the Bendix engineers were unfamiliar with the problems of 360° hemispheric search and the speed of modern combat attacks.

Although the Bendix lower turret was still in the earliest stages of fabrication in the spring of 1940, the need for such a turret had become acute. Douglas queried Bendix on the possibilities of a lower turret for use in the B-23, while the lower turret requirement for the B-25 had become absolutely mandatory.⁴² In the B-25, weight and balance

40. Contract W535 ac 14144, 14 May 1940, in Arm. Lab. file, E.O. 553-1-119.

41. Bendix to MD (WF), 17 June 1940, in ibid.

42. TWX, AC Res. Rep., Douglas to MD (WF), 21 March 1940, in ibid.

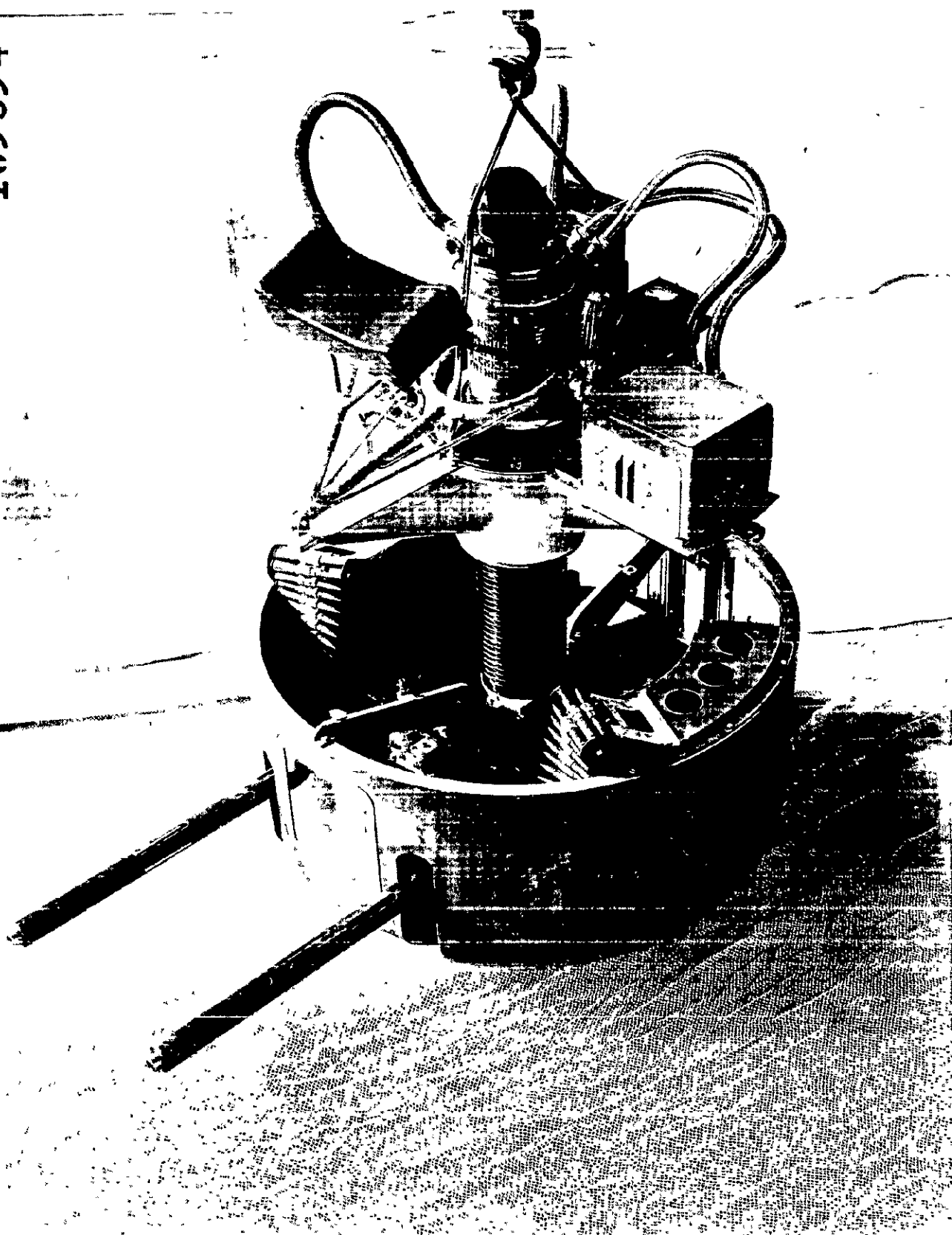
considerations were of such critical importance that upper and lower turrets were necessary to eliminate the tail gun installation entirely.⁴³

The pressing demand for a lower turret led the Armament Laboratory to recommend that the GFE Branch of the Materiel Division open negotiations with Bendix to prepare the way for lower turrets in production quantities to fulfil the turret requirements for medium and heavy bombardment airplanes.⁴⁴ Somewhat earlier the Ordnance officer at Wright Field had suggested that production would be best served if each type of turret could be designed for a specific plane model, but the demand for turrets ran ahead of design perfection and the turret primarily developed for the B-25 was of necessity considered for the B-17 and the B-24. The Ordnance officer also suggested a system of design control, routing all drawings and design problems through Wright Field to insure production "exactly as desired" by the Armament Branch.⁴⁵ An organization accustomed to processing a peacetime budget of a few thousand dollars abruptly found itself concerned with contracts involving millions, and the techniques of monitoring engineering developments and establishing effective design controls had to be perfected even as the contracts were in effect and being fulfilled.

By September 1940 the Bendix lower turret was undergoing firing tests at the Aberdeen Proving Grounds, and a month later aerial tests, conducted in a B-17B, revealed the basic difficulties which were to hound

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43. North American to MD (WF), 15 March 1940, in Arm. Lab. file, North American B-25 Contract ac 13258.
44. IOM, Chief, Arm. Br. to Chief, GFE Br., 15 July 1940, in ATSC 473.5, General.
45. IOM, Chief, Ord. Dept. to Chief, Arm. Br., WF, in Arm. Lab. file, E.O. 553-1-119.

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Bendix electrically driven lower turret mounting twin cal. .50 machine guns. This photograph shows the gunner's chest rest and the eyepiece of the periscope sight mounted on top of the main retraction screw. 1941.

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the turret throughout its production career: an unsatisfactory cone of vision, inadequate scanning, a sight head rendered ineffective a few minutes after take-off by oil smudge, and an unsatisfactory ammunition feed system.⁴⁶

Glenn L. Martin Company

The Glenn L. Martin Company, in its specifications for a new medium bomber, the B-26, originally called for a total armament installation of four flexible .30's. The drawings of July 1939 called for a single nose and tail gun, a floor gun, and an upper single .30 mounted in a "rotating enclosure," all hand-held.

The Martin upper turret as originally conceived called for hydraulic retraction mechanism for a gun swinging free through an 8° cone of fire. Movement in excess of 8° closed electric circuits to rotate the turret in azimuth. Elevation movement was to be entirely manual. The enclosure dome was designed to be quickly detachable for emergency exit.

The azimuth power rotation system was not unlike the Armstrong-Whitworth and Boulton-Paul patents perfected a number of years earlier in England, but the limitations of the day regarding the concept of combat realities were inherent in the stipulations requiring "rapidity and ease" of movement for a single gunner changing from one gun position to another.⁴⁷ The earliest turret version visualized a friction drive, but at Wright Field it was felt that a positive gear train drive would be superior.⁴⁸

46. Memo Rpt., EES, 15 Nov. 1940, in *ibid.*

47. Martin Spec. Model 179, 1 July 1939, in Arm. Lab. Spec. file.

48. Memo Rpt., ES, 12 Aug. 1939, in Arm. Br. file, Airplane Evaluation Folder 1, C.P. 39-800, 38-385, Airplanes A-17 to B-26.

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A Martin Company report "to demonstrate the initiative of this company" and "to stimulate interest, and particularly, to establish . . . the most promising line of development for future business on the B-26 type" revealed that firm's method of attacking a problem. The whole question of the aircraft's armament was broken down into sections or projects with one or two men assigned to concentrate on each specific task. One group made an "approach probability analysis," a study of the angles of attack. Other groups studied armor plate protection and remote control possibilities, while still another studied the weight and balance potentialities of the new airplane with particular regard for its influence on armament disposition.⁴⁹

This technique of delegating specific problems to specialized engineers working cooperatively brought immediate results, but in January 1940 an Air Corps Mock-up Board inspected the B-26 and found the turret inadequate. The revised turret design, mounting twin .30's, remained 10 or 12 inches above the fuselage level even when fully retracted. The board's recommendation to install a single .50 in lieu of twin .30's increased the retracted turret extension by two additional inches. This protuberance promised to reduce the airplane's performance, but Martin was unwilling to make armament alterations which were likely to make the aircraft fall below the contractor's guaranteed speed. The Materiel Division apparently did not wish to permit Martin this escape from the guaranteed performance figure, so a compromise was decided upon to permit

49. Inter-Dept. Communication, G. L. Martin, 22 Jan. 1940, in Arm. Lab. file, Martin B-26 Airplane Contract ac 13243.

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the company to pass the performance test with .30's installed and then to modify for .50's.⁵⁰

It is impossible to determine just how much the guarantee controversy delayed the turret development project, but it is significant that it was not until June 1940 that Martin produced the prototype B-26 turret with full power operation in azimuth and elevation for twin-.50 machine guns, each equipped with 100-round magazines. This Martin turret utilized General Electric amplidyne controls, which were developments of the initial G.E. B-18 tail gun drive. The production prototype carried a heavy semicircular sheet of armor plate, a novel feature in aircraft armament at that time, but there were many elements of the installation still in a rudimentary stage of development. The gun apertures were not equipped with slot closures, and at Wright Field it was recommended that the total ammunition allowance be raised to 800 rounds.⁵¹

Like all other turrets the Martin development was not the product of a single initial concept but the result of a gradual accretion of ideas. The importance of the Martin turret in contrast to other types lay in its essentially simple design; once through the initial experimental state, the turret proved sufficiently satisfactory to go directly into large-scale production. The success of this turret was attested by the Armament Laboratory's plan to construct it along such generalized specifications that it would be readily suited to application in airplanes other than the B-26.⁵²

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50. Memo, Capt. P. E. Shanahan to Maj. Grandison Gardner re visit to Martin, 19 Jan. 1940, in Arm. Lab. file, Machine Gun Mounts 1940.
 51. TWK, Martin to MD (WF), 4 June 1940; Martin to MD (WF), 5 June 1940; and IOM, EES to PES, 11 June 1940, in Arm. Lab. file, Martin B-26 Airplane Contract ac 13243.
 52. Memo Rpt., EES, 23 Sep. 1940, in ibid.

Firing tests conducted at Aberdeen revealed the usual number of minor discrepancies, but the test reports concluded that the Martin design marked "a distinctive advance in the development of electrical power controlled turrets."⁵³ The Chief of the Engineering Section at Wright Field warned of the British decision against electric systems, but the Martin turret demonstrated that the British had reckoned without amplidyne.⁵⁴

The Martin G.E. amplidyne system provided speed control; that is, control handle displacement determined the rate of angular rotation of the turret. General Electric had another system, the selsyn control unit, which provided position control; that is, positioning a control bar attached to a sight induced a remotely located turret to come to rest in a position comparable to and coincident with that of the control handle. The Materiel Division, lacking the test of combat upon which to reach a decision, requested Martin to construct a twin-.50 turret similar to the B-26 version in every respect save the control circuit, which was to be selsyn rather than amplidyne. Martin engineers constructed a selsyn turret by working 24 hours a day for five days.⁵⁵ It proved less satisfactory, however, than the amplidyne speed control; and the Materiel Division negotiated a contract for 159 amplidyne upper turrets at \$4,645 each, or a total of \$738,555.⁵⁶

53. Memo Rpt., E3, 21 Sep. 1940, in ibid.

54. Buckslip, 25 Sep. 1940, signed F.O.C. [Frank O. Carroll], in ibid.

55. Martin to MD (WF), 15 Oct. 1940, and Martin to MD (WF), 10 Oct. 1940, in Arm. Lab. file, E.O. 554-1-130.

56. Contract W535 ac 15773, 14 Oct. 1940, in Arm. Lab. file, Machine Gun Mounts 1940.

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~~RESTRICTED~~Westinghouse Electric and Manufacturing Company

Because of the previous experience of the Westinghouse Electric and Manufacturing Company in producing searchlight and machine controls, it was quite logical for the Armament Laboratory to invite representatives of that company to Wright Field in May 1939 to discuss the problems involved in fabricating a power turret. Westinghouse had already undertaken a project in tank controls for the Ordnance Department, and it was felt that this experience could be profitably utilized in designing an aircraft turret.⁵⁷

The Westinghouse engineers inspected B-17, B-18, and B-21 armament installations and then set out to compile a turret proposal. Three months later Westinghouse submitted three tentative proposals, a DC motor system, an AC motor system, and a hydraulic system. The hydraulic version was given scant attention, since it involved too many long pressure lines; and the AC system was proposed only as an alternate to the DC system.⁵⁸ Wright Field opinion favored the DC system, and Westinghouse set out to develop it in detail.

A formal Westinghouse proposal appeared in September 1939 offering a complex fire control apparatus aiming several guns from a single sighting station. The proposal, offering a single experimental system for \$76,200, was rejected by the Armament Branch because it contained "too much gadgetry," in particular, 16 separate motors which made the entire system excessively heavy and subject to a disproportionate power drain.

57. Memo Rpt., EES, 1 June 1939, in Arm. Lab. file, E.O. 554-1-116.

58. Memo Rpt., EES, 24 July 1939, in ibid.

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When the Materiel Division asked for new proposals, Westinghouse submitted another system to control several .30-cal. guns from a single sighting station. This experimental unit, at \$58,400, was rejected for substantially the same reason as the earlier version.⁵⁹ A succession of Westinghouse proposals met an equal fate, and as late as October 1940 none had been found satisfactory for procurement.⁶⁰

General Electric Company

When Wright Field called for turret proposals in September 1939, the General Electric Company at Schenectady was well prepared to make a substantial contribution. The practical experience acquired in designing the B-18 remote tail gun and the extensive nature of G.E. resources and engineering talent made it possible for this manufacturer to present an effectual turret design within a comparatively short time.⁶¹

The research engineers of G.E. prepared an analysis of the problem to define the objectives desired. This study contemplated a speed range of 3° to 91.5° per second, a load range of 8.8 to 122 foot pounds, and a power requirement of 500 watts in a 12-volt system with a line current of 42 amps. While these figures were approximations, they represented specific goals where other manufacturers were still searching for relatively tentative specifications as a point of departure.

The G.E. analysis recommended DC "power control," that is, field control rather than resistance control, because rheostat line control

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59. Westinghouse to MD (WF), 5 Oct. 1939; and R&R No. 2, M. E. Goll to P. E. Shanahan, 6 Nov. 1939, in Arm. Lab. file, Misc. Fire Control 1940.
60. Memo Rpt., EES, 15 Oct. 1940, in Arm. Lab. file, E.O. 554-1-116.
61. Notes on conference at G.E. by M. E. Goll, 15 Nov. 1940, in Arm. Lab. file, E.O. 554-2-96.

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imposed maximum power requirements in the resistor for high torques at low speed. The report further recommended speed control rather than position control.

The amplidyne circuit was the G.E. contribution to "power control." It offered a number of advantages over rival systems. Unlike the Tucker drive, described earlier, it had no large capacity resistors and maintained a high operating efficiency for low speeds at high torque. Unlike the Bendix pulsating DC system, amplidyne involved the use of no high current contacts with all the drawbacks contingent upon arcing. More important than all these advantages, the amplidyne potentiometer control gave smooth tracking through continuously variable training speeds directly proportional to a rotary control handle deflection, and any given potentiometer deflection produced a constant speed value regardless of load variations.⁶²

The Materiel Division was anxious to utilize G.E. research and design facilities in seeking an answer to the fire control problem, but there were hurdles in the path of direct approach. However ready G.E. was to accept Air Corps projects, prior Navy obligations stood in the way. The Armament Laboratory was especially interested in securing details concerning the gyroscopically stabilized lead computer under contract at G.E. for the Navy, and the Chief of the Air Corps was called upon to arrange for permission to do so officially.⁶³ Negotiations lagged when

62. Proposition ANG-33232, B. R. Prentice, 21 Sep. 1939, G.E. Schenectady, N.Y., in ibid.

63. IOM, Chief, EES to Chief, MD (Wash.), 17 Oct. 1939, in Arm. Lab. file, Misc. Fire Control 1940.

the Armament Laboratory complained of the "severe limitations" imposed on Air Corps fire control projects by the Navy. Again, it seemed, the Navy was frustrating Materiel Division procurement plans. The G.E. case was but one of several. When the Air Corps negotiated with Bendix' Pioneer Instrument Division, the Navy objected; and the matter was dropped. When the Air Corps negotiated with Bendix Eclipse, the Navy objected; and again the matter was dropped. Inter-service coordination was proving extremely hard to attain.⁶⁴

If fire control equipment was delayed by inter-service competition for facilities, G.E. did not linger in producing locally controlled turret drives. Before developing the controls and drives manufactured on subcontract to Martin, G.E. had contemplated an assisted motion flexible gun mount with potentiometer controls directly on the spade grips for possible application in the B-25. North American Aviation had planned the B-25 with a single flexible upper midship hand-held machine gun, but the Armament Laboratory recommended that the G.E. development be "considered carefully, provided the Mock-up Board feels that either the hydraulic or electric system must be definitely decided upon at once," an expression of opinion which would seem to indicate that the final decision in fire power policy rested ultimately with the Mock-up Board.

However, even if the Mock-up Board had rejected turret armament, the Armament Laboratory intended to press the project by purchasing an amplidyne system for experimental installation in a B-18 upper turret. Considerable delay had been encountered in trying to reach a decision

64. Arm. Lab. to EES, 27 Oct. 1939, in ibid.

between hydraulic and electric systems. Both systems promised satisfactory performance; but the balance seemed to favor the electric version since hydraulic operation raised extensive questions of servicing, performance over wide temperature ranges, and reliability.⁶⁵

Paralleling the search for adequate turret design, there was an extended investigation of individual aircraft designs for armament modernization potentialities. Studies of the defensive characteristics of the A-20 indicated that an important increase in tail cone coverage might result if aft-firing guns could be installed in the engine nacelles. Early G.E. developments in the B-18 tail gun made it plausible for the Armament Laboratory to direct Douglas to negotiate directly with G.E. in designing a nacelle installation.⁶⁶

The Hughes Aircraft Company of Burbank, Calif., as well as Douglas and Martin, approached G.E. on the possibilities of a fire control system for bombardment aircraft as a whole.⁶⁷ In the Schenectady plant, G.E. had an engineering organization assigned entirely to aircraft and naval fire control projects. The research staff was supported by a large design staff and almost unlimited machine-tool and other manufacturing facilities. This organization was admirably suited to the task of perfecting a fire control system, but as long as the contract for B-26 turret controls and drives remained in the balance, G.E. was unwilling to undertake any extended and costly experimental program.

65. Capt. F. C. Wolfe to Maj. Grandison Gardner, 8 Nov. 1939, in ibid.

66. Contract Sec., WF to Douglas, 8 Jan. 1940, in Arm. Lab. file, Douglas A-20 Contract ac 12967.

67. EES to G.E., 5 Feb. 1940; Martin to MD (WF), 24 Jan. 1940; and MD (WF) to Hughes, 6 Feb. 1940, in Arm. Lab. file, E.O. 554-2-96.

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One reason for the delay in executing the Martin turret contract lay in the fact that the price asked by G.E. seemed in the eyes of Wright Field personnel to be "completely out of line." Whatever the extent of the delay, the point is significant because it suggests that G.E. attempted to absorb development costs in a production contract and probably attempted to absorb them too fast, even to the point of endangering the successful execution of the contract. Apparently the only escape from such a situation lay in advance assurances to the manufacturer of sufficient production contracts to absorb development costs or in outright experimental contracts giving direct reimbursement for experimental developments.

Whatever decision was reached regarding the G.E. contract for Martin B-26 turret components, the Armament Branch at Wright Field was particularly anxious to have research work continue unabated at Schenectady, where the project engineers visualized a number of fire control systems, including "shallow turrets" for installation on the upper midship section of the B-17, nacelle installations directing a pair of .50's over the "important rearward area where at least 80% of the attacks can be expected," and central-station fire control (CFC) systems.

The G.E. analysis of CFC conceived of two possible systems. One involved a completely synchronous control of all guns--nacelle, tail, and upper and lower turrets--from a single sighting station with a computer unit. The other system involved a combination control plan in which one sighting station and computer would control all rearward-firing guns, the nacelle, and tail positions, while another station and computer would control the upper and lower turrets. Neither of these two systems was simple, but G.E. favored the second plan, which called for only 10 amplidynes and 10 drive motors and afforded the increased reliability of two gunners rather than one.

Wright Field and G.E. representatives met in Schenectady in February 1940. The conference proved so successful in "clearing the fog and getting new ideas" that the personnel involved favored frequent repetition of the process. The proposals drawn up at the conference were referred to the Armament Laboratory by the Wright Field representative, with this recommendation that a careful analysis of the G.E. proposals be made "so we can give them a decision in order that they will not be too far amiss from the other competitors."⁶⁸

Plans to install a CFC system in the A-20 ran afoul of weight and balance considerations. Originally G.E. had visualized three installations similar to the remotely controlled B-18 tail gun for the A-20 nacelle-tail combination, but the critical weight and balance factor made it impossible to utilize the existing equipment with .50-cal. guns.⁶⁹ An Authority for Purchase was prepared in March 1940 for a \$50,000 three-gun rear-firing system, but the weight factor led Wright Field to consider transferring the whole fire control project to the B-26.⁷⁰

The difficulties encountered at Wright Field in obtaining an A-20 for experimental installations undoubtedly encouraged this inclination to shift CFC to the B-26. After reiterating the necessity, for reasons of economy, of pressing the experimental phase to completion before entering upon production, the Materiel Division warned that "If permission to use the A-20A airplane for this purpose is refused, it is possible that

68. Notes on conference at G.E., by M. E. Goll, Arm. Lab., 15 Nov. 1940, in *ibid.*

69. IOM, Chief, Arm. Lab. to Capt. C. S. Irvine, 11 March 1940, in Arm. Lab. file, Misc. Fire Control 1940.

70. A for P 156546, 15 March 1940, in Arm. Lab. file, E.O. 554-1-123.

71. R&R, MD (Wash.) to Exec., AF, 20 March 1940, in Arm. Lab. file, Douglas A-20 Contract ac 12967.

the entire project pertaining to fire control . . . will be delayed for months."⁷¹ The Chief of the Air Corps agreed with the division's point of view and ordered a B-26 and an A-20 allocated to fire-control experiments.⁷²

While the weight and balance difficulties of the A-20 armament installation remained undecided, G.E. engaged Bausch & Lomb to undertake the development of a double-ended periscope with a single eyepiece sighting arrangement "ingeniously suggested" by a Douglas engineer.⁷³ It was contemplated that this device would permit one gunner to serve in place of two and thereby effectively resolve the limitations hitherto imposed on armament.⁷⁴

In March 1940 G.E. prepared specifications for a complete fire control system involving two computers and sighting stations with upper turret, lower turret, and tail gun positions so devised that it was possible for either station to take control of the tail gun drive. The lower station was periscopic, but the upper station was mounted in a direct sighting observation dome.

The G.E. installation followed the position control principle with a selsyn AC rectifier and an electron tube impulse-amplifier circuit operating in conjunction with an amplidyne drive.⁷⁵ This proposal contemplated a cost of \$95,000, exclusive of optics, for a complete fire

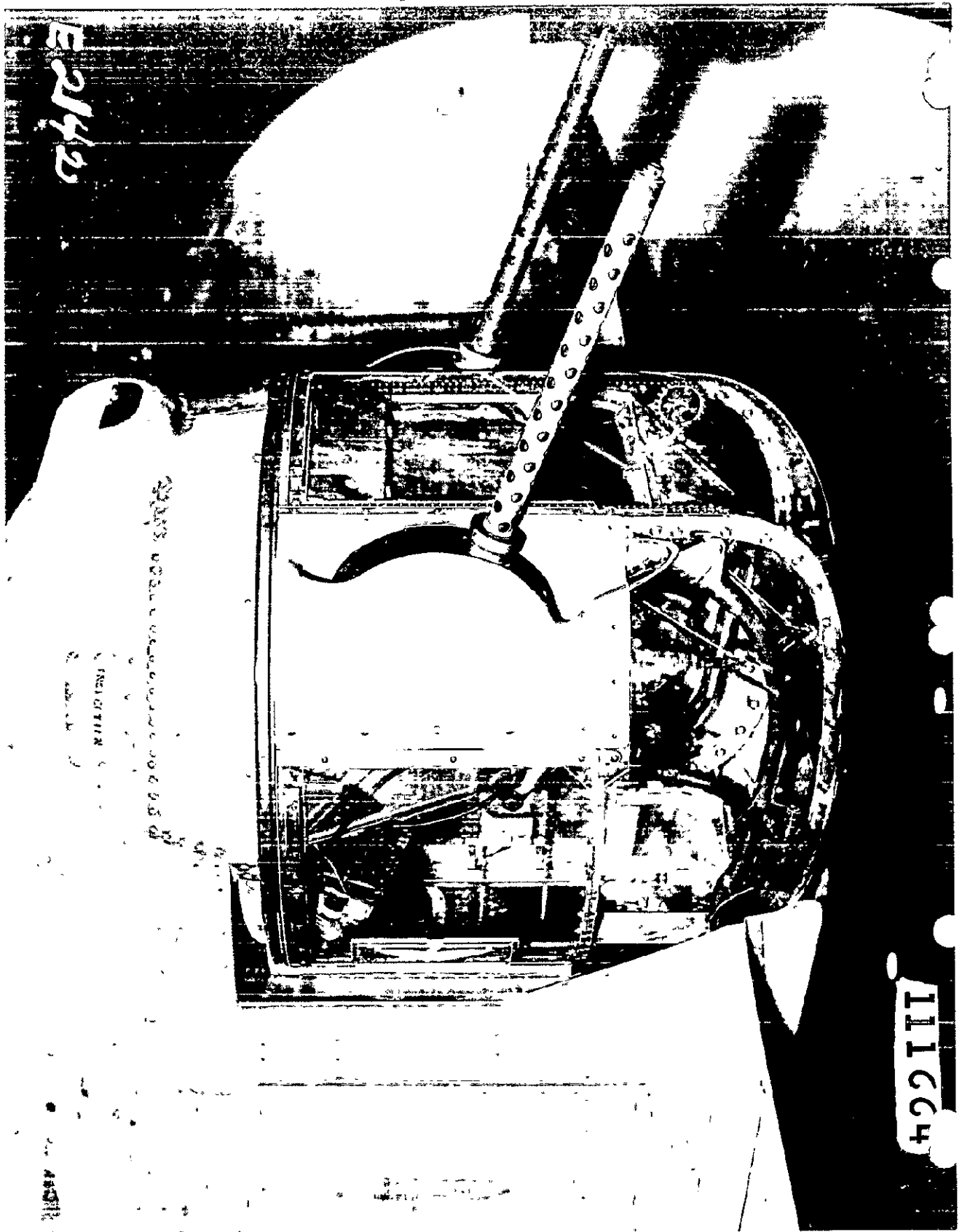
71. R&R, MD (Wash.) to Exec., WF, 20 March 1940, in Arm. Lab. file, Douglas A-20 Contract ac 12967.

72. TI-188, 4 May 1940, in Arm. Lab. file, Technical Instructions.

73. Chief, EES to Douglas, 28 Feb. 1940, in Arm. Lab. file, E.O. 554-1-123.

74. Douglas to MD (WF), 21 March 1940, in ibid.

75. G.E. Spec. GO-16282A, 28 March 1940, in Arm. Lab. file, E.O. 554-1-130.



The Emerson nose and tail turret mounting twin
cal. .50 machine guns installed in the tail
of a B-24. Note the chain and sprocket drive for
positioning the bullet-resisting sighting panel.
1942.

control system, to be delivered one year after the date of contract.⁷⁶
 The Materiel Division did not favor this offer, and G.E. made another during the following month in which the whole system, less optics, was priced at \$75,000.

Neither Bausch & Lomb nor Keuffel & Esser were willing to quote prices on the optical units under development for the fire control system. Both companies were already overburdened with Ordnance and Navy contracts, and neither was anxious to embark on a lengthy experimental program coincident with peak-load production. In addition to these factors, the CFC optical system was still in the design state and defied accurate quotation.⁷⁷

The imponderable element of optics both with regard to cost and design development undoubtedly delayed the evolution of the G.E. fire control system, but there were still other factors involved. A G.E. proposal for CFC sets, complete in production quantities, offered a single set at \$25,000 and 13 successive sets at \$10,000 each, or:

1 plane,	\$11,500	upper turret	\$13,500	lower turret
10 planes,	4,300	upper turret	5,700	lower turret
20 planes,	2,900	upper turret	3,100	lower turret
50 planes,	2,400	upper turret	2,600	lower turret

These prices were accompanied by a production schedule: 1 turret in 90 days, 2 turrets in 120 days, 5 turrets per week in 16 weeks, and 10 turrets per week in 20 weeks. This proposal included only the drive and control sets, however, not the ring gear.⁷⁸

76. G.E. to MD (WF), 28 March 1940, in ibid.

77. G.E. to MD (WF), 4 April 1940, in ibid.

78. Notes on Central Station Fire Control, G.E., 20 April 1940, in ibid.

Unfortunately for the accuracy of the contemplated production and delivery schedule, the internal ring gear proved to be a most difficult tooling process and, as G.E. discovered in the following year, sufficiently critical to delay the entire course of turret development. The artificiality of production schedules not based on tooling realities was to impair planning by the Materiel Division for months to come.

The increasing probability of extended delay in the development of G.E. fire control equipment led the Materiel Division to consider a series of interim measures, or a simplified fire control system. Both the B-24 and the B-17 were without adequate armament in May 1940, and the division considered it wiser to plan local turrets in predictable quantities for immediate production than to put too much faith in fire control systems of uncertain status.⁷⁹

A General Electric proposal considered building an upper local turret for the B-17C at a cost of \$55,000, less the cost of optical units. This turret resembled the Martin B-26 version in many respects. It mounted twin .50's and employed amplidyne speed control along with sprocket-type ammunition boosters and thumb-switch slewing speed control. In addition, however, the G.E. design provided for manual retraction and a compensating sight. Characteristic of that stage of turret development, the design specified a 60°-per-second maximum azimuth rotation speed but failed to establish any minimum.⁸⁰

79. Memo prepared by Capt. F. C. Wolfe, 24 May 1940, in Arm. Lab. file, E.O. 554-1-123. See also phone transcript, Mr. Prentice, G.E. and Capt. P. E. Shanahan, WF, 25 June 1940, in Arm. Lab. file, E.O. 554-1-130.

80. G.E. to MD (WF), 4 April 1940, in Arm. Lab. file, E.O. 554-1-130; see also G.E. Spec., 2 April 1940.

The pressing urgency for some form of lower hemisphere fire power coverage for heavy bombardment airplanes led G.E. to undertake several projects. A "shallow type bottom turret" designed for the B-23 was converted for use as a power turret with the application of an amplidyne azimuth drive system, but the limitations of such an installation were immediately apparent. Even with a "target indicator" attachment, the floor gun proved inadequate and another project was initiated.⁸¹

The improved G.E. proposal for a lower gun installation comprised a spherical turret with an amplidyne speed control system, the whole offered at a cost of \$50,000. This turret, utilizing a simple N2-A reflex sight without any compensating features, was followed by a similar proposal for a lower turret to include amplidyne speed control in azimuth and selsyn position control in elevation.⁸² None of these G.E. spherical turrets came to maturity, partly because other manufacturers came forward with practical devices before the G.E. designs were much beyond the drawing board stage, and partly, in all probability, because the focus of G.E. interest fell upon the more complex fire control systems. In June 1940 the Materiel Division negotiated a contract with G.E. to include one tail and nacelle gun fire control system for the A-20 at \$50,000 and one combination upper and lower turret fire control system for the B-24C at \$95,000.⁸³

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81. A for P 167293, 17 Oct. 1940; and Sub Order of 23 May 1940, in Arm. Lab. file, E.O. 553-1-309.
 82. G.E. to MD (WF), 11 Oct. 1940; G.E. to MD (WF), 14 Oct. 1940; and G.E. Spec. & Proposal, 8 Nov. 1940, in Arm. Lab. file, E.O. 553-1-354.
 83. Contract W535 ac 14666, 6 June 1940, in Arm. Lab. file, E.O. 554-1-130, folder 2.

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The original specifications for the fire control system to be built into the A-20 called for a machine gun in the tail as well as one in either nacelle. When weight and balance considerations made the tail gun seem an impossible feature, the specification of July 1940 stipulated upper and lower turrets with a double-ended periscopic sight in conjunction with rear-firing nacelle guns. By the end of August these specifications had been revised again to exclude the nacelle guns entirely.

The A-20 fire control system consisted of a pair of twin .50's mounted in upper and lower turrets and controlled from a remote sighting station. The drive system followed the general line of G.E. development, an amplidyne with selsyn controls and DC-AC inverter. The specifications contemplated an allowable mechanical or gear train backlash of ± 7 mils. The drive was to reach a 60° -per-second azimuth speed and a 40° -per-second elevation speed. Moreover, the system was to be equipped with mechanically operated spring limit stops rather than electric limit switches, but the sighting station was designed to de-energize the drive when it reached the limits of the predetermined zone of fire.⁸⁴

Among the many novel devices incorporated in the A-20 turret was a continuous feed ammunition system. A fabric belt lifted shells to the machine gun; when the triggers closed the firing circuit, an additional circuit energized a drive which wound the empty belt on reels serving in the capacity of a booster system.⁸⁵

84. TWX, MD (WF) to G.E., 29 June 1940; G.E. Specs., 15 July 1940 and 21 Aug. 1940; and Change Order No. 8, 2 Nov. 1940 on Contract ac 12967, in ibid.

85. Memo Rpt., EES, 5 Sep. 1940, in Arm. Lab. file, E.O. 554-1-123.

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The G.E. contract raised some difficult issues. Delivery of the A-20 turret was conditional, so G.E. considered, upon an early order for a production prototype, and the Materiel Division was unwilling to allocate funds earmarked for experimental development to the design of a prototype. The Experimental Engineering Section wanted development; the Production Engineering Section wanted quantity; and G.E. wanted a production contract to absorb engineering costs.

The question of funds, however, was of far less immediate importance than the issues raised in determining the dividing line of manufacturing responsibility. The Materiel Division favored charging the turret manufacturer with complete responsibility for all aspects of turret production, "eliminating difficulties that will inevitably arise if units of the system are procured from various sources."⁸⁶ Already a number of vexing coordination problems had been raised by G.E. engineers. By the end of August 1940 the A-20 fire control system was nearing the stage where there was but little possibility of major design change, yet G.E. requested the advice of Douglas designers concerning such critical elements as the mounting ring bearing system, the location of the elevation drive gear sector, and the type of ammunition feed to be employed.⁸⁷

Despite the fact that the light bomber received a high priority in the fall of 1940, it became apparent that the G.E. system would not be ready for the A-20.⁸⁸ When in December 1940 the Materiel Division negotiated a \$60,000 contract with G.E. for a fire control system suited

86. IOM, Chief, EES to Chief, PES, 1 Aug. 1940, in Arm. Lab. file, E.O. 554-1-142.

87. G.E. to Douglas, 24 Aug. 1940, in ibid.

88. Douglas to MD (WF), 19 Nov. 1940, in Arm. Lab. file, Douglas A-20 Contract ac 12967.

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to the A-20A, Douglas made plans to equip the initial A-20 series with hand-held guns only.⁸⁹

While the G.E. A-20 turret developments were under way, a number of other aircraft manufacturers studied the new system for possible installation in projected bombardment and attack airplanes. Curtiss-Wright, Northrop, Grumman, and the Vought-Sikorsky Division of United Aircraft all considered the G.E. project, but of these companies only Northrop carried negotiations to a point which eventually led to production with the P-61 armament installation.⁹⁰

Among the more important projects running parallel to the G.E. A-20 system was the installation designed for North American's proposed stratospheric bomber, the XB-28. In April 1940 the Materiel Division selected Sperry to manufacture the XB-28 fire control system, inasmuch as Sperry fire control developments were more advanced than any others. Later, however, the division felt that Sperry facilities were overloaded and requested G.E. to undertake the project. The division preferred the Sperry sight and computer unit to that designed by G.E., and it was decided to have G.E. build G.E. turrets to include Sperry sighting units.⁹¹

The XB-28 contracted for in February 1940 carried a fire control system of twin .50's in three positions, upper and lower turrets and a

89. Memo Rpt., EES, 24 Dec. 1940, in *ibid.* See also Contract W535 ac 16599, 6 Dec. 1940, in Arm. Lab. file, E.O. 554-1-142.

90. General Inspector of Naval Aircraft, WF to Chief, Arm. Lab., 16 Dec. 1940; G.E. to Vought-Sikorsky, 14 March 1941; Chief, EES to G.E., 8 Oct. 1940; and Chief, EES to Curtiss-Wright, 7 Oct. 1940, in Arm. Lab. file, E.O. 554-1-130.

91. G.E. Memo on conference re XB-28 Armament, 18-20 June 1940, at Schenectady, in *ibid.* See also IOM, Chief, Arm. Lab. to Chief, EES, 12 April 1940, in Arm. Lab. file, E.O. 554-1-124.

tail installation. The initial North American plan called for a single .30-cal. hand-held nose gun and a similar gun in the tail, but as early as October 1939 the Armament Laboratory had insisted that .50-cal. weapons be used.

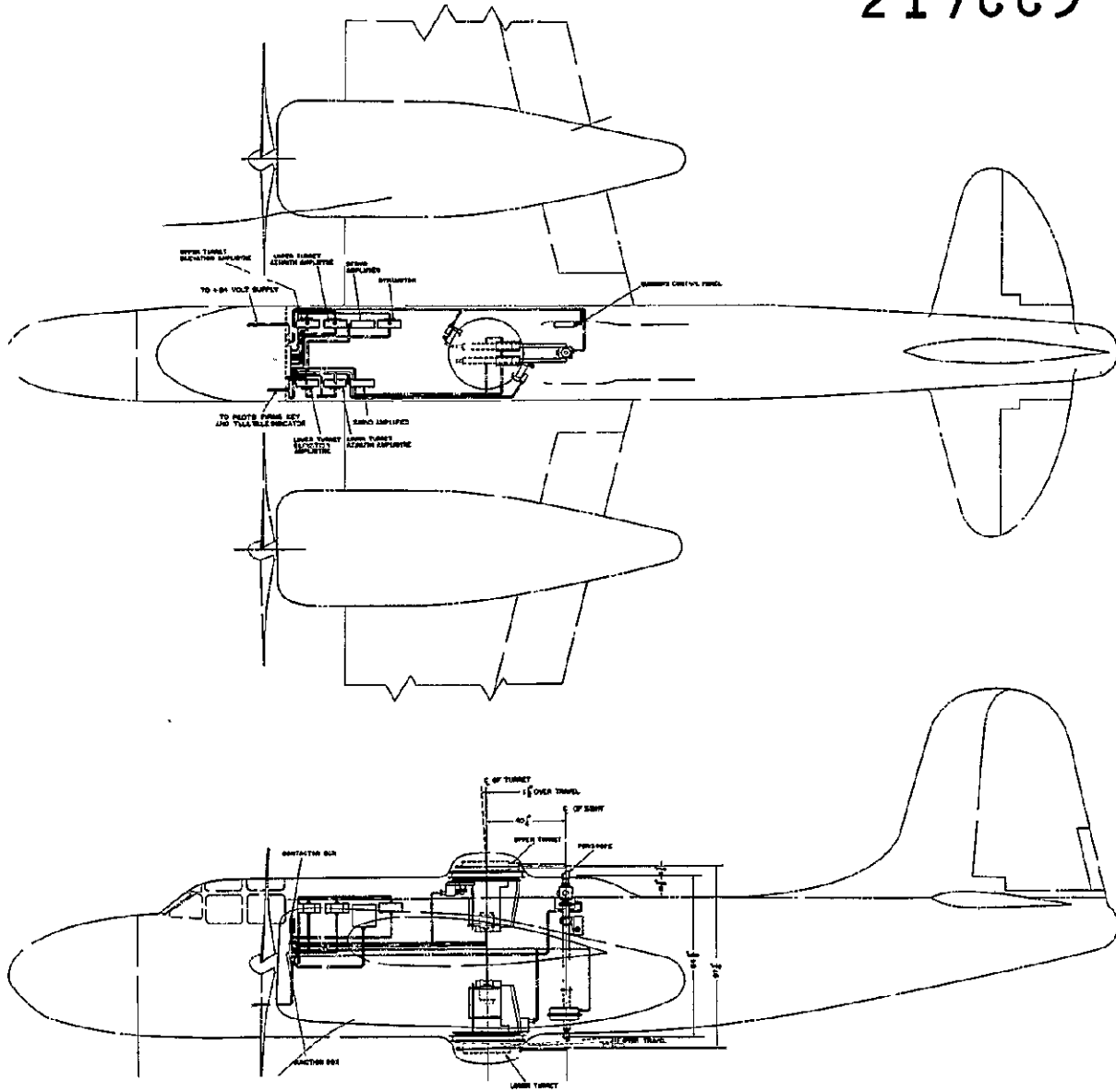
The problems contingent upon the change from Sperry to G.E. were serious. Under the original plan Sperry developed the computers and control systems, but North American built the gun mounts and actual turret structure. When G.E. took over the XB-28 fire control project, it was decided that the entire unit would be built by that company. Hence, the entire Air Corps investment in North American was nullified.⁹²

By December 1940 four of the six manufacturers who had undertaken to develop power turrets were ready to begin work on production contracts. Sperry equipment was more or less earmarked for B-17 use; G.E. production was destined for the Martin B-26 and the Douglas A-20; and Bendix planned to install turrets in the B-25. Before examining the details of quantity production it is necessary to consider such diverse matters as the Wright Field technique for preparing a Circular Proposal, the problem of standardization, and the search for alternate methods of providing power drives.

92. North American Spec. NA-63 (XB-28), rev. to 5 July 1940. See also Memo Rpt., EES, 20 Oct. 1939; and phone transcript, Henry Escher, G.E., Mr. Hendricksen, North American, and Maj. M. D. Burnside, WF, PES, 25 June 1941, in Arm. Lab. file, North American XB-28 Contract ac 13583.

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 GENERAL ASSEMBLY. FOR MODEL 2CFR21A-
 ARMAMENT-CONTROL SYSTEM.

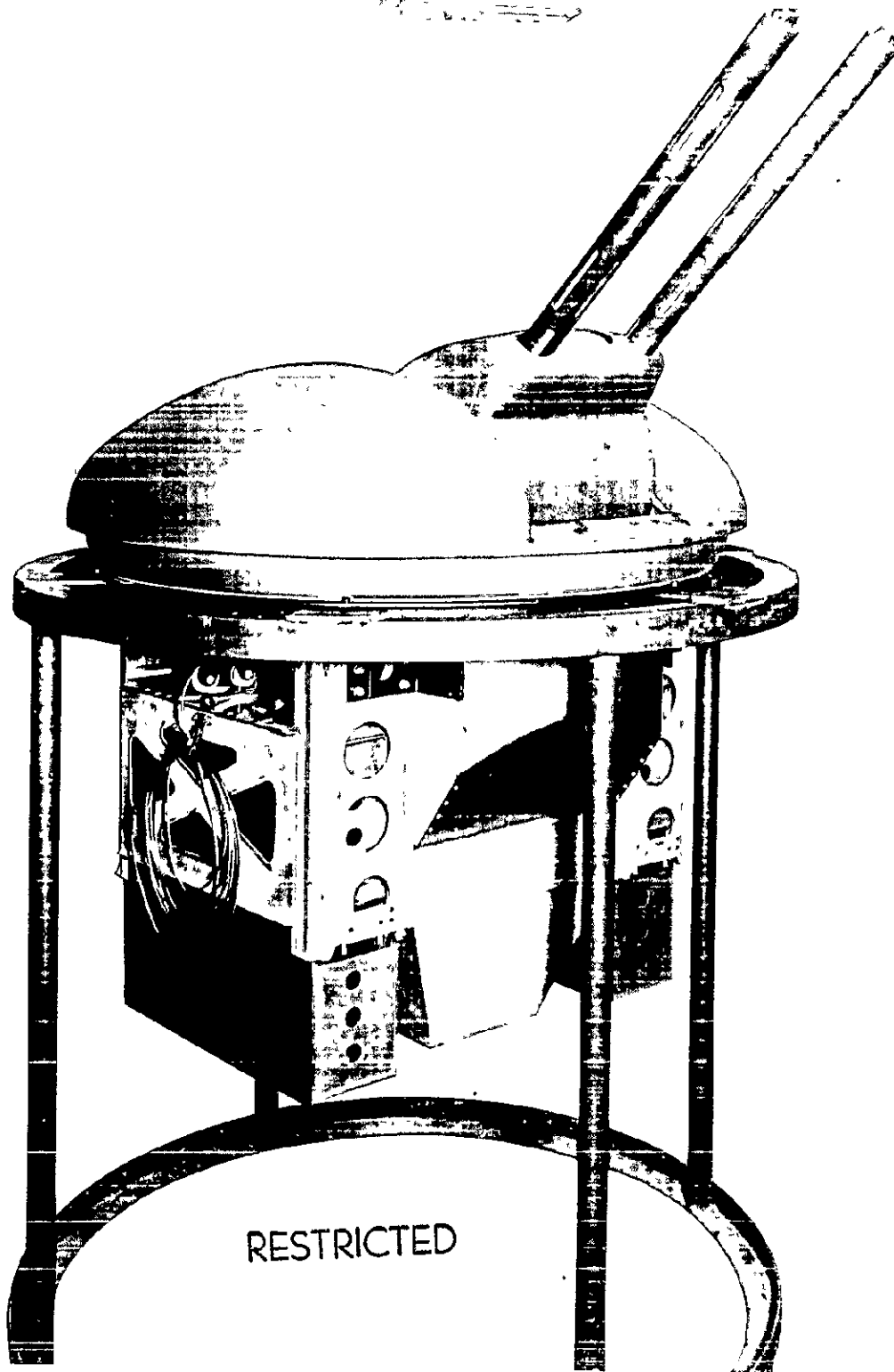
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Diagram illustrating typical installation of G.E.
turrets with periscopic sights. 1942.

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Twin cal. .50 machine-gun remote control unit
for use in the G.E. central-station fire control
system. Note the streamlining of the dome section
and the compactness of the unit as a whole. 1943.

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Chapter VII

POWER TURRETS AND CENTRAL-STATION FIRE CONTROL, 1939-1940

In January 1939 there were three civilians and one officer working on fire control projects in the Armament Laboratory at Wright Field, and the budget for 1940 allocated \$45,000 to fire control in addition to the \$25,000 set aside for power mounts. Despite the fact that these sums represented a substantially large portion of the funds apportioned to the whole experimental armament program, at the Armament Laboratory they were considered "wholly inadequate to insure advancement in the field of fire control development within the next twelve months."¹

After a year of accelerated activity, the Armament Branch was able to report in April 1940 that:

As a result of examination of reports from abroad, activities of Air Corps Tactical Units, and experience gained recently from testing experimental gun arrangements by personnel of the Materiel Division, it appears that the subject of armament should be given careful consideration at this time. . . .

"Careful consideration" evoked this report:

Until very recently, airplanes of a multi-place type have been defended by installations of singly mounted .30 caliber machine guns. Revisions to employ the .50 caliber weapon . . . have been seriously handicapped by limited space and the absence of power drives.

The conversion of installations designed for .30-cal. to .50-cal. use had resulted in such serious compromises that the entire question of aircraft armament had to be reconsidered.

1. Chief, ES to Chief, Arm. Br., 20 Jan. 1939, in Arm. Lab. file, Misc. Fire Control 1940.

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Reconsideration involved decisions regarding the choice of blisters or flush installations, .30's or .50's, multiple or single gun mounts, remote or local turret control, pressurized or nonpressurized turrets, machine guns or cannon, and turrets or remotes in nacelles and wing structures. Inasmuch as it was impossible to answer all these questions at once, the Armament Laboratory recommended that a board be formed to prepare detailed specifications for aircraft armament commensurate with wartime requirements. The laboratory further recommended that it be authorized to specify the armament requirement for each particular airplane under contract to insure a more exact and specific compliance with Wright Field fire power concepts.²

The studies undertaken as a result of the survey of aircraft armament provoked a comment which echoed the contention of gunnery officers in World War I: "All present standard gun installations require manual operation. At the high speeds possible with modern types of airplanes, the large wind forces make accurate control of turret guns impossible. Power operation is, therefore, required."

Projects initiated before the end of 1939 were primarily for experimental installations, but the modernization program of 1940 made it imperative that the experience of the earlier design stage be devoted to the development of fire control systems. The Armament Laboratory recognized that the critical phase of fire control development lay in the fabrication of initial installations, because the arrangements for the defense of future airplanes would be "largely influenced by the results collected from tests of the experimental apparatus" already under construction.

2. Memo Rpt., EES, 1 April 1940, in Arm. Lab. file, Misc. Airplanes 1940.

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The Armament Laboratory was also conscious of the fact that only by the most careful collaboration between the sections of the Materiel Division would it be possible to avoid dangerous revisions of production aircraft after delivery. A number of problems in connection with the design of various fire control components remained to be solved. Among them, the relationship between armament and aerodynamic design had yet to reach a satisfactory compromise. A compromise implied a high order of coordination between the Aircraft Laboratory and the Armament Laboratory at Wright Field; but any such coordinated development was certain to be impaired, if not frustrated, unless funds "greatly in excess of those available in the past" could be provided for an experimental program.³

By October 1940 a sum of \$10,000 was allocated to "conduct a study to determine the correct design of power operated multiple gun turrets with maximum fields of fire and good aerodynamic features with a view of improving defensive characteristics." This study sought to establish the best possible compromise between efficient defensive installations and objectionable aerodynamic conditions, resolving the data made available into specific designs.⁴ Both the National Advisory Committee for Aeronautics (NACA) Laboratory at Langley Field and the Aircraft Laboratory at Wright Field undertook a series of tests along this line.⁵

The Aircraft Laboratory reported, on the basis of the evidence compiled by testing, that all turrets save those of the blister type produced a

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3. Memo Rpt., EES, 17 May 1940, in Arm. Lab. file, Misc. Fire Control 1940.
 4. E.O. 553-1-341, 5 Oct. 1940, in Arm. Lab. file.
 5. MD Liaison Officer, NACA, Langley Fld. to Chief, MD (WF), 10 June 1940, in Arm. Lab. file, Machine Gun Mounts, 1940.

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"prohibitive" drag:⁶

The installation of such turrets would nullify the great effort and expense involved in producing low drag basic airplanes. Means must be found for providing necessary defensive fire power without excessive drag, or the idea of the airplanes concerned operating at over 300 mph might as well be given up.

Without questioning the accuracy of this conclusion, the fact still remains that the Aircraft Laboratory's report did not reach the necessary compromise, nor did it resolve its findings into a specific design as requested by the Armament Laboratory. For this reason there seemed little justice in the scathing attack of the Aircraft Laboratory chief, made some months later, when he charged that Armament Branch personnel had made but one visit to the Aircraft Laboratory in the year past and that current turret design was "basically very inefficient aerodynamically . . . and new airplane designs should not be handicapped with such turret configurations."⁷

Even before the Aircraft Laboratory had recommended the use of central-station fire control systems to reduce the high drag coefficients of protuberant turrets, the Armament Laboratory had plans for fire control installations. As early as November 1938 a memo prepared for the Assistant Secretary of War pointed out that the advent of pressure cabins would in turn necessitate a "central control position from which various machine guns and cannon can be remotely controlled."⁸

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6. Chief, Aircraft Lab. to Chief, Arm. Lab., 29 Oct. 1940, in *ibid.*
 7. IOM, Chief, Arm. Lab. to Chief, Eng. Div., 10 March 1943; and 2d ind. ^{basic unknown} Chief, Aircraft Lab. to Chief, Eng. Div., 6 May 1943, in Arm. Lab. file, Inventions, Fink, E.
 8. Chief, ES to Dir., Army Aeronautical Museum, 15 Nov. 1938, in Arm. Lab. file, Misc. Correspondence 1938.

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Early in the winter of 1940, the Chief of the Armament Laboratory reported to the Chief of the Experimental Engineering Section that the question of CFC was "ripe for assignment to a specific plane."⁹ Throughout the month of January, representatives of the Armament Laboratory and several turret manufacturers interested in fire control projects explored the CFC field extensively. In February a circular letter went out from the Materiel Division to Westinghouse, Bendix, General Electric, and Sperry, outlining the tentative requirements for a complete CFC system.

The circular letter considered an installation of seven .50-cal. guns, provision for scanning throughout the entire sphere, a computing sight, a fire cut-out or interrupter device to protect the vital structures of the plane from gunfire, and all the other equipment which had been perfected for use in local turrets, such as hydraulic charging, reflex sighting, etc. The system was to mount twin .50's in upper and lower turrets, each with 360° azimuth and 90° elevation, a lone .50 in the tail with a 30° cone of fire, and single rear-firing .50's in each nacelle with 40° cones of fire.

The proposed system was to incorporate a twin periscopic system so arranged that the gunner could, without undue effort, glance up from the station to pick up an approaching target by direct vision. The computing sight itself was to compensate for ranges up to 1,000 yards and airspeeds of 325 mph as well as for parallax; but no provision was to be made for stabilization, although the letter required the incorporation of a range finder to get continuous range input without affecting tracking ability.

9. IOM, Chief, Arm. Lab. to Chief, EES, 25 Jan. 1940, in Arm. Lab. file, E.O. 554-1-123.

Inasmuch as weight and balance considerations were critical, competitors submitting design proposals were urged to take every precaution to reduce weight wherever possible. Moreover, the specifications pointed out that existing aircraft electrical systems provided 12-volt DC current "in limited amounts" only, and auxiliary power plants would be mandatory. Finally, the circular letter required that all proposals submitted be of a design suitable for interchangeable use in more than one type of plane.¹⁰ In order to facilitate coordination between turret and plan manufacturers, the Materiel Division dispatched telegrams to Douglas, Boeing, Consolidated, Lockheed, and Martin, authorizing those firms to negotiate directly with the turret designers on problems of space, weight, and balance.¹¹

When the Armament Laboratory first sought proposals for a fire control system it was generally presumed that the installation would be used on the A-20, but since all programs were in a constant state of flux the B-26 was alternately considered.¹²

Bendix signified an interest in the field by submitting a "preliminary suggestion" in the form of a tentative outline for a complete fire control system.¹³ Westinghouse offered a more detailed description of a system consisting of a series of synchronous cable and pulley drives operating from main power shafts hydraulically actuated. Quarter-inch cables operating on sheaves and drums, with idlers to absorb excess cable deflections, seemed to offer a fire control system simpler and less costly than electric installations.¹⁴

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10. Chief, EES to Westinghouse, Sperry, G.E., and Bendix, 2 Feb. 1940, in ibid.
 11. TXX, MD (WF) to Boeing, Douglas, Consolidated, Lockheed, and Martin, 9 Feb. 1940, in ibid.
 12. Notes on visit of M. E. Goll to fire control manufacturers, Feb. 1940, by Capt. P. E. Shanahan, in ibid.
 13. Bendix spec., Central Fire Control for Twin Engine Bomber, 18 Jan. 1940, in ibid.
 14. Record of conference with Westinghouse, 13 Feb. 1940, in ibid.

By the time a decision had been reached regarding the A-20 armament, all the principal turret manufacturers had displayed an interest in CFG, but the field was so novel and there was so little precedent to build on that it proved exceedingly difficult to prescribe the exact nature of the equipment sought. An Armament Laboratory representative visited the several interested manufacturers to garner ideas for mounts, sights, retracting mechanisms, typical weights, and dimensions. It was believed that the industrial designers would have a number of ideas to offer, in-
as much as the war-inspired deluge of requests for information on CFG from airplane manufacturers could not help but stimulate interest in turret planning.¹⁵

The Wright Field engineer who visited the four major fire control facilities reported that there was an immediate need for clarifying the manner in which proposals were to be prepared. If Wright Field was working in the dark, so were the manufacturers. The very magnitude of the problem and the variety of potential solutions made it impossible for manufacturers to organize their studies in any fashion suitable for comparative consideration. Without some organization along this line it would be difficult for the manufacturers to quote on complete systems with any degree of validity.

At Wright Field it was recommended that the manufacturers be allowed two to four weeks to prepare schematics along with weight and power estimates to meet a specific circular proposal. These first rough studies would then give a basis for deciding whether or not to proceed, after having evaluated the initial studies comparatively.

15. Notes on visit of M. E. Goll to fire control manufacturers, Feb. 1940, by Capt. P. E. Shanahan, in ibid.

This recommendation raised a number of questions. If the Armament Laboratory sought tentative, rough-draft proposals, some decision would have to be reached as to whether or not any competitor should be allowed to submit more than one design. Since the initial contribution would determine which design would be selected for amplification, there would be a natural tendency on the part of the manufacturer to submit several different designs as insurance, and a multiplicity of offerings implied less concentration in perfecting a single design.

Furthermore, a policy of preliminary proposals raised the issue of payments. Inasmuch as the rough draft design involved engineering studies of an extended nature, some manufacturers might prove unwilling to undertake the necessary research unless a system of compensation could be established to cover the studies rejected at the first sifting.¹⁶

Although no immediate solution could be reached regarding this question of policy, the issue, once raised, could not be avoided indefinitely. Like so many other problems which became evident only during the acceleration of war projects, this question thrust itself forward for eventual consideration, even though the immediate contingencies of engineering questions had pushed problems of organization and procedure into momentary eclipse.

To carry out the recommendation for a more organized and specific proposal format, the chiefs of the Armament Laboratory and the Experimental Engineering Section held a conference late in February 1940 to reach a definition of terms and a delineation of responsibilities for

16. Memo, M. E. Coll to Capt. P. E. Shanahan, 21 Feb. 1940, in ibid.

fire control equipment. The various types of sighting stations and gun positions were systematized, and preliminary armament specifications were outlined for the A-20, B-17, B-24, B-25, and B-26. A minimum requirement of at least two sighting stations was established for heavy bombardment airplanes, and a plan of coordination prepared for correlating armament current-consumption requirements with the Equipment Laboratory.¹⁷

Toward the end of March 1940 another circular letter left the Armament Laboratory for the four major turret manufacturers, Westinghouse, Sperry, G.E., and Bendix. This circular, profiting by the experience of the earlier search, was carefully defined in detail. In addition to a statement of general design requirements, the circular stipulated that proposals would be submitted on the first day of April, 11 days away, and would include a quotation on five fire control systems, together with complete drawings and a statement regarding possible future deliveries.

The complete system, deliveries to begin in one year, was conceived for a four-engine heavy bomber. The general requirements included provision for installation in a pressurized cabin, twin-.50 turrets throughout and twin .50's with a 20-mm. cannon in the tail, all-around defense with a crew of 6 or 7, reliable functioning in speeds up to 450 mph and at 40,000-foot ceiling--in all, not less than ten .50's and a cannon distributed in at least 5 emplacements controlled from 2 or 3 sighting stations.¹⁸

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17. Central station fire control program as outlined in a conference between Maj. Frank Carroll and Maj. Grandison Gardner, 27 Feb. 1940, by Capt. P. E. Shanahan, in ibid.
18. MD (WF) to Sperry, Westinghouse, G.E., and Bendix, 20 March 1940, in ibid.

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A few days before the competition closed, Sperry and G.E. telephoned Wright Field to record their intentions of entering formal proposals.¹⁹ Westinghouse was unable to prepare a proposal of any sort in the time allowed, so it proved impossible to consider that manufacturer in the April competition.²⁰ When the bids were opened, the three systems offered were sufficiently similar to form a basis for comparison:²¹

<u>Company</u>	<u>Delivery</u>	<u>Unit Cost</u>	<u>Cost of Five</u>	<u>System</u>
Bendix	12 months	\$ 84,000	\$420,000	2 stations, 6 guns
Sperry	15 months	83,790	418,950	2 stations, 6 guns
G.E.	18-20 months	150,000	450,000	3 stations, 6 guns

All these bids were prepared on short notice and fell considerably below the minimum requirements established by the Armament Laboratory. However, since they all represented the projects under development by the several competitors, they provided an accurate index of the evolution in fire control equipment to that time.

The Sperry proposal won the competition with a figure of merit of 1,000 points, G.E. came second with 790 points, and Bendix trailed with 645. Both G.E. and Bendix were severely penalized because, in contrast to Sperry, neither presented more than an undeveloped sketch of ^{the} all-important computer unit. The Sperry computer unit utilized the accumulated fund of experience acquired in designing the ZFK-1 computer, which gave a reasonably definite assurance of successful operation. Bendix, on the

19. IOM, Chief, Arm. Lab. to Chief, MD (WF), 28 March 1940 (marked "not sent"), in ibid.
 20. Chief, Contract Sec., WF to Westinghouse, 5 April 1940, in ibid.
 21. Quotations on CFC invitation of 20 March 1940 (proposal 218), 2 April 1940, in ibid.

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other hand, felt that no solution to the computer's critical range-finding problem existed short of adding another man to operate a range input continuously or compromising with an approximation in terms of a fixed range. Furthermore, while Sperry definitely lined up Keuffel & Esser for optical units, G.E. planned to procure optical units from Bausch & Lomb, who were already overburdened with contracts. Bendix intended to rely upon optical units within its own organization, men who were all less experienced than those of Keuffel & Esser.

The Armament Laboratory directed Sperry to develop the proposal in detail, making estimates on materials, facilities, and priorities. All aircraft manufacturers were instructed to communicate with Sperry regarding the CFC system, but it was also suggested that G.E. and Bendix be kept in touch with the progress of the Sperry developments in order to maintain an adequate point of departure for future proposals.²²

More than a week after the competition closed, Westinghouse presented a proposal which Wright Field officials considered "very clumsy" and "unduly complicated." Although one laboratory representative agreed that the "Westinghouse Company would undoubtedly be a fine one" in the turret field, the proposal was sufficiently crude to indicate that any money spent would go "largely to educating the Westinghouse Company in the fire control field."²³ But in April 1940 it was rather late to educate. The experimental contracts with G.E., Sperry, and Bendix running from 1936 through 1939 were beginning to show results.

22. Memo Rpt., EES, 15 April 1940; and Bendix to MD (WF), 5 April 1940, in ibid.

23. Informal proposal for central station fire control system, Westinghouse, 9 April 1940; and IDM to Capt. P. E. Shanahan, 30 April 1940, in ibid.

By the end of April 1940 both G.E. and Sperry promised local turrets without compensating sights within the next 90 days with expectations of peak production sometime in September or October of 1940, the Armament Laboratory optimistically reported. Every effort was being made to standardize sights and gun installations "to eliminate the necessity for tailor-making for each type of airplane."

Standardization or no standardization, the evolution of fire control apparatus above the level of local turret development inevitably stumbled on the critical element of optical units. Range finders were the bottleneck of computing sights, but even if a satisfactory range finder were to be devised, the limited production capacity for sight optics available to the Materiel Division threatened to defeat the whole fire control program.²⁴

To reduce the optical unit production hazard, the Materiel Division canvassed a number of instrument and optical concerns for "a brief statement of your interest" as well as "an account of your resources in personnel and manufacturing facilities."²⁵ Just as in the case of Westinghouse, April 1940 appeared rather late to be conducting a survey of supplementary facilities for information which was probably already available in the Industrial Planning Section at Wright Field.

The importance, even the absolute necessity, of educational orders or design studies is nowhere better illustrated than in the reply of one

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24. Information on fire control, prepared by Capt. F. C. Wolfe on verbal request from Brig. Gen. B. K. Yount, 25 April 1940, in ibid.
25. Chief, EES to Wollensak Optical Co., American Optical Co., Spencer Lens Co., Simpson Optical Mfg. Co., Kollmorgan Optical Corp., and Rochester University, 9 April 1940, in ibid.

instrument company:²⁶

This company does not profess wide experience with sights and range finders; however, with the assistance and suggestions of the Ordnance Department of [or] the U.S. Army Air Corps, together with the consulting services of West Coast engineers who are familiar with this field, we do not anticipate any difficulty in working out this phase of the problem.

The evolution of a successful fire control system was in its earliest phase. The manufacturers had much to learn.

The GHQ Air Force, in reiterating the immediate need for medium and long-range bombers, the B-28 and B-29, noted that these bombers included a "remote fire control system which is experimental." Discussions with officers familiar with fire control gave the GHQ Air Force a "very definite impression" that while the development was promising, it would be "several years" before the system could be made ready for combat use. "In other words it is believed that in these types we have too many eggs in one basket because of the experimental fire control system." The Deputy Chief of Staff for Air was reported to be of substantially the same opinion.²⁷

Whatever promise central-station fire control held for the future, in the winter of 1940-41 there were more immediate problems pressing for a prior solution. The locally controlled turret had reached the verge of quantity production, and for at least two years the major interest was to center on the problems attending the perfection of local turrets rather than on the development of remote and central-station fire control systems.

26. Librascope Inc., Burbank, Calif. to MD (WF), 5 June 1940, in ibid.
27. CG, GHQ AF to C/AC 6 March 1941, quoted in CTI-214, in Arm. Lab. CTI file.

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Chapter VIII

AN ATTEMPT AT STANDARDIZATION, 1940-1941

By December 1940 a large number of turret projects were under way in the United States. An objective and comprehensive picture of these projects as a whole is given in the report on turret development prepared for the British Air Commission by B. B. Henderson, the chief designer for Nash-Thompson, Ltd., and Parnall Aircraft, Ltd., of England.

Henderson came to the United States in December 1940 to prepare his study of the turret industry at the direction of the Ministry of Aircraft Production. In all, he inspected 36 different turret models, of which 10 were finished and operating and 5 were finished but not under power. Of the remaining 21, 7 were mock-ups and 14 were either very sketchy mock-ups or drawings only. Of the total number, 26 had hydraulic control, 9 had electric control, and 1 had mechanical control. All the hydraulic systems relied on some form of Vickers unit for pressures ranging from 400 to 100 pounds per square inch. Five of the electric systems were amplidyne, two operated with some form of pulsating DC control.

British practice in the turret industry had been to restrict production to two manufacturers. Each designer utilized a standardized mounting ring, which made the products of either readily interchangeable, to retain a healthy state of competition. These two sources designed and produced

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four basic types of turrets—nose, tail, upper midship, and lower. Production policy in the United States at the time was markedly different.

There were too many designs in progress at once in the United States, the British engineer reported. Too many manufacturers retarded rather than encouraged development, for not only did each new competitor explore the field and learn by experience the lessons already learned by those who entered the business earlier, but a multitude of designs required a disproportionately large amount of time for testing the merits of each and selecting the best points for standardization.

With regard to power drives and controls, Henderson felt that in the majority of cases insufficient attention had been paid to "the importance of slow training rates as opposed to fast." Furthermore, every hydraulic system tested revealed a dead spot at neutral in changing from one deflection to another. British combat experience had stressed the fact that smooth transitions from positive to negative deflections were "extremely important when following a target." Although Henderson considered the hydraulic systems "satisfactory up to a point," he concluded that he could regard none of them as "adequate for operation under war conditions."

The verdict on electric controls was somewhat more promising. "The amplidyne system," the report notes, was "very satisfactory indeed." The G.E. position control seemed to offer great promise in remote turrets and nose or tail cone fire turrets, but not for upper or lower turrets requiring continuous rotation, in which case speed control seemed best suited.

The Bendix lower turret was judged "unsatisfactory" by Henderson. Not only did the apparatus reveal a dead spot at neutral but a complete loss of control as well. Henderson was emphatic: "I feel that this particular system has so little to recommend it that it should be dropped in favor of either the hydraulic or the G.E. system [amplidyne]." Many gunners agreed with this verdict when the Bendix turret reached the stage of combat operations.

Summarizing turret projects in the United States, Henderson pointed out that in every case turret designers had devoted too little time and attention to gunner comfort. Seat design, hand control position, slot closure, and heating were all important but neglected considerations. Moreover, besides the unfavorable feature of a dead-spot neutral, most of the turrets revealed that inadequate consideration had been devoted to gun and loading accessibility. Few of the turrets contained harmonization facilities. In short, very few of the turret designers knew much about the practical aspects of gunnery.

Perhaps the two most critical comments of the Henderson report which affected turret designers in the United States were: (1) entirely too little attention had been devoted to the scanning area, the field of view, provided in each turret; and (2) it was imperative to standardize sights before attempting to standardize turrets because turret design hinged inevitably upon sight design. The validity of this axiom became all too apparent when the Materiel Division procured the Consolidated tail turret, but for the moment division policy had seemed to settle on the N-series reflex sight.¹

1. "Notes on gun turrets for aircraft in the USA," by B. B. Henderson, BAC, 28 Feb. 1941, in WF Lib., D/72.11/117.

The British Air Commission was anxious to secure turrets for British aircraft or Lend-Lease aircraft in British service. There were two possible courses of action to this end--manufacturing British turrets in the United States or standardizing a turret for use in both the Air Corps and the RAF. Either course of action promised to be difficult. Space and weight considerations, among others, made it impractical to install British turrets on aircraft built in the United States. On the other hand, converting domestic machine tools to British specifications would be inevitably complex, while the prospect of coordinating the Air Corps and the RAF in a joint production plan contained difficulties that were all too obvious to Materiel Division officers who had had experience with inter-Allied cooperation in the first World War.²

In June 1940 the Curtiss Aeroplane Company received an inquiry from the British regarding Curtiss' interest in taking up the license to manufacture Frazer-Nash, Boulton-Paul, and English Vickers components in the United States. Curtiss did not wish to undertake such a project, but reported the inquiry to the Materiel Division, suggesting that it could be steered to some other manufacturer if the division so wished.³

Procurement of B-24's for the British under Lend-Lease brought the question of turret installations to a head. In November 1940 two British engineers, C. B. Lowe of Nash-Thompson, Ltd., and a Mr. Hughes of Boulton-Paul, arrived in the United States with three Frazer-Nash and two

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2. For specific case histories on this point see "History of Bureau of Aircraft Production" [World War I], chapters on Foreign Missions to the U.S., and Bureau of Aircraft Missions Overseas, pp. 1161-1278, Reel No. 2 of microfilm copy in AFSHO files.
 3. B. S. Wright to Col. O. P. Echols, 28 June 1940, in ATSC 473.5, General.

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Boulton-Paul turrets to hold a conference with Army and Navy personnel at Wright Field.⁴

The Chief of the Materiel Division in Washington reduced the problem to its simplest terms and directed Wright Field to prepare plans for producing either the Boulton-Paul or the Frazer-Nash in the United States. When the several models became available for test and inspection, the directive added, a selection of the better of the two makes could be made and the production plan put into effect.⁵ To facilitate this program the British were willing to send a "works manager" and technicians to assist in demonstrating vital shop practices to speed the establishment of domestic turret production.⁶

At the Wright Field turret conference in December 1940, British engineers described and demonstrated several types of British turrets, which were considered in great detail by a widely representative board of Air Corps officers who had gathered to study the turret production problem. In general, British policy favored locally controlled turrets. "Remote sighting is not considered feasible by the British," the conference reported, "for the reason that serious deflection problems are bound to result." As a matter of practice, the RAF was temporarily abandoning remote systems when initial inaccuracies of three mils were encountered.

After the discussion narrowed down to local turrets, it was decided that the Frazer-Nash type control handles, a modified "handle bar"

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4. Memo, Chief, Arm. Sec. (Wash.), to Chief, MD (Wash.), 22 Nov. 1940, in AAG 473.5.
 5. CTI-129, 4 Nov. 1940, in Arm. Lab. Classified Technical Instruction file.
 6. Chief, Arm. Sec. (Wash.) to MD (WF), 4 Nov. 1940, in Arm. Lab. file, E.O. 553-1-350.

arrangement, were superior to the Boulton-Paul stick control, but at that point the discussions bogged down. By December 1940 the Materiel Division had let a number of turret contracts, and manufacturers were well along toward production.

When the conference turned to consider future standardization, it was pointed out that the need for production quantities before the end of the development period effectively killed all hope of immediate standardization. However, as a starting point, mounting ring dimensions had to be standardized to give aircraft designers a basis for planning.

The Wright Field argument against manufacturing British turrets in the United States was that even with a nucleus of technical experts from the United Kingdom, production of British turrets in the United States would not begin to roll for 18 months, by which time domestic production would be well advanced. It was felt, however, that British turrets could be manufactured in the United States if supported by priorities, providing such production did not interfere with domestic output. To do this, the conference considered it wise to allocate British turrets to a manufacturer not already tied up with Air Corps turret contracts.⁷

It was evident that the RAF was as lukewarm to standardization as the Air Corps, according to a panel discussion at the Ministry of Aircraft Production in London. Inevitably, the point was raised that concentration on any single type of turret must be avoided in order to retain a wide potential range for every possible future need. To illustrate this with a pointed case, consider the limitations on the

7. Memo Rpt., EES and PES, 13 Dec. 1940, in ibid.

development of stabilized turrets which would have been imposed if all Air Corps turrets had been equipped with tapered cone friction clutch speed controls when electric stabilization came in. An RAF wing commander who had toured the United States inspecting turret manufacturing facilities reported that the Materiel Division had gone into production with turrets which were "admittedly inferior," planning to improve designs after production was rolling and after the end of the emergency created by the virtually unarmed planes being tured out in the United States.⁸

The Production Engineering Section of the Materiel Division was specific in pointing out that the mere fact that British turrets utilized .30-cal. while domestic turrets utilized .50-cal. guns was "sufficient to discourage any further consideration of the use of British turrets," for the loss of time involved in changing over design and accessories from a .30 to⁵ .50 turret would nullify the time saved by using a ready-built foreign design.⁹ Complete standardization of all turrets was quite obviously an utter impossibility, but the project to build a British type of turret in the United States forged ahead nonetheless, urged on by the dire need for turrets in the United Kingdom and the pressure of interested industrialists.

A number of manufacturers, including Packard and General Motors, indicated a desire to consider turret production when it became evident that turrets had reached the stage of large-scale industry, but the Chief

8. "Minutes of First Meeting of Fifty Caliber Gun Turret Panel Held 24 Feb. 1941," by U. S. Military Attaché, England, Rpt. 42699, 24 Feb. 1941, in WF Lib., D72.11/116.

9. IOM, Chief, Bomb Br. to Chief, GFE Br., 28 Nov. 1940, in Arm. Lab. file, E.O. 553-1-350.

of the Materiel Division in Washington directed Wright Field to withhold release of British turret designs until a decision could be reached regarding production policy. In view of the magnitude of the problem, it was recommended that the question be placed before the National Defense Advisory Commission (NDAC) with the suggestion that the question be disposed of in a manner similar to the method used in the case of American production of the British Rolls-Royce engine.¹⁰

A number of factors were involved in the ultimate decision to build British turrets in the United States, but none was so vexing as the problem of coordinating both the quantity requirements and the design standards of the Army, Navy, and British air arms. The inter-service nature of the question made it an obvious one to refer to the Joint Aircraft Committee (JAC), where it was handled by a Subcommittee on Standardization of Aircraft Turrets.

Although the JAC had discussed turret standardization in principle as early as August 1940, the subcommittee on turrets did not hold its first meeting until January 1941. During the course of this and two meetings the following month, it was decided that a combination of the best features of Boulton-Paul and Frazer-Nash turrets could be combined to design a twin-.50 turret acceptable to the Army, the Navy, and the British. The proposed turret, called the ANB, would not be suitable for planes already on contract, but could stand as an objective in anticipated aircraft design.

10. TMX, Chief, MD (Wash.) to MD (WF), 30 Dec. 1940, in *ibid.* The National Defense Advisory Commission (NDAC) is sometimes referred to as National Defense Council. It was merged into the Office of Production Management (1941), and the War Production Board (1942).

The JAC subcommittee planned to establish a completely free pool for design ideas, patent rights, etc., in an effort to speed the pace toward design stabilization as a factor in standardization. To make a start in this direction, the subcommittee directed the Army, Navy, and British air arms to submit a statement of estimated ANB turret requirements in order to arrive at a cumulative production figure. This total would then be submitted to the NDAC, which would establish facilities for production. The JAC plan called for preliminary turret drawings from England in May 1941 and final drawings in the United States by August 1941. As a point of departure, the plan suggested the manufacture of 500 upper and 500 tail turrets of ANB design. JAC directed the Office of Production Management (OPM, successor to NDAC) to survey industrial facilities in the United States for the purpose of selecting a suitable manufacturer with adequate potential production capacity.¹¹

Specifications for the proposed ANB turret were drawn up, stipulating Frazer-Nash hand controls, a minimum of 600 rounds of ammunition for each gun, twin .50's, an elevation arc from plus 85° to minus 30°, and with 30°-per-second and 50°-per-second maximum elevation and azimuth speeds from a minimum of 1/2° per second, both laying and training. The specifications combined all the best features of turrets, both foreign and domestic, including armor plate, adequate harmonization facilities,

11. Report of JAC Subcommittee on Standardization of Aircraft Turrets, 20 Feb. 1941, in Arm. Lab. file, Secret Correspondence, folder 2, 1941. See also Minutes of Conference of BAC, NDAC, and Air Corps representatives on standardization, WF, 27 Aug. 1940, in AC Project Records 1940-1941, compiled by Col. A. J. Lyon (microfilm), vol. 38, "Conferences, etc.," ATSC Historical Office.

ammunition boosters capable of sustaining three G's, automatic gun chargers, emergency manual operation facilities, and many other important devices already appearing in one or another of the turrets being independently manufactured.¹² The ANB standard turret seemed off to a flying start.

Materiel Division engineers familiar with the practical problems of production were less enthusiastic than the Washington planners. The division insisted that turrets were required to meet aircraft delivery schedules; and if it proved impossible to meet such schedules, steps would have to be taken to "freeze the design" of a domestic turret type to furnish design data to aircraft manufacturers. In any event, it had become imperative to decide upon a definite manufacturer for the ANB standard turret, in order to plan tool requirements in advance.¹³

The earlier plan to manufacture unmodified British turrets in the United States fell to one side as the ANB project gathered headway. In March 1941 the Chief of the Materiel Division in Washington informed Wright Field of a decision to shelve the British turret production program. Up to that moment there had been no written agreement concerning detailed requirements for such turrets. The transition from .30-cal. to .50-cal. guns promised to consume a year; and inasmuch as turret production in the United States had already achieved a substantial level of development, it was decided that no action would be undertaken on British turret production until a definite requirement appeared.¹⁴

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12. JAC Subcommittee on Standardization of Aircraft Turrets, ANB upper midship turret specification, Feb. 1941, in AAG 473.5.
 13. TWK, EES (WF) to MD (Wash.), 14 Feb. 1941, in Arm. Lab. file, E.O. 553-1-350.
 14. Exec., MD (Wash.) to Tech. Exec. (WF), 1 March 1941, in ibid.

The OPM committee assigned to investigate potential turret manufacturers soon narrowed the field down to two St. Louis concerns, the Emerson Electric Manufacturing Company and the Knapp Monarch Company, the former specializing in small motors, the latter in electrical appliances. Both represented well-established, efficient organizations. Emerson had an ample but old array of machine tools which would require little revision for turret production. Knapp had a number of new machine tools, but they were not particularly well adapted to turret tooling. Both manufacturers lacked adequate engineering staffs, but each had large floor-space areas and a sufficient number of millwrights and toolmakers to undertake a novel project. Although neither concern had had much experience in the precision work required in turret manufacture, both were anxious to enter the field.¹⁵

The OPM favored Emerson, since its capacity was not already overloaded with defense work. Following the JAC plan, OPM opened negotiations with Emerson regarding facilities, contracts, etc., and the Materiel Division prepared to send a liaison officer to England with an Emerson representative to obtain detailed manufacturing drawings of British turrets. The division felt that it was essential to send a liaison officer, for, as one officer said, "If we let the manufacturers go over there on their own, probably they'd make a theatrical of it."¹⁶

Emerson acquired an interest in the turret field by buying up certain manufacturing rights which became available when the Tucker turret project dissolved after failing to secure a production contract from the Air Corps.¹⁷

15. T.W.K., Chief, EES (WF) to Chief, ES (Wash.), 15 April 1941, in Arm. Lab. file, Machine Gun Mounts 1941.

16. Asst. Chief, Aircraft Sec., (Wash.) to Chief, MD, 18 April 1941, in ibid.

17. Contract Sec. (WF) to Emerson, 27 March 1941, in ibid.

The OPM decision to select Emerson to manufacture the ANB turret was made without special reference to the Materiel Division, which had evinced little faith in Emerson's capacity to produce. One Air Corps official in Washington probably reflected the prevailing Materiel Division opinion when he said of Emerson's ANB contract, "I don't know whether they'll ever get them done or not, but don't much care." Plans to increase aircraft production to 1,500 planes per month in June 1943 made it essential to anticipate increased turret production; but the burden was expected to fall upon Sperry and Bendix rather than upon any new, untried manufacturer.¹⁸

Very shortly after the OPM had decided upon a facility for the ANB turret, W. S. Symington, representing Emerson, set off for England, where he learned that the Ministry of Aircraft Production wanted both the Boulton-Paul and the Frazer-Nash manufactured in the United States. This plan was, of course, contrary to the JAC standardization program; and in addition, as Symington pointed out, to produce two completely different British turrets in the United States would result in an extravagant waste of tooling. This apparent impasse was settled when it was decided that a selection would be made between the two major British manufacturers' models by Wing Commander Spreckley, the turret project officer who had previously toured the turret facilities of the United States.¹⁹

Wing Commander Spreckley and Symington visited the various centers of turret manufacture in the United Kingdom to secure firsthand information upon which to decide between the two turret types. Symington was

18. Phone transcript, Col. Grandison Gardner and Maj. F. C. Wolfe, 25 April 1941, in *ibid.*

19. Maj. J. T. Murtha to Brig. Gen. O. P. Echols, 13 May 1941, in AAG 473.5, Mounts.

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impressed with what he saw. The Frazer-Nash plants he described as "jewels of efficiency" even though they were working through "blitz" debris. Their handling of magnesium casting he rated as "far ahead of anything we have seen in the States." Nevertheless, Wing Commander Spreckley selected the Boulton-Paul as the model for use in the ANB project.

The Boulton-Paul turret was ideal for the purpose intended, not only because it was less complex than the Frazer-Nash but also because it was produced under conditions which lent themselves admirably to application in the United States. The Boulton-Paul turret was not actually manufactured in the Boulton-Paul aircraft plant where it had been designed by J. D. North, the Managing Director. Instead, only drawings were prepared there and all production was carried on by the Lucas Company, an emergency turret facility in Wales with a capacity of approximately 400 turrets a month. This "remote control" project played directly into the hands of the ANB plan, for it forced Boulton-Paul to prepare manufacturing drawings that were much more detailed than if the turrets had been constructed directly in the home plant.

Even though Boulton-Paul drawings were available in vastly more elaborate detail than Frazer-Nash drawings, the intricate task of preparing tracings suited to industrial standards in the United States threatened to be a time-consuming process. To insure a sufficiently domestic interpretation, Symington was accompanied by two engineering draftsmen from his Emerson staff. At the same time they were assisted by a corps of Boulton-Paul technicians.

The design selected represented a long evolution of turret structures. North, the Boulton-Paul designer, had worked on turrets for over 10 years and held a number of basic patents in the field. The fundamental principles of the turret were, by a curious coincidence, of French origin.²⁰ According to the report of an RAF officer, it was shortly after the racing car designer, Frazer-Nash, had built his first power turret in 1933 that a British armament dealer stumbled upon a lead which took him to a M. de Bouisson in Charentan, just outside of Paris. The De Bouisson turret, which contained the basic elements of the electro-hydraulic system of the future Boulton-Paul turret, had been offered to a French official. When that official refused to consider the turret without benefit of a bribe, the furious inventor had turned his manufacturing license over to Boulton-Paul in England.²¹

The decision to select Boulton-Paul was cabled back to the United States, where there had been a good deal of disturbance over the delay encountered between the time of the OPI' decision on the Emerson facility and the time when British drawings would be available to begin production.²² The Chief of the Materiel Division had been especially disturbed, and had written to the assistant chief at Wright Field: "It is my opinion that if we cannot come to an agreement at once, we should forget the whole proposition and manufacture Sperry turrets."²³

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20. Rpt. of W. S. Symington on trip to the United Kingdom, 5 May 1941, in Arm. Br. file, Secret Correspondence, folder 2, 1941.
21. London Sunday Pictorial, 22 Oct. 1944, feature article by Group Captain C. Hilton Keith. De Bouisson is sometimes spelled De Boysson.
22. R&R, OCAC to Chief, MD, 6 May 1941, in AAG 473.5, Mounts. See also R&R, Chief, MD (Wash.) to Chief, MD (WF), 12 May 1941, in ibid.
23. IGM, Chief, MD (Wash.) to Asst. Chief, MD (WF), 8 May 1941, in ibid.

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The Air Corps representative who had been scheduled to accompany Symington to England arrived after the decision had been made on the Boulton-Paul. Fearing that Frazer-Nash or Parnall, Ltd., might later wish to make a political issue of the selection and bring unfavorable publicity to the Air Corps, the representative, Maj. J. T. Murtha, an officer who had been intimately associated with the Materiel Division's armament program, adroitly arranged to have it officially reiterated that the selection of Boulton-Paul was a British decision.

It was perhaps unfortunate that there was such an urgency in the whole decision, for the fate of the ANB standard turret was largely decided when it had been determined to follow Boulton-Paul's fundamental design. Major Murtha reported, "it appeared wise to accept without question anything they have to offer. The whole thing has now progressed too far to delay by fighting over further changes."²⁴ The Materiel Division accepted the Boulton-Paul decision as final in May 1941; and, upon Symington's return from England in June, the first steps in ANB turret production were undertaken.²⁵

In May 1941 the Chief of the Materiel Division in Washington directed Wright Field to make a survey of the various types of Air Corps bombers that might be able to utilize the ANB standard turret. The Materiel Division did not look with favor upon the ANB turret, which would not come into production until late in 1941, when the domestic turrets already

24. Maj. J. T. Murtha to Brig. Gen. O. P. Echols, 13 May 1941, in ibid.

25. Chief, MD (Wash.) to Anderson-Nichols Associates, 2 June 1941, in ibid. See also Memo Rpt. by Maj. Murtha, 10 June 1941, in Arm. Lab. file, Secret Correspondence, folder 2, 1941.

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under contract would be ready for installation. However, the division agreed that if the ANB proved superior to domestic turrets, it could be exchanged later when production increased.

A proposed program for allocating ANB turrets was prepared for OPM for the 700 Liberators scheduled by Lend-Lease production plans, 500 Vega Venturas, more than 450 Lockheed Hudsons, and 500 Martin Marauders, in addition to an unallocated 2,500 to the Navy—a grand total of over 6,500 turrets. Although an almost entirely speculative figure, this number offered a starting point upon which to plan ANB contracts. Emerson expected to reach a 1,000-a-month production rate by June 1943; but the Materiel Division planned to issue a letter of intent on a total of a mere 1,000 turrets in order to help get Emerson started.

The Materiel Division looked askance at the ANB turret, which, apart from being a compromise to begin with, was reported as unsuitable for many types of aircraft because of space and weight limitations and airplane design characteristics.²⁶ The division was, however, very willing to have OPM assist Emerson with priorities; for even if the major portion of ANB turrets produced were allocated for British and Navy use, the Emerson facility by that time represented a turret capacity which could not be ignored.²⁷

Even before a decision had been reached on the armament of the B-24, for which the ANB turret had been seriously considered, the Materiel Division decided, at least tentatively, to "wash out" the ANB program

26. Memo prepared for H. R. Boyer, OPM, 9 June 1941, in ATSC 473.5, General.

27. Chief, MD (Wash.) to H. R. Boyer, OPM, 1 July 1941, in AAG 473.5, Mounts.

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after the first limited production order had been run through. It was suggested that the Emerson facility might well be devoted to subcontract work for Sperry or Consolidated. Bendix turret deliveries had been so poor up to July 1941 that it seemed not unreasonable to switch some of the Bendix contract to utilize Emerson's capacity. The chief of the Armament Laboratory spoke for the future when he suggested that it would be wiser to pile the bulk of the subcontract work "into Symington's lap" and build up one facility rather than three or four.²⁸

The Defense Plant Corporation (DPC) signed a plant-expansion contract with Emerson on 15 July 1941, under the sponsorship of the OPM. However, as early as June construction had been under way on the new Emerson turret plant in St. Louis. By the middle of July, at least 70 per cent of the necessary machine tools, most of them procured secondhand to facilitate delivery, were installed in temporary quarters.²⁹ The original DPC lease provided for 704,000 square feet of plant space equipped to produce 1,000 turrets a month, the whole expansion to be financed by DPC at approximately \$10,500,000.

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28. Phone transcript, Lt. Col. Grandison Gardner and Maj. F. C. Wolfe, 10 July 1941, in Arm. Br. file, E.O. 54-1-130. See also phone transcript, Maj. S. R. Brentnall, Bendix Res. Rep. South Bend and Col. K. B. Wolfe, 22 July 1941, in *ibid.*
29. Symington, Emerson to Boyer, OPM, Rpt. No. 3 on Emerson DPC project, 22 July 1941, in AAG 473.5, Mounts.

The magnitude of the turret manufacturing business at the Emerson facility alone is suggested in this table:

DPC Projects

Items	78A original	78A-1 18 Dec. 41	78A-2 21 Jan. 42	78A-3 27 Mar. 42	78A-4 28 Apr. 42
Land, etc.	65,001	unchanged	\$ 92,901	unchanged	unchanged
Buildings, etc.	2,742,315	\$3,283,915	3,994,857	\$4,398,880	\$5,485,352
Machinery, etc.	7,583,370	unchanged	unchanged	8,819,434	unchanged
Autos, etc.	21,545	unchanged	unchanged	30,017	unchanged
TOTAL	10,422,231	10,953,831	11,692,673	13,341,232	14,427,704

By June 1943 the project was substantially complete, with 817,300 square feet of floor space at a total cost of \$14,870,794 to the DPC.³⁰ The original Emerson plan called for a capacity of 1,000 turrets of a single design, with all major assemblies subcontracted to one or more outside manufacturers. By March 1942 Emerson was producing 2,000 turrets monthly, representing seven different designs. The original plan for an office staff of 300 employees and a factory roster of 2,200 employees had increased by March 1942 to nearly 2,000 and 5,500 employees, respectively.³¹

By the end of July the ANB turret at Emerson had run upon some very definite snags. Of the estimated 750 drawings considered necessary to

30. Memo, Brig. Gen. F. M. Hopkins, Jr., MM&D Resources Div. to USH, 17 June 1943, in AAG 004.03. For information in table, see DPC project 78A, App. A, Schedule IV, 28 April 1942, in ibid. Totals in table include items not shown in detailed breakdown.

31. Schedule 111, 78A-3 project, ftn., pp. 2 ff., 27 March 1942, in ibid.

produce the ANB turret, only 554 had arrived from England. Symington, president of the new Emerson turret plant, complained that the perpetual flow of minor changes being entered on the British drawings to keep pace with combat developments delayed the Emerson project intolerably.

More important, perhaps, was that Emerson had run into production troubles with the magnesium castings necessary for the ANB. Shop practice in the United States proved notably inferior in this field to that prevailing in the United Kingdom, and Emerson was anxious to secure some British artisans as well as some special-purpose machinery, necessary despite the fact that one of the original reasons Boulton-Paul had been chosen over Frazer-Nash was that the latter required more special-purpose machinery in the course of manufacture than the former and threatened to be a machine-tool bottleneck if chosen for production in the United States. As late as September 1943 the War Production Board (WPB, successor to OPM) was still negotiating with Emerson regarding an extension on the Emerson plant to include a magnesium foundry.³²

By the middle of August 1941 still other troubles appeared to the detriment of Emerson production. Sixteen roller bearing manufacturers throughout the United States were canvassed as suitable bearing subcontractors, but not one of them was interested. While Emerson invoked the aid of the OPM in the quest for ANB standard turret bearings, British engineers warned that Emerson's worries were just beginning, for the

32. W. S. Symington to Col. Grandison Gardner, 23 July 1941, in AAG 473.5, Mounts. See also memo, Brig. Gen. F. M. Hopkins, Jr., M&D Resources Div., to USW, 10 Sep. 1943, in AAG 004.03.

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really difficult problem of turret construction in the United Kingdom was the construction of a transparent canopy with adequate optical properties.³³

Technological difficulties, furthermore, were only a part of Emerson's problem. By November 1941 the ANB turret project was bogging down with administrative difficulties as well. Emerson complained that three different agencies, the Experimental Engineering Section at Wright Field, the Technical Subcommittee of the Joint Aircraft Committee, and the British Air Commission, were all sending letters of instructions relating to modification details on the ANB turret.³⁴

A shipment of Boulton-Paul drawings to Emerson accidentally enclosed a letter from a Boulton-Paul draftsman to the Ministry of Aircraft Production (MAP) advising the MAP to hold up production at Emerson because certain accessories in the Boulton-Paul drawings sent to the United States had proved unsatisfactory in combat. This information had not been transmitted to the United States by the MAP, and Emerson wrote indignantly to the British Air Commission:³⁵

It seems to us that someone was negligent in not cabling this information as we have been going right ahead. . . . This work has been in process of actual manufacture by subcontractor, which means that we have a lot more scrap loss than if we had been notified promptly.

International coordination was proving to be a difficult and costly venture.

If negotiations with the British proved troublesome, coordination with the Navy was equally difficult. In July 1941 the Chief of the Navy's Bureau

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33. Emerson to MD (WF), 11 Aug. 1941, in Arm. Lab. file, Secret Correspondence, folder 2, 1941.
 34. Emerson to MD (WF), 18 Nov. 1941, in AAG 473.5, Mounts.
 35. Emerson to BAC, 3 Dec. 1941, in ibid.

of Ordnance informed the Chief of the Air Corps that the Navy requirement for ANB turrets would amount to a total of approximately 759 units for use with the Martin PBM-4, deliveries of which were to begin in April 1943.³⁶ From an initial plan scheduling over 6,500 turrets for all services, the total requirement had dropped to 759 for the Navy alone. The British and the Air Corps were no longer interested in the ANB.³⁷

When the trend downward in ANB requirements became evident, Emerson began rapidly casting about for production to utilize the enormous potential capacity of the new plant. By September 1941 Emerson was busy urging the OPM to route Ordnance tank turrets to the new facility, not alone to exploit the capacity available but also to maintain the existing organization. Outside promotion groups, Emerson claimed, were luring away subcontractors to become prime contractors on Ordnance projects. "Naturally," the president of Emerson pointed out, "such muddying takes the interest of our subcontractors off the main job at hand; namely, furnishing Emerson subassemblies."³⁸

In December 1941 Emerson reported that the new facility was down to 17.5 per cent of capacity. Moreover, an important subcontractor, Serval, a gas refrigerator concern, was represented as ready to sever all ties with Emerson because up until that time all Emerson's work had been tool-room rather than production jobs. Consequently, Emerson was anxious to line up production contracts with the Materiel Division.³⁹

36. Chief, Navy BuOrd to C/AC, 30 Sep. 1941, in Arm. Lab. file, Correspondence, folder 3, 1941.

37. IOM, Chief, Arm. Br. to Chief, PES, 24 Dec. 1941, in AAG 473.5, Mounts.

38. W. S. Symington, Emerson to H. R. Boyer, OPM, 26 Sep. 1941, in *ibid.*

39. Phone transcript, W. S. Symington, Emerson and Maj. M. D. Burnside, MD (WF), 1 Dec. 1941, in Arm. Lab. file, Correspondence, folder 3, 1941.

The Materiel Division was equally anxious to foster Emerson as a turret manufacturer. The chief of the Production Engineering Section described Emerson as the first facility for that class of equipment "really honestly and conscientiously going into this subcontracting picture on the scale we'd like to see it done." When the Ford Motor Company sought a subcontractor for the tail turret on Ford-built Consolidated B-24's, Wright Field suggested that Ford utilize the excess Emerson capacity which had been established for the now unwanted ANB turret.

Ford had hoped that the Materiel Division would designate the B-24 tail turret as government-furnished equipment (GFE), but the division, already overloaded with work, was only too glad to let the turret remain a part of the airplane contract as it had been originally, relieving the Armament Branch at Wright Field of an additional and onerous responsibility. For this reason, as well as to prime the Emerson capacity, the chief of the Production Engineering Section was more than willing to encourage Ford to build tail turrets at Emerson.⁴⁰ In August 1941, therefore, Ford opened negotiations with the new turret facility.

The Emerson technique of arriving at an estimate on the Consolidated tail turret for Ford gives an enlightening side glance into Emerson's large-scale industrial cost-accounting methods. In the ANB there were approximately 1,800 parts, 1,000 processed by Emerson, 800 procured by purchase. Studies revealed that an average of 13 jigs, dies, or other tools were required for every part processed, or a total of 13,000 tools

40. Phone transcripts, A. H. Wibel, Ford and Lt. Col. K. B. Wolfe, PEs, 29 July 1941, in ATSC 473.5, General.

which cost an average of \$100 per tool. This placed the cost of tooling the ANB at \$1,300,000. On this basis 7,500 tools for the Consolidated turret machined to a finer degree of tolerance would cost an estimated \$750,000, which Emerson offered Ford on a take-it-or-leave-it basis.

Emerson had tooled a turret and knew with the bitterness of experience that turrets were not run-of-the-mill machine-tool jobs for mass production. Symington, the president of Emerson's turret division, expressed the point tersely when he wrote to Ford: "Turrets may not be as hard to build as gun sights. But they are not as easy as sometimes thought. They have never been built in real production in this country."⁴¹

Emerson knew what Ford did not realize. Turret production throughout the development stage, which had not yet terminated, was a tool-room job. Ford informed Wright Field that Emerson did not appear to be a satisfactory source, and Ford was determined to canvass the Detroit automotive concerns in search of a better price.⁴²

When the Consolidated tail turret contract plan died out, the Production Engineering Section chief asked if Emerson had ever considered the Sperry turret. Symington reported that the president of Sperry had mentioned Emerson favorably as a facility for Sperry units. When a similar proposal was suggested for G.E. turrets, Symington hedged and sparred; for he was unwilling to commit Emerson to a subcontract policy, since his organization had its own group of subcontractors and an established "assembly capacity."

41. Emerson to Ford, 13 Aug. 1941, in Arm. Lab. file, Secret Correspondence, folder 2, 1941.

42. Phone transcript, A. H. Wibel, Ford and Lt. Col. K. B. Wolfe, PES, 14 Aug. 1941, in ibid.

It became essential, however, to reach a decision shortly; for the original Emerson plant had a production capacity of 250 turrets a month, and the new turret division which would be completed in January 1942 promised to increase that figure to a potential capacity of more than 1,000 turrets a month. Even if Emerson had to forswear the superior profits of prime-contract production work, the time drew near when it was absolutely necessary to utilize Emerson's capacity.

Sperry asked Emerson to consider manufacturing 100 upper local turrets a month beginning in July 1942; and Emerson, once convinced of the necessity of accepting work on such a basis, entered wholeheartedly into the project, sending Sperry a 75-page list of Emerson machine tools to support the Symington claim that Emerson stood among the "best Midwest machine tool plants." When the chief of the Armament Laboratory at Wright Field suggested that a similar list be sent to G.E., Symington reported that Emerson would build any turret steered in by Wright Field so long as volume production was assured. Of the three major concerns, Emerson would prefer G.E. first and Sperry second. Symington, however, was unwilling to touch Bendix turrets, which the British had condemned.⁴³

After visiting the Sperry plant, Emerson moved the upper local turret schedule ahead from January 1942 to the production of 10 in August 1941 and 100 a month by the end of the year. With an optimism known only to salesmen, Symington informed Wright Field that Emerson would welcome all the business of swamped turret manufacturers which the Materiel Division could route through St. Louis.⁴⁴

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43. Phone transcripts, W. S. Symington, Emerson and Maj. F. C. Wolfe, Arm. Lab., 12 Aug. 1941, in *ibid.*
 44. Emerson to MD (WF), 12 Aug. 1941, *et seq.*, in Arm. Lab. file, Machine Gun Mounts 1941.

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The Materiel Division took Emerson at its word; and soon the Emerson facility was heavily engaged in Sperry contracts, building both upper and lower turrets as a part of the production complex built up beneath the Sperry organization. As if the ANB project had been but an initiation, Emerson was soon in the very midst of a series of baffling coordination problems. Another of the Sperry subcontractors, the Steel Products Engineering Company of Springfield, Ohio, also built Sperry upper turrets; and, to establish a smoothly functioning system of coordinating design and industrial methods, Emerson and Steel Products agreed to have representatives visit each other's plants on alternate weeks to press cooperation and standardization to the limit.

Even at its best, however, coordination was difficult. When Steel Products engineers designed a new canopy or turret dome, the project had to be approved by Wright Field, not directly but through channels—that is, through the prime contractor, Sperry—before drawings for the improved design could be circulated from the point of origin.⁴⁵ This cumbersome but necessary system was annoying even among amicable concerns, but between hostile competitors it became intolerable.

Briggs Manufacturing Company at Detroit, another Sperry subcontractor, seemed, so Emerson believed, to be thwarting Emerson's development despite the fact that Briggs, an automobile body concern, and Emerson, a manufacturer of electric motors, could in no sense be termed competitors in the peacetime market. Emerson charged Briggs with obstruction in refusing to reveal the list of Briggs subcontractors to Emerson even in face of the

45. Emerson to Steel Products, 28 Nov. 1941, in Arm. Lab. file, Secret Correspondence, folder 3, 1941.

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fact that both concerns were straining to produce Sperry lower ball turrets fast enough to meet an ever more critical need. Moreover, Emerson complained, the drawings which Sperry directed Briggs to send Emerson were "inadequate," calling for "unreasonable tolerances" for unmated parts.

To judge from the record of the turret industry, as late as September 1941 it seemed that holding the market was more important than cooperative production. When Emerson undertook the Sperry subcontracts, Sperry agreed to furnish controls, drive units, and fire interrupters. Vickers, Inc., the Detroit satellite of Sperry, was the sole source of all-essential Vickers units. When Emerson's turret production rate in conjunction with the other Sperry subcontractors brought the demand for Vickers units above Vickers' capacity to produce, Emerson sought to produce Vickers units independently.

When Vickers gave every impression of being unwilling to expand or to let Emerson attempt Vickers unit production, Symington threatened to make the unit anyway, patent or no patent, saying, "tell them to sue as far as I'm concerned"; but the Production Engineering Section at Wright Field wisely sought to keep peace by making some sort of acceptable arrangement to increase Vickers unit output.⁴⁶ Meanwhile, the Vickers unit became a critical production bottleneck, and the Materiel Division cast about for a substitute power drive.

46. Phone transcript, W. S. Symington, Emerson and Maj. M. D. Burnside, PES, 23 Sep. 1941, in ibid.

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The futile search for standardization had ended in dismal failure, but the enormous expense of the Emerson facility was far from wasted. In that facility the Materiel Division secured the services of an aggressive, well-equipped, production-wise industrial organization just when the accelerated upswing of aircraft deliveries made turrets in production quantities an absolute necessity.

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Chapter IX
POWER DRIVES, 1940-1942

The Vickers unit bottleneck which threatened to cripple turret production down through May 1942 was but one of the Materiel Division's typical production problems, but for the Armament Laboratory it represented one of the most critical elements in the armament program. As far back as December 1939, when turrets were still largely in the drawing board stage, the chief of the Armament Laboratory had inaugurated a search for suitable drive units to power the novel gun installations.

Typical of the many concerns found in the canvass of potential sources was the L.A.B. Corporation of Summit, N. J., a manufacturer primarily interested in the field of instruments and controls. After reviewing the Armament Laboratory's suggested "two gun installation," L.A.B. proposed two methods of turret drive, a constant-pressure pneumatic system utilizing flow-valve speed control and an AC electric motor generator regulating turret speeds with a circuit for adding and subtracting impulse signals. The Materiel Division processed an Authority for Purchase for the modest sum of \$4,300 to press development of the latter system, but the project never developed beyond an experimental model which suffered from such excessive dynamic lag as to be useless without extended development.¹

1. L.A.B. Corp. to MD (WF), 4 Dec. 1939, in Arm. Lab. file, E.O. 554-1-122. See also L.A.B. Corp. to MD (WF), 22 Dec. 1939 and 4 Jan. 1940; A for P 156520, 16 Jan. 1940; and Memo Rpt., EES, 7 Aug. 1940, in ibid.

The L.A.E. project was no more important than a number of other similar schemes, but it is worth mentioning because it illustrates the type of exploratory procurement the Armament Laboratory was undertaking. The most obvious lesson, perhaps, was that insufficient research funds, either company or government, curbed the project just when it reached the point where it might have matured. Only slightly less obvious was the fact that a longer period of familiarization would undoubtedly have produced better results. As it turned out, by the time the L.A.E. experimental model reached the testing stage it had already been superseded by more advanced designs of other competitors.

The Bethlehem torque amplifier was another illustrative case, which demonstrated the necessity of long-range planning in procurement programs. In June 1940 J. P. Madden, holder of the Bethlehem Steel torque amplifier patents, offered his patents to the Air Corps for possible application in a turret drive. The amplifier had been developed in the late 1920's by Bethlehem Steel and dropped for want of funds, Siemens, holder of the German patent rights, applied the device in anti-aircraft gun controls for the German Army.

Regardless of any potential merit in the torque amplifier, the offer was rejected at Wright Field, where it was explained that experience had shown it to be wiser to consider turret units as a whole rather than to consider components thereof. When the patent holder protested that he was in no position to develop a complete turret unit, he was directed to negotiate with Martin, where a possible use for the amplifier might be found. Martin, however, already under way with the amplidyne drive which was later to prove so successful, brushed off the torque amplifier

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with scant attention, and Madden went off complaining that "other governments" could use what the United States ignored.²

Aside from the possible value of the Bethlehem torque amplifier as a mechanical device, the incident is noteworthy in that it suggests the dangers inherent in a system which compelled the rejection of innovations once the process of design and development had reached a degree of perfection where it would no longer be profitable to consider major innovations. Quite obviously the Materiel Division could not throw its experimental program into reverse for each new item of apparatus appearing on the horizon, but the case suggested a certain utility in exploring the drive field exhaustively during the impecunious period between wars to prevent the misfortune of being forced to reject a potentially significant device in the final stages of development when it would be too late to do otherwise.

By December 1940 it became all too apparent to the Materiel Division that turret designs were channelizing around two types of drives, the Vickers unit and the amplidyne. In an effort to break away from this threatening bottleneck, the chief of the Experimental Engineering Section sent out a series of exploratory letters to possible turret drive manufacturers. Typical in this search was the case of the Submarine Signal Company in Boston.

The Experimental Engineering Section wrote Submarine Signal explaining that division engineers had noticed the company's advertisement for a variable-speed lathe drive in the June 1940 issue of the trade journal,

2. J. P. Madden to C/AC, 5 June 1940, et seq., in ATSC 473.81.

Products Engineering. The section elaborated on the problems involved in designing variable-speed turret drives, even to the point of specifying speed ranges and torque loadings, information which but a short time before would not have been circulated without elaborate precautions to insure secrecy. This undue haste in revealing the whole problem in a preliminary letter was excused on the basis of the "urgency making it necessary that the work be gotten under way as soon as possible."³

The Submarine Signal reply led to a conference with Wright Field representatives where the speed control, designed for use with a Rivett lathe, was described as an electric motor actuated by current impulses triggered by thyatron tubes. Speed variations were determined by the grid voltage of the thyatron, which in turn was affected by the motor's back electromotive force. The device seemed to hold some promise despite the fact that it was designed to operate on an AC system. To be sure, the apparatus in its existing form was too heavy for aircraft use; but the fundamental theory of operation, not unlike the Lorfeuvre patent of 1938 in the United Kingdom, gave promise for the future, especially if aircraft were likely to go over to AC electric systems.⁴

Unfortunately, in April 1941 there were no hydraulic turret drives available at Wright Field to use as a basis of comparison with the Submarine Signal system, and so the chief of the Armament Laboratory directed the company to negotiate directly with Bendix, at that time searching for a satisfactory power drive. Bendix procured a sample

3. Chief, EES to Submarine Signal Co., 5 Dec. 1940, in Arm. Lab. file, E.O. 553-1-343.

4. United Kingdom Patent 482,325, 28 March 1938, for Lorfeuvre "thyatron" type control; Chief, PES to Bendix, 31 March 1941, in Arm. Lab. file, Machine Gun Mounts, 1941.

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Submarine Signal system, and as late as October 1941 reports to the Materiel Division indicated that an experimental system had been installed for trial. The project never developed beyond that stage, in all probability because of the weight and space complications attendant upon the necessity of installing an AC-DC converter.⁵

The case of the Submarine Signal drive is representative of the method of procurement employed by the Materiel Division in its search for a substitute drive. The Armament Laboratory's limitations in testing facilities and personnel were never more apparent. The discrepancies between existing 24-volt DC aircraft electrical systems and the Submarine Signal device probably accounted for the fact that nothing ever came of the drive.⁶

The drive search in December 1940 turned up another potential source, Lear Avia, Inc. at Wandalia, Ohio. This manufacturer optimistically promised a drive in 60 or 90 days, a drive capable of speed ranges from $1/8^{\circ}$ to 45° per second with accelerations up to 45° per second per second⁷ and control handle movement spread eccentrically over the deflection range to give an "ideal" control curve. The Materiel Division in April 1941, approved a \$3,000 contract for an experimental installation.

5. Memo Rpt. by G. T. Bixby, 13 Oct. 1941, in ibid.

6. The episode raises an interesting problem. Since the shortage of personnel and equipment prevented any conclusive testing of the apparatus at Wright Field, it was turned over to Bendix. Does that mark the end of Armament Laboratory interest? Is there any division record of the apparatus and an evaluation of its worth for possible future reference? If military aircraft should at some future time switch over to AC electrical systems, the thyatron control might possibly prove to be of considerable utility. This particular idea may be sufficiently familiar to insure consideration if eventually needed, but is this true of every idea rejected by immediate requirements?

7. "Per second per second" refers to acceleration, while "per second" refers to speed; that is, to a variable rate-time ratio and a constant rate-time ratio, respectively.

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The Lear drive principle was essentially simple. It consisted of two parallel electric motors controlled by the same potentiometer. The motor drive shafts fed rates into a differential with a reversible output shaft pinioned from the gear assembly. Potentiometer deflections gave a wide range of speed variations. However, the task of perfecting the simple principle to the point where it would satisfy the rigid requirements of a turret drive proved extremely more difficult than had been at first expected.⁸ In April 1942 the Contract Section at Wright Field requested some form of results at the threat of terminating the contract. By July 1942 Lear reported that the "pressure of other work" had induced the company to abandon all efforts to perfect the drive.⁹

This case illustrates pointedly the difficulties facing the Armament Laboratory. As in the case of the Submarine Signal drive, the Lear Avia device dwindled down to an inconclusive end at the hands of a manufacturer; and the Armament Laboratory had no record of the trials, the errors, the mistakes, and the innovations which the Lear differential drive evolved. The real value of the \$3,000 research contract died when the accumulated experience of the project failed to reach the Armament Laboratory for future reference. Regardless of the necessities of economy and the limitations of personnel that forced the Materiel Division to farm out much of its experimental work to manufacturers, a system and procedure were necessary for extracting every last possible element of experience from the manufacturer's research for the benefit of the division.

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8. Lear Avia to MD (WF), 20 Dec. 1940, in Arm. Lab. file, E.O. 553-1-343. See also Contract W535 ac 18567, 15 April 1941.
9. Contract Sec. to Lear Avia, 23 April 1942, and Lear Avia to MD (WF), 2 July 1942, in ibid.

The "pressure of the work" purportedly induced Lear Avia to neglect the experimental drive contract. A question arises as to how many potentially important ideas of the kind have been lost to the Materiel Division through a similar neglect. Although in wartime the manufacturer has a seller's market and can afford to neglect some lines of development for other more profitable items, this situation probably does not prevail in peacetime. It would seem that the Armament Laboratory would get substantially more for its money if it could begin exploratory contracts such as the Lear Avia \$3,000 experiment at a time when the sum would loom sufficiently large to lure manufacturers into pushing research projects toward the point of fruitful conclusion. The Bethlehem torque amplifier, the Lear differential, and a half dozen other such ideas illustrate vividly the conclusion that components arriving after the production period begins have but slight chance of survival.

Quite obviously, then, the time for research came long before the moment of production; and if the lack of funds made it impossible to enter into actual experimental contracts on any large scale, there should have been little to hinder an over-all survey, with the resultant lining up of potential components such as drive units.

The disparity between armament installations in Europe and the United States at the outbreak of the second World War led the chief of the Experimental Engineering Section to appreciate the need for an improved system of evaluating attaché and other technical intelligence reports. Even apart from this consideration, which affected the entire division, the belated search of December 1940 for a turret power drive suggests that there might have been substantial utility in some plan of systematic search through the technical literature of the day.

When the Vickers unit bottleneck threatened to reach destructive proportions in the early months of 1941, the Armament Laboratory might possibly have had an emergency measure available if some survey of the technical literature had been maintained. This conclusion may be illustrated by an example. As far back as 1938 both the British aircraft magazine Aeroplane and the trade publication Engineering had carried articles on an ingenious hydraulic motor for aircraft use produced by the machine-tool firm R.A.D., Ltd., of Sidcup, Kent.¹⁰ Throughout the period during which the chief of the Experimental Engineering Section conducted his frantic search for a Vickers substitute, the R.A.D. drive was readily available; but information concerning it did not reach the Materiel Division until it was sent in by a military attaché in February 1941.¹¹

The Vickers unit bottleneck, which resulted in the necessity of revising turret delivery schedules downward, was the product of several factors: the intrinsic difficulty of machining the unit, Vickers' initial unwillingness to expand, and the problems involved in finding a capable subcontractor. The following chart of scheduled deliveries indicates the nature of the bottleneck.¹²

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10. This information made available at Wright Field, in "Description of RAD cannon turret and comparison with S.M.I turret," by U.S. Military Attaché for Air, England, Report No. 40897, 9 Feb. 1941, in WF Lib., D72.21/11.
 11. A careful re-check of ATSC files reveals no indication that the R.A.D. drive was known to Wright Field before the attaché report of February 1941 was received.
 12. Sperry to MD (WF), 3 Feb. 1941, in PES Arm. Unit file, Turrets, Sperry, General to 1941.

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<u>1941</u>	<u>Sperry Upper Local Turrets</u>	<u>Vickers Units</u>
30 March	6	1
15 April	0	5
30 April	12	0
30 June	25	10
30 July	40	20
30 Aug.	40	30
30 Sep.	40	40
30 Oct.	40	40
30 Nov.	40	40
30 Dec.	40	40

By the fall of 1941 the Vickers unit shortage promised to become so critical that the Production Engineering Section of the Materiel Division focused attention on the Vickers plant in an effort to break the bottleneck.

Vickers complained that at least part of the delay in reaching production grew out of the fact that the several members of the Sperry complex--Briggs, Emerson, and Steel Products--had expressed their intentions of using Vickers units, but no formal orders had been placed. Because of this, Vickers subcontractors, wary of the potential losses awaiting the manufacturer who made commitments in advance of contracts, were unwilling to produce component parts.¹³ The Production Engineering Section (PES) undertook to speed the approval of formal contracts to unleash the productive capacity of Vickers' subcontractors, but discovered a new hurdle in the process.

Several of the manufacturers using Vickers units were found to be accumulating units in stock far in excess of their actual production requirements, so PES evolved a rigid plan of inventory control to prevent

13. Phone transcript, Mr. McCabe, Vickers, and Maj. M. D. Burnside, PES, 10 Nov. 1941, in Arm. Lab. file, Machine Gun Mounts, 1941.

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an artificial internal bottleneck. A system of serial numbers on each unit manufactured made it possible to prevent excess stocks from piling up "on the shelf" at the various assembly facilities.¹⁴

When the Ordnance Department requested permission to divert a portion of Vickers unit output to ground turrets for the Coast Artillery and Armored Force, it became evident to PES that no time could be lost in expanding Vickers' capacity.¹⁵ After an extensive OPM survey of facilities capable of machining the close tolerance of the Vickers unit, the Hobart Manufacturing Company of Troy, Ohio, makers of food-preparing machinery, was selected to increase Vickers' capacity. Delco Remy of Dayton, Ohio, had been considered, but with some justice Vickers was unwilling to turn over a choice item to a potentially serious competitor in the same market. Hobart, however, was sufficiently specialized not to offer a threat in the future.¹⁶

Repeated rejections of Vickers units because of "creep," that is, slight leakages giving rotation when the controls are theoretically at neutral, forced the Experimental Engineering Section to revise the specifications for Vickers units to permit inspectors to pass units with creep up to $1/4^{\circ}$ per second because it had been found impossible to achieve 0° per second creep under "allowable existing manufacturing tolerances."¹⁷ The struggle to maintain the margin of allowable tolerances

14. PES to Sperry, Briggs, Emerson, and Steel Products, 26 Dec. 1941, and PES to Vickers, 22 Dec. 1941, in *ibid.*

15. Chief, Arm. Sec. (Wash.) to PES, WF, 23 Dec. 1941, in *ibid.*

16. Phone transcript, Lt. Col. K. B. Wolfe, PES and Warren Clark, OPM, 24 Sep. 1941, in ATSC 473.5, General. See also PES to Vickers, 19 Jan. 1942, in Arm. Lab. file, E.O. 553-1-373.

17. Memo Rpt., EES, 10 Dec. 1942, in Arm. Lab. file, E.O. 553-1-343. See also IOM, Chief, PES to Chief, EES, 28 Oct. 1942, in *ibid.*

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within a reasonably minimal figure graphically illustrates the heart of the difficulties encountered by the Production Engineering Section and OPM in the quest for a facility capable of enlarging the Vickers unit output.

As late as May 1942 the Production Engineering Section warned the Experimental Engineering Section that despite the increased output of Vickers and Hobart, the Vickers unit production outlook was "not too bright" and recommended that a substitute drive be found, saying, "This variable displacement pump is considered to be the most difficult piece of equipment to manufacture of the entire armament series; indeed it has proven impossible to find a manufacturing source to augment the two existing sources."

At the Armament Laboratory this discouraging shortage was all too obvious, although in the spring of 1942 there was a general impression that among the several turret manufacturing companies some solution to the problem would appear. Before examining the products of the individual manufacturers in detail, it is well to follow the laboratory's record of the search for a substitute drive down to the time when production problems were no longer critical in the United States.¹⁸

In March 1941 the Armament Laboratory made a survey of the existing electric drive projects to plan a campaign of future developments. The report of the survey reached the conclusion that varying resistance controls in series with drive motor armature circuits were useless because they gave inherently poor speed control at varying loads. The Tucker

18. ICM, Chief, PES to Chief, EES, 21 May 1942, and 1st ind., EES to PES, 29 May 1942, in ibid.

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drive typified this control. Variable resistance in drive motor field circuits gave too narrow a control range. Amplidyne control was considered excellent but carried with it a severe weight penalty. The DC pulsating controls, typified by the Bendix drive, stalled at slow speeds and showed a tendency to arc excessively. The AC systems involving a rectifier and electronic grid control, typified by the Submarine Signal drive, had a severe weight penalty but gave promise of proving to be a simple, accurate control when perfected. Finally, the torque amplifier, typified by the Bethlehem patent device, was not sufficiently developed to evaluate properly.

The survey report recommended amplidyne for the present, with continued investigation of pulsation, torque amplifier, and rectified AC electron control systems for future consideration. Furthermore, it was recommended that manufacturers offering novel drive systems should accompany their proposals with test data to substantiate their claims regarding speed variations and load capacity, to give the Armament Laboratory some means for making immediate appraisals and for sorting the probables from the impossibles to avoid wasting the time of valuable personnel in final tests.¹⁹

Just after the electric drive survey had been completed, a request for information regarding metadyne drives reached the Armament Laboratory from the Naval Aircraft Factory in Philadelphia. Back in 1938 and 1939, there had been a considerable exchange of information on electric drives, but the Navy's resurrection of the long-dead metadyne indicated a low

19. Memo Rpt., EES, 10 March 1941; and Memo Rpt., EES, 29 March 1941, in ibid.

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level of coordination between the two services.²⁰ But even though inter-service liaison was poor, the Materiel Division continued its aggressive drive search throughout the industrial field.

The Experimental Engineering Section addressed letters similar to the one sent Submarine Signal to a number of other manufacturing concerns, with diverse results. A query to the Briggs & Stratton Corporation at Milwaukee revealed that that concern had sold its speed control business to the Graham Manufacturing Company at Providence, R. I., who in turn reported that the Graham speed control unit weighed over 200 pounds and had a life rating of approximately 50 hours, which made the apparatus entirely unsuited to aircraft use.²¹

Negotiations with the Burklyn Corporation at Los Angeles, Calif., for a transmission gear drive came to an end when it was discovered that the Burklyn drive required an exertion of some 20 pounds by the operator.²² A similar proposition to General Motor's New Departure Division at Bristol, Conn., brought the information that the New Departure variable speed control, "Transitorq", had been discontinued in 1938 and would not warrant special manufacture for aircraft use because it was critical with regard to lubrication.²³

But not all the Materiel Division's efforts in searching for a drive unit ended in rejection. An initial query in February 1941 aroused the

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20. Manager, Naval Aircraft Factory to General Inspector Naval Aircraft, (NF), in Arm. Lab. file, E.O. 554-1-123.
 21. MD (WF) to Graham Mfg. Co., 17 Feb. 1941, in Arm. Lab. file, E.O. 553-1-343; MD (WF) to Briggs & Stratton, 12 March 1941, 13 March 1941; and Graham to MD (WF), 29 March 1941, in *ibid.*
 22. MD (WF) to Burklyn Corp., 2 March 1942, *et seq.*, in *ibid.*
 23. MD (WF) to New Departure, 17 Feb. 1941, *et seq.*, in *ibid.*

interest of the Master Electric Company of Dayton, Ohio, in turret drives, and the company's engineers set to work designing a suitable installation. By November little or no progress had been made in perfecting a drive. The Materiel Division directed Master to cooperate with Emerson in providing a substitute drive in time for the anticipated peak production of the St. Louis plant, but the Master design was so rudimentary and development progress so slow that Emerson predicted that the Master drive could not be ready for months.²⁴

The Master engineers were confident that their drive represented a step in the right direction toward a solution of the difficult turret power problem: "We are so firmly of the belief that our drive has outstanding advantages from a tactical standpoint that we propose to do all the necessary work at our own expense and without imposing any obligation on the Government whatsoever." Five months later this confidence was gone. All efforts to perfect the Master drive left the device with controls too stiff under load and with unbalanced torques on change of rotation. The Master engineers confessed a lack of engineering ability, and noted that the press of other war work had seriously hindered the process of development. An amusing sidelight on its engineering ability appeared in a request from the firm for help from Wright Field to put together a turret borrowed for experimental purposes.²⁵

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24. MD (WF) to Master Electric, 17 Feb. 1941; and Emerson to Master Electric, 21 Nov. 1941, in *ibid.* See also Emerson to MD (WF), 29 Nov. 1941, in Arm. Br. file, Confidential Correspondence, folder 3, 1941.
25. Master Electric to MD (WF), 19 Nov. 1941; and Master Electric to MD (WF), 23 March 1942, in ATSC 473.5, General.

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There were some, however, who had great faith in the Master drive principle; and in June 1942, after the Master engineers had abandoned the project, a new group, the American Aircraft Associates of Dayton, Ohio, proposed to carry on the task of development. This new manufacturer was "firmly convinced that the mechanical traction type variable speed drive" offered "distinct advantages over existing drives," and, like the original designers, expressed this confidence in writing to the Materiel Center: "Because of a fervent belief that it would be a serious loss to the Army Air Forces if this development were allowed to lie dormant, we are willing to undertake the job of carrying on the development work until a satisfactory conclusion is reached." To this end the services of Hans Heynau, the inventor of the principles involved in the Master variable-speed drive, were acquired for Aircraft Associates.

Apparently the Materiel Center approved of the manufacturer's enthusiasm, for in August 1942 an Authority for Purchase authorized an expenditure of \$6,955 to perfect a drive to be interchangeable with the Vickers unit of a Sperry upper turret. The manufacturer set to work evolving a suitable design, but not until December 1943 was a demonstration installation ready for test.²⁶

Aircraft Associates claimed many advantages for the improved Master drive. It was 15 pounds lighter than the Vickers installation; it was not influenced by temperature changes; and, in contrast to the Vickers version, it required only 22 amps current at neutral and 36 amps at full

26. American Aircraft Associates to MD (AF), 2 June 1942, in Arm. Lab. file, E.O. 553-1-474; see also A for P No. 181644, 4 Aug. 1942.

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load in contrast to Vickers requirements of 37 and 48, respectively. Furthermore, the differential drive was reported to have: a positive neutral, that is, no creep; no dead spots on the controls; no critical adjustments; and a speed spread approaching the ideal, with one-half the control displacement giving one-third the total speed. The entire unit was so constructed as to be easily interchangeable with the Vickers installation in the field, and the manufacturer estimated a cost of \$500 per unit, as against Vickers' \$1,400.

Armament Laboratory tests found the drive acceptable, and the manufacturer reported that it would be possible to produce up to 4,000 drive units per month after a four-month tooling period. But in January 1944, when the laboratory report was submitted, the Vickers unit bottleneck had already been broken and the urgent requirement for a substitute drive no longer remained. The Aircraft Associates' drive died without issue.²⁷

Nevertheless, back in June 1942 the Armament Laboratory still had dire need of a substitute for the hard-to-manufacture Vickers hydraulic drive when the Experimental Engineering Section dispatched the usual query to Graham Transmissions, Inc., at Milwaukee, Wis. After a design conference with Wright Field engineers, Graham presented tentative drawings for a drive unit to be delivered in 90 days at an estimated cost of \$17,000. This drive consisted of two separate transmissions linked to a common Diehl electric-drive motor, to be installed in a Steel Products upper local Sperry turret in place of the two Vickers units usually employed.

27. Aircraft Associates to MD (AF), 3 Jan. 1944, et seq., in Arm. Lab. file, E.O. 553-1-474.

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From its very inception the Graham drive was designed with an eye toward future production. Simplicity of principle and ease of quantity manufacture were cardinal points in the decision to push its development as an alternate to existing drive systems. Essentially the Graham drive consisted of two mechanical, variable-speed friction drives, one for azimuth, one for elevation. Infinite speed variations were obtained by means of tapered rollers in contact with rotating external ring gears. The gears operated in an oil-filled housing, and hydraulic servo provided the force necessary to move the ring along the tapered rollers.

In March 1943 Graham had not yet produced a satisfactory drive despite the 90-day promise. In April the manufacturer reported that costs, excluding profit and the allowable 10 per cent overhead, had reached \$22,000, and that the drive still required reworking before it could be presented for testing at Wright Field.²⁸

When at last an acceptable experimental model had been fabricated, tests proved disheartening. The neutral no-load current drain amounted to 70 amps, twice the consumption of a Sperry turret with Vickers drives. The hand controls linked to Graham drives required more than the usual amount of effort for tracking and gave withal a coarse control. The gear system was noisy, and after 30 minutes of operation heated to the smoking point.

A final Engineering Division report in February 1944 pointed out that the Graham drive was unsatisfactory in its existing state of development; that the project was initiated during a critical shortage of Vickers units; that that shortage no longer existed; and that, therefore, there

28. EES to Graham, 10 June 1942, in Arm. Lab. file, E.O. 553-1-343;
Graham to MD (WF), 22 June 1942, in Arm. Lab. file, E.O. 553-1-472.

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was no need to carry the project further. However, the report foresightedly concluded that the "Graham power unit should be given more extensive performance tests to obtain information on this type of drive for future reference."²⁹

The Submarine Signal drive, the Bethlehem torque converter, and the Graham and the Master drives are but a few representative cases selected from a large number of projects initiated by the Materiel Division in the search for drive substitutes. They are of interest less for their specific technological merit than as significant case studies pointing up the problems involved in organizing the Armament Laboratory at Wright Field to handle efficiently the difficult problems of armament development.

29. Memo Rpt., Eng. Div., 17 Feb. 1944, in Arm. Lab. file, E.O. 553-1-472.

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Chapter X

POWER TURRET DEVELOPMENT: SECOND INDUSTRIAL PHASE, 1941-1942

Sperry Gyroscope Company

In December 1940 Sperry undertook production contracts for the upper local and lower remote turrets which had been evolved in the previous 12 months. It was apparent from the very beginning that Sperry facilities would never provide the capacity necessary to fulfill the requirements anticipated by the Materiel Division, and the Production Engineering Section (PES) urged Sperry to line up suitable subcontractors. After a number of weeks in which various subcontractors were considered and found wanting in some respect, PES forced the issue and selected Emerson to build turrets in conjunction with Sperry's two choices, Briggs and Steel Products Engineering.

The vital importance of getting Sperry designs into production was forcefully illustrated when the chief of PES said he was "going to get Sperry products if we have to go out and make prime contracts ourselves to a thousand different subcontractors." However complimentary this may have been to the quality of Sperry designs, it gave cold comfort to a manufacturer who saw more than five years of experimental effort going out to future competitors. Nevertheless, the urgency of aircraft armament requirements precipitated the decision to let subcontractors handle turret production, while Sperry retained the auto-pilot project.¹

1. Phone transcript, Lt. Col. K. B. Wolfe, PES and Lt. Col. Grandison Gardner, OCAC, 25 Sep. 1941, in ATSC 473.5, General.

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Despite the intention to subcontract turrets, not all of the business left Sperry's hands. In February 1941 Steel Products had finished six upper local and six lower remotes, but neither type of turret was entirely a Steel Products project. The computing sight unit built and assembled by Sperry went directly to the Boeing plant for installation in completed B-17 airplanes. The Sperry plant also built the fire cut-out or interrupter unit which was shipped to Springfield for assembly in the Steel Products turret. Furthermore, the power drive system, consisting of a pair of Vickers units, was manufactured in Detroit and sent to Steel Products for final assembly. The composite turret assembly was then shipped to Boeing where a Sperry representative performed the final critical adjustments after installation.

The upper local turret cost \$7,185 per unit, the lower remote, \$11,275, as contrasted with an estimated \$7,185 for the lower ball when it eventually should come into production.² The computing sight in the upper turret accounted for \$2,250 of the cost, and the controls, \$1,335. The controls for the lower remote represented \$1,855, but the more complicated sighting station and computer came to \$4,569.³

The original Sperry upper local experimental project, a turret of welded steel tubing framework construction with fabric belt feed and ammunition containers below the revolving platform, gave way to a production version of cast metal framework, ammunition boxes directly below twin .50's without boosters, and disintegrating link rather than fabric

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2. Sperry to MD (WF), 25 Feb. 1941, in Arm. Lab. file, E.O. 554-1-141.
 3. Sperry to MD (WF), 6 May 1941, in PES Arm. Unit file, Turrets, Sperry, General to 1941.

ammunition belts. By March 1941 the upper local had been tested sufficiently at Wright Field to release quantity production.

The Sperry hand controls in the production version were modeled after the Frazer-Nash system.⁴ The engineers at Steel Products, however, devoted a considerable period of time in perfecting the controls to British standards. Like all other manufacturers, Steel Products neglected to design hand controls with a "knife edge neutral" until the Chief of the Armament Laboratory pointed out that a smooth transition from left or right deflection past neutral while tracking was more important than absolute neutral, or no creep.⁵

The initial Steel Products production models revealed the usual assortment of turret problems: faulty link ejection chutes, malfunctioning case ejection at high angles of elevation, fouling charging cables at high angles of elevation, and excessive ammunition drag causing poor feeding.⁶ All of these problems, and many others like them, inevitably accompanied a new design. As engineering problems, they are incidental; but they are important in illustrating the complexity of the liaison problems involved in coordinating the Sperry industrial combination with service requirements.

The Steel Products turret contract did not incorporate all the best Sperry design features as initially conceived, because the Production Engineering Section considered it expedient to facilitate quantity

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4. LMK, EES (LP) to Arm. Sec. (Wash.), 23 Dec. 1940, in Arm. Lab. file, E.O. 553-1-350.
 5. Phone transcript, H. Eastwick, Sperry and Maj. F. C. Wolfe, Arm. Lab., May 1941, in Arm. Lab. file, E.O. 554-1-141.
 6. Memo Rpt., EES, 2 June 1941, in ibid.

production by permitting certain performance deficiencies. As a consequence of this tolerance, the Materiel Division specifically instructed Steel Products to "pursue a policy of change with unabated production." The manufacturer was to investigate design improvements which could be evaluated by the Materiel Division. Improvements accepted by the division would be standardized and coordinated for all interested facilities.⁷

The previously mentioned turret dome case illustrates this process. In line with the Materiel Division's policy of design improvement, Steel Products engineers perfected a paneled plexiglas dome with cast aluminum ribs. To secure approval, the design had to be routed from the subcontractor, Steel Products, to the prime contractor, Sperry, and thence to the Materiel Division for approval before being circulated to the other manufacturers of Sperry turrets. Superficially the route seemed overly involved; but insistence upon channels insured a higher degree of standardization and interchangeability, which was later to pay substantial dividends.

If the coordination of subcontractors cast a burden of unusual responsibility upon the Materiel Division, the mere fact that subcontracts frequently were filled by facilities utterly lacking in aircraft manufacturing experience created a new and serious problem. The case of the Steel Products dome or canopy illustrates this problem. The original Steel Products dome design submitted to the Materiel Division specified square-edge panel ribs. In passing approval on the drawings, division engineers

7. Chief, PES to Steel Products, 13 Nov. 1941, in Arma. Lab. file, Machine Gun Mounts 1941.

pointed out that the design would be substantially improved if the rib edges were rounded to avoid unnecessary turbulence and drag.⁸ The point is comparatively minor, but it represents the difficulties facing the Materiel Division in every step of the production expansion program. Not only was it necessary to coordinate the work of numerous competitive industries quite unaccustomed to pulling together; but the division found itself involved in the difficult task of familiarizing industrial engineers with the fundamental elements of aircraft design and construction requirements, even while embarking on an ever accelerating production program.

In view of the extensive difficulties encountered in organizational control, coordination, and contractual relations with subcontractors, it is perhaps surprising that production figures achieved the levels they did. In December 1941, approximately a year after the Sperry contract was approved, Steel Products had delivered 91 lower remote and 111 upper local turrets.⁹

The evolution of the Sperry upper local turret from December 1941 onward became comparatively little more than a process of detailed engineering improvement. For all practical purposes, quantity production accelerated rapidly and design changes confined themselves to such modifications as could be accomplished without serious disruption to delivery.

The primary Sperry consideration, so far as upper local turrets were concerned, centered in the inescapable problem of coordination. In

8. Memo Rpt., CES, 19 April 1941, in Arm. Lab. file, E.O. 554-1-141.

9. Steel Products to MD (MF), 12 Dec. 1941, in Arm. Lab. file, Machine Gun Mounts 1941.

the middle of 1942, Sperry protested that Steel Products modifications and "improvements" were seriously compromising the efficiency of the Sperry computing sight. To prevent such misdirected efforts, Sperry proposed to place an engineer permanently in the Steel Products plant to insure a high degree of liaison between the separate manufacturing organizations.¹⁰ Apparently the Materiel Division's insistence on routing all changes through the prime contractor only proved that a system of coordination by mail could never effectually replace over-the-counter negotiation and liaison.

A cursory glance at some of the design problems encountered in perfecting the Sperry upper local turret will suffice to illustrate the intricacies of coordination facing all turret manufacturers. Combat gunners protested against the scanning limitations imposed by the heavy ribs in the Steel Products dome. Steel Products devised a single-panel, curved-plexiglas, forward-sighting section, but it was then that Sperry claimed the modification was detrimental to the accuracy of the computing sight. Sperry engineers reported that the curved sighting panel resulted in refraction errors "unduly large and undesirable primarily because the advantage of using a computing sight is almost completely nullified." To overcome this weakness and satisfy both parties, the plexiglas manufacturers, Rohm & Haas, undertook to design a panel of varying thicknesses to reduce refraction errors to insignificant quantities.¹¹

10. Chief, PES to Steel Products, 22 Aug. 1942, in Arm. Lab. file, E.O. 553-1-396. See also Chief, PES to Driggs, 10 Nov. 1941, in Arm. Lab. file, Machine Gun Mounts 1941; and Chief, PES to Driggs, 22 Aug. 1942, in Arm. Lab. file, E.O. 553-1-373.

11. Memo Rpt., PES, 6 April 1942, in Arm. Lab. file, E.O. 554-1-141.

Another less vexing but equally significant problem concerned booster systems. When Sperry abandoned the fabric belt feed, no servo-mechanism was installed to replace it. When the excessive gravitational loads of combat accelerations made recoil feed insufficient, a number of innovations, including feed chute rollers and "constant level" ammunition boxes, were utilized to avoid recourse to the conventional sprocket system employed in Martin designs.¹² Only by trial and error was it possible to attain a continual and positive evolution in design.

Among the more interesting design problems were those surrounding the evolution of the Sperry fire cut-out or gun interrupter device, an ingenious profile cam which rotated in constant orientation with turret movement to provide positive firing circuit interruption whenever the guns threatened to fire into an area essential to flight. Unfortunately the Sperry engineers who designed the device had never suffered aerial attack from enemy pursuits, and both guns cut out simultaneously, thus depriving the turret of a large element of fire power in the marginal area at either extremity of a restricted zone.

No sooner had the operational units begun to request individual gun interruption than another problem appeared. Successive models of B-17 airplanes had slightly different characteristics in structure and in attitudes of flight. Each turret installed required a profile cam especially suited to the particular model of aircraft involved. Only by the most careful coordination between Sperry, Boeing, the Materiel Division, and the Sperry subcontractors was it possible to avoid disastrous mistakes with improperly designed fire cut-out cams.¹³

12. Memo Rpt., EES, 4 June 1942, in Arm. Lab. file, E.O. 553-1-396.

13. Chief, PDS to Boeing, 21 March 1942, in Arm. Lab. file, E.O. 554-1-141.

Perhaps the most intricate technical problem pertaining to fire cut-out mechanisms grew out of reported failures appearing when the turret was slewed into a restricted zone at high speed. The period elapsing between the time when the interrupter cam opened the circuit and the time when the last-fired projectile actually left the gun was of sufficient magnitude to nullify the protective feature of the cut-out. To overcome this design weakness, Sperry engineers set out to construct a differential which would advance the interrupter cam in proportion with increasing turret speeds to provide an adequate margin of protection against gunfire damage in vital areas resulting from firing while slewing.¹⁴

Individual interruption, dome refraction, and ammunition booster difficulties are but a representative cross section of the many engineering problems confronting the designers who sought to improve the Sperry upper local turret. They are not selected as of greater importance than a number of other problems not mentioned, but rather as specific illustrations of the trend in turret modification once the basic design had been developed. The fate of the Sperry lower remote turret, however, was quite different.

From its very inception the Sperry lower remote turret met with handicaps. Operationally it suffered from the usual drawbacks of remote turrets: restricted cone of vision; difficulties encountered by the stationary gunner in keeping himself oriented with his guns; and the inevitable obscuring of the scanning head by exhaust spray which tended

14. Chief, IES to Steel Products, 5 Dec. 1942, in Arm. Lab. file, E.O. 553-1-396.

to render the lower sight "almost useless."¹⁵ The distance from Sperry drawing boards to aerial combat was so great that the lower remote turret remained an uncertain quantity even in its final testing stages. Reports from the Materiel Division in November 1941 left the issue in doubt:¹⁶

Preliminary information indicates that while it is difficult to pick up a target initially, as soon as it is picked up, it can be held easily in the sight and hits can be scored. After firing 2000 rounds at a target on the ground, the outfit at Salt Lake says that the turret is no good. It is the belief of the Armament Section that after thorough training in firing at air targets this turret will be far better than present rumors indicate and no one is justified at the present time in saying that it is useless.

If the lower remote had drawbacks of a tactical or operational nature, to a greater extent it suffered from mechanical complexity. Essentially the remote turret consisted of an autosyn 115-volt AC control operating from an inverter. Control handle displacement transmitted signals through an autosyn system to a remote amplifier. The amplifier produced impulses of sufficient magnitude to turn an inertia motor which was linked to the booster tilting a conventional Vickers unit. The autosyn position control circuit was extremely delicate and involved such critical adjustment that it required the services of a highly trained engineer to keep it in operation. Indeed, the turrets had become so complex by the fall of 1941 that the manufacturer organized a training course to instruct maintenance men in the intricacies of Sperry apparatus. What had formally been an extra responsibility for armorers now became the work of a trained specialist.¹⁷

15. ICM, Chief, EEs to Chief, PLS, 29 May 1941, in Arm. Lab. file, E.O. 554-1-141.

16. TWK, Asst. Chief, MD (AF), to Chief, MD (wash.), 10 Nov. 1941, in AAG 473.5, Mounts.

17. Sperry to LD (AF), 29 Oct. 1941, in Arm. Lab. file, E.O. 554-1-141.

The not entirely successful debut of the lower remote turret induced Sperry to speed development of the locally controlled lower ball turret. Early in June 1941 it was apparent that the time had come to choose between the lower remote and the lower ball. Sperry was unwilling to sink more capital in improvements on the remote if the Materiel Division intended to put the ball into production. The division was loath to decide on the ball until cost estimates were available. Sperry's sub-contractor for the ball, Briggs, did not wish to undertake development of the ball without assurance of a quantity contract sufficient to cover possible manufacturing losses. Since the ball turret was a novel design entirely undeveloped, Sperry could not offer estimates to the Materiel Division until a cost analysis had been run on the prototype at Briggs.¹⁸

By the first of April 1941 the ball turret was in the final stages of assembly. A shortage of aluminum castings delayed the project somewhat, but pressure from Wright Field grew increasingly insistent, for the question of lower sphere armament for bombardment was daily becoming more urgent. Early in May the first ball turret was ready for tests at Wright Field.¹⁹

The unusual design of the new turret, requiring a gunner to ride in an "embryonic" position, made it most essential to test the ball for accommodation. The chief of the Armament Branch directed Briggs to run a series of endurance tests at the factory to determine if it would be possible to occupy the ball for long missions. Time tests of men "slightly

18. Phone transcript, H. Bostwick, Sperry and Maj. F. C. Wolfe, Arm. Lab., 2 June 1941; in Arm. Lab. File, E.O. 553-1-373.

19. Chief, EES, to Briggs, 1 April 1941; and note by E. E. Goll, Arm. Lab., 5 May 1941, in ibid.

smaller than average" indicated "little or no loss of efficiency" based on the evidence of scores compiled with photoelectric light guns fired periodically throughout the trial run.²⁰

Despite the concern that was felt for gunners' comfort, the Materiel Division approved the Briggs contract for 250 ball turrets, leaving until a later date the decision on large-scale production quantities. The Production Engineering Section chief favored delaying the contract until air firing tests could be run to determine whether or not the ball would be acceptable. The assistant chief of the Materiel Division was of a like mind; but in Washington, Materiel Division officers were forced to approve a limited production on the ball, because any delay in ball production would require a continuation of the lower remote contract to avoid a failure in meeting aircraft deliveries with adequate armament output. Since Briggs refused to consider any fewer than 250 balls, the Materiel Division was forced to approve the ball contract to avoid losing Briggs as a Sperry subcontractor, even though Sperry could not furnish the division with cost breakdowns until Briggs production began.²¹

Fortunately air firing tests vindicated the decision to begin production before final approval. Surprisingly enough, the ball was reported to "compare most favorably in control with any turret which has been demonstrated in this country." The report compiled from the information acquired while testing the ball in flight concluded that the new turret was "unusually correct in conception and design for a first experimental

20. T.M. Br. (..ash.) to EES (..F), 2 June 1941; and Memo Rpt., EES, 17 June 1941, in ibid.

21. Phone transcripts, Col. Grandison Gardner, CCAC and Maj. Jack Murtha, Arm. Lab., 21 June 1941; and Gardner and Maj. M. D. Burnside, PLS, 14 June 1941, in ibid.

article." Trial tow-target tests produced favorable scores; and the flaws that were immediately apparent, such as link ejection jamming in the slipstream, clouding of the sighting panel, and limitations on side scanning, were common to all lower turrets.²²

Sperry offered to build the first 250 balls "by hand" at Briggs for \$20,300 each. Later, when production tooling was installed, it was estimated that a production contract for 2,050 units would supply turrets at \$14,099 each. The initial cost breakdown placed the turret at \$14,300, with \$3,700 for the sight, \$1,400 for the Vickers power drives, and \$900 for the hand control.²³ The first 250 turrets promised to be slow work, but there seemed no escape.

Briggs design studies indicated an estimated 1,100 hours of machine work in manufacturing the ball. Of this, subcontractors accounted for 94 per cent, Briggs performing the remaining 6 per cent. The high degree of accuracy required in cutting the main ring gear for the ball induced Briggs to search far afield for a suitable subcontractor, even to the extent of sounding out Anderson-Nichols Associates, the precision machining specialists. However, there were only three machines in the country, one at Ford and two at Chrysler, large enough to cut the ring gear on a production basis. Using existing equipment Briggs estimated the ring gear as a 100-hour job.²⁴ By all indications, the ball turret, however ingenious as a solution to the lower sphere fire power problem, promised to present tremendous production difficulties.

22. Memo Spt., EES, 30 June 1941, in *ibid.*

23. Sperry to MD (AF), 28 July 1941, in EES, Arm. Unit file, Turrets, Briggs Ball, to May 1942.

24. Phone transcript, W. P. Brown (Briggs) and Maj. M. D. Burnside, P&S, 14 Aug. 1941, in ATSC 473.5, Sperry 1941. See also Anderson Nichols to MD (AF), 29 Sep. 1941, in ATSC 473.5, General.

A Production Engineering Section representative went to Detroit to find suitable subcontractors for turret components, but a search from "Boston to Iowa" netted scant result. Meanwhile the ball turret requirement grew more urgent. To meet the demands of aircraft expected off the line in September 1941, the Chief of PES gave the ball a "No. 1-AAA priority" and summed up the ball situation most graphically by saying, "It's hot because we're short." Intrinsically the ball did not represent an overwhelmingly difficult manufacturing project, but a two-month deadline was hard to meet.²⁵

When the CFM curtailed Briggs auto body production, Briggs threatened to pull out of the turret business entirely. This threat played into the hands of PES, for it gave the section an argument against Sperry as a prime contractor and made it possible to force a policy of direct negotiation with the Materiel Division's new turret source, Emerson, rather than indirect negotiation through Sperry. Sperry apparently had misgivings about Emerson, possibly with an eye to future competition and possibly fearing the salesmanship of Synington, the president; but when it became evident that Sperry could not guarantee ball turret production unless Briggs secured a facility expansion through the Defense Plant Corporation (DPC), Sperry agreed to turn over all turret manufacturing rights to the Materiel Division.²⁶

25. Phone transcript, E. A. Burdg, PES and Lt. Col. K. B. Wolfe, PES, 20 Aug. 1941, in ATSC 473.5, General.

26. Phone transcripts, Col. Crandison Gardner, OCAC and Col. K. B. Wolfe, PES, 25 Aug. 1941; Wolfe and Maj. M. D. Burnside, 28 Aug. 1941, both in Arm. Lab. file, E.O. 553-1-373. See also Press Release on Briggs DPC expansion, 20 Sep. 1941, in AAG 473.5, Mounts.

As soon as detailed manufacturing drawings of the ball reached Wright Field from Briggs, they were sent to Emerson. Four months later, in January 1942, the first Emerson ball was finished, despite the charge that Briggs was curbing production by withholding vital design information.²⁷

With the entry of the Emerson facility into the Sperry complex, the already complicated production network became extremely involved. Officially Emerson was directly responsible as a prime contractor to the Materiel Division, but in terms of production, the Sperry organization still dominated. Although Emerson planned to manufacture most component assemblies ultimately, the first turrets fabricated depended largely upon existing sources. The Briggs ball utilized sights, fire cut-out, and hand control units built by Sperry and drive units by Vickers. This same system prevailed in the case of the Steel Products upper. Since Emerson planned to build both ball and upper turrets, the Production Engineering Section chief expected that Sperry would carry out some similar subcontract arrangement with Emerson. The situation was still further complicated by the fact that Sperry subcontracted some of the "Sperry-furnished equipment" to the Delaval Separator Company.²⁸

When Emerson, as a Materiel Division prime contractor rather than a Sperry subcontractor, failed to coordinate with Sperry regarding anticipated production schedules, delays in subassembly deliveries

27. Chief, PES to Emerson, 29 Sep. 1941; and Emerson to MD (AF), 9 Jan. 1942, in Arm. Lab. file, E.O. 553-1-373.

28. IGL, Chief, PES to Chief, GFE Br., PES, 28 Nov. 1941, in ATSC 473.5, Sperry 1941.

retarded Emerson's output. As previously mentioned, a Vickers unit shortage threatened to wreck the entire turret program. Actually the shortage was never as acute as it appeared on the surface. Apart from artificial bottlenecks arising out of idle inventories, the Vickers company itself brought about some of the misapprehension in being unwilling to promise a high-production figure while negotiating for a DFC plant. The artificially depressed estimate of Vickers unit production was immediately apparent when DFC approved the Vickers expansion plan and Vickers suddenly promised more units per month from existing facilities.²⁹

The problems incidental to coordinating the production plans of the Sperry complex and planning to meet requirements in the face of manufacturers' efforts to "wangle" DFC plants continued for several years, but by the early months of 1942 the ball turret had reached design maturity and subsequent changes were on the order of modifications.

Like the upper local, the ball turret went through a period of months of modification during which "bugs" that appeared with further testing were eliminated. Boeing engineers noted that the sighting window became fouled on take-off, and the Armament Laboratory engineers suggested designing a wiper. Complaints that the turret lacked interphone volume control, an external power switch, and "deadman" switches raised a variety of problems. Two of the most vexing problems, jerky range pedal operation and fouling of the ammunition belts in the cans when half empty, were to trouble the ball turret for two or three years.³⁰ But only one modification reached major proportions.

29. Phone transcript, Frank Conace, Sperry and Maj. M. D. Burnside, PES, 3 Dec. 1941, in ATSC 473.5, General.

30. Memo Rpt., EES, 4 March 1942; memo, Maj. H. A. Berliner to Maj. Gen. M. S. Fairchild, OCAG, 18 April 1942; and Memo Rpt., EES, 30 Sep. 1942, in Arma. Lab. file, E.C. 553-1-373.

The excessive drag resulting from the ball protuberance inevitably suggested a retraction mechanism of some sort, and after experimenting with an electric drive version, the Armament Laboratory finally approved a hydraulic system with comparatively positive action.³¹

While the ball turret was in process of modification the several manufacturers of the Sperry group were experimenting with new projects which were to surpass the existing production items. Sperry engineers were busy developing a computing gunsight with a gyroscopic prediction element, and central-station fire control equipment projects were well along toward the production prototype phase.³²

The Armament Laboratory authorized Steel Products to undertake an experimental project pressurizing an upper local turret. Briggs considered a similar project for the ball.³³ In January 1943 a conference of turret manufacturers at Wright Field decided to redesign the ball turret entirely to include such features as external ammunition containers, hot air heating, quickly detachable guns, larger scanning windows, wider control range, lever action gun charging, and increased armor plate, all in a magnesium casting ball. Furthermore, the Armament Laboratory initiated projects on four-gun ball turrets. A full year later neither of these projects had progressed very far, since the lack of any well defined tactical requirement tended to push these experimental projects to one side.³⁴ These turrets, it would seem, were for the more distant future.

31. A for P 182172 (Briggs), 19 Dec. 1942; and Memo Rpt., Arm. Lab. 5 June 1943, in Arm. Lab. file, E.O. 553-1-519.

32. Memo Rpt., EES, 22 Nov. 1941, in Arm. Lab. file, E.O. 554-1-129.

33. A for P 175537, 25 Sep. 1941, in Arm. Lab. file, E.O. 553-1-396. See also Chief, EES to Briggs, 23 July 1942; and Memo Rpt., Arm. Lab., 22 Dec. 1942, in Arm. Lab. file, E.O. 553-1-446.

34. Memo Rpt., Arm. Lab., 2 Jan. 1943, in Arm. Lab. file, E.O. 553-1-373. See also Briggs to PES, 16 April 1943; and Memo Rpt., Arm. Lab., 6 Jan. 1944, in Arm. Lab. file, E.O. 553-1-515.

General Electric Company

Parallel to the growth of Sperry equipment was that of a number of other turret manufacturers who vied for the production market. Among these concerns, General Electric was one of the most important. The most active G.E. project in the early months of 1941 was the A-20 fire control system, an arrangement of upper and lower twin-.50 turrets with periscopic sighting heads. In February, tests at Aberdeen Proving Ground reported the G.E. installation as "satisfactory," and a month later the Contract Section at Wright Field informed Douglas that the unit had been sufficiently perfected to install in the A-20 airplane.³⁵

As A-20 production ran ahead of turret development at G.E., Douglas planned to send an A-20 to the G.E. plant, where turrets could be installed on an empirical cut-and-try basis without drawings.³⁶ Flight tests in September 1941 demonstrated that the G.E. upper turret was "very reliable." A report from the Air Corps Proving Ground was emphatic in its opinion: "All pilots and gunners are enthusiastically pleased with the operation of the General Electric turret in the A-20A airplane."

There were, of course, a number of shortcomings to the G.E. turret: the scanning area was too limited; gunners found it difficult to keep oriented with the guns without a revolving seat or target locator; and the sight showed an unfortunate tendency to excessive vibration, coupled with a quality of reflecting an operational movement in the control lever

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35. Ordnance Program Rpt. 5082, Aberdeen Proving Ground, 26 Feb. 1941, in AAG 473.5, Mounts. See also Chief, Contract Sec., LF to Douglas, 20 March 1941, in Arm. Lab. file, E.O. 554-1-130.
36. Douglas to MD (LF), 31 March 1941, in Arm. Lab. file, E.O. 554-1-142.

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during pull-outs. None of these functional problems was of particular moment, however, compared with the fact that the lower turret of the A-20 was not ready to be shipped to Wright Field for tests until January 1942.³⁷ The A-20 project became, perforce, the A-26 project, because the initial period of development consumed such a disproportionately long time.

In addition to the A-20 armament project, G.E. signed a contract in June 1941 to construct fire control systems for the XA-26, the XP-58, and the XP-61, similar to that used with the initial A-20 double turret arrangement or to the one involving a single four-gun upper turret of the type eventually perfected for the production P-61.³⁸ It is apparent that the G.E. production pattern had become extremely complex, largely as result of two factors: the G.E. systems were designed primarily for airplanes not yet in production; and the very fact that the installations represented complete systems rather than individual turrets made G.E. production plans contingent upon airplane production.

Throughout the summer of 1941 a great deal of uncertainty existed regarding the fate of the XB-28 and XB-33 airplane projects, and G.E., already laden with prospective production for as yet undeveloped airplanes, was hesitant about accepting commitments which did not guarantee extensive ultimate production.³⁹ In June G.E. reported a turret capacity of 330 turret units per month and appeared unwilling to expand any further, since

37. IOW, Chief, EES to Chief, Contract Sec., 2 Jan. 1942, in *ibid.* See also Memo Rpt., EES, 15 Oct. 1941, and memo, Capt. J. O. Guthrie, Arm. Sec. AC Proving Ground to Air Corps Board, 30 Sep. 1941, in Arm. Lab. file, E.O. 553-1-362.

38. Contract 1535 ac-191EO, 28 June 1941, in ATSC Contract files.

39. Phone transcript, Lt. Col. Grandison Gardner, OCAC and Maj. F. C. Wolfe, Arm. Lab., 10 July 1941, in Arm. Lab. file, E.O. 554-1-130.

all G.E. fire control projects had been more or less limited to experimental contracts. By August, however, the promise of production contracts seemed immeasurably greater; and G.E. studied a plan to utilize Emerson floor space to expand G.E. output.

By December 1941 Emerson was negotiating with G.E. to secure manufacturing rights for the amplidyne drive on a license and royalty basis, and the Materiel Division was fostering G.E. in a \$12,000,000 machine-tool financing plan.⁴⁰ The following chart shows the limited extent of G.E. production in January 1942:

	<u>Units on Contract</u>	<u>Additional Required</u>	<u>Delivered to Date</u>
P-61 System	215	360	0
A-26 System	503	0	0
B-28 System	2	600	0
B-33 System	402	0	0

These figures indicate the narrow range of G.E. production up through January 1942, especially in view of the fact that neither the B-28 nor B-33 were past the experimental stage; but in May a contract for more than \$98,000,000 was negotiated with G.E. for 3,924 units covering the four production airplanes mentioned above.⁴¹ The development of these systems continued actively over the next several years, but that contract marked the maturing of G.E. turret design.

If Sperry spent the larger part of 1941 and 1942 in organizing production, G.E. did not even reach the production phase until the middle of

40. T.M. Tech. Exec. (IF) to Tech. Exec. (Wash), 19 June 1941, in Arm. Lab. file, E.O. 554-1-142. See also Memo rpt., EES, 14 Aug. 1941, in Arm. Lab. file, E.O. 554-1-159; Chief, Contract Sec. to G.E., 20 Oct. 1941; and Emerson to G.E., 11 Dec. 1941, in Arm. Lab. file, Machine Gun Mounts 1941.

41. Contract 1535 ac 27375, 4 May 1942, in ATSC Contract file and in Arm. Lab. file, E.O. 554-1-130.

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1942, largely because of delays in the appearance of anticipated aircraft models. Some of the other turret manufacturers were not so long in entering into production, or at least the developmental stage overlapped initial production activities.

Glean L. Martin Company

One of the most successful turrets of the war from the standpoint of design as well as that of production was the Martin amplidyne drive turret originally conceived for the B-26. It is perhaps surprising that this turret turned out as well as it did. Designed as a specialized piece of equipment to fit the specific needs of the B-26, the Martin turret proved remarkably adaptable for use in several airplanes, including the B-24, B-34, AT-18, and others.

The success of the Martin turret as a design undoubtedly stemmed primarily from the essential soundness of amplidyne as a drive; but beyond that, the Martin industrial organization seems to have been extremely successful. The Martin engineering staff appears to have analyzed the basic requirements for a functional turret from the very beginning, since the original production model remained the basis for future production designs almost unchanged in major considerations. Gun mounts, ammunition boosters, armor plate, and control system were so soundly designed in the prototype that subsequent improvements were matters of detail rather than fundamental changes. Emergency manual operation, quickly detachable ammunition cans, profile cam fire cut-out and structural interrupter, and even the addition of a computing sight, all left the original turret concept unimpaired.

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In terms of production, the Martin turret success probably reflected two fundamentally important organizational policies. In the first place, unlike some of the other turret manufacturers, notably Bendix, Martin lined up a group of subcontractors and controlled them with sufficient firmness to get production results without any considerable aid from the Materiel Division. Where other manufacturers felt constrained to have recourse to PES or the OPM to compel subcontractor compliance, Martin was able to get results without reliance upon outside whips.

The second organizational factor in Martin's production success was, whether consciously or unconsciously, based on the best recommended British practice. Martin was the first turret manufacturer to go into production to meet the immediate need, with a turret which was basically sound though admittedly lacking in refinements. Then, without seriously impairing the flow of production, the manufacturer inserted modifications and improvements which had been perfected on the side while production continued unabated.⁴²

In June 1941 PES negotiated with Martin on the possibility of producing upper turrets for the B-24. The manufacturer reported that Martin facilities had "plenty of capacity," and the company was "perfectly willing and glad to build the upper turrets."⁴³

In November the outlook was not so promising. As B-24 production expectations turned sharply upward, Martin capacity seemed dwarfed. Fifteen

42. For British opinion, see "Information on Frazer-Nash and Boulton-Paul Aircraft Machine Gun Turrets," by U.S. Naval Attaché, England, Rpt. 1569, 29 Nov. 1940, in WF Lib., D72.11/102.

43. Phone transcript, Henry Esher, G.E. and Maj. M. D. Burnside, PES, 25 June 1941, in Arm. Lab. file, Secret Correspondence, folder 2, 1941.

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manufacturers, already pressed with war work, declined to subcontract for Martin; and Emerson was not expected to come into production with Martin turrets until the spring of 1942.⁴⁴ By the end of December 1941, however, Martin expected to deliver 2,000 or 3,500 turrets in the following year, depending upon the number of specification changes which might slow down production.⁴⁵ The trend toward reduction in B-26 production, the lag in B-24 production, and the unexpected growth of Emerson capacity saved the Martin turret from becoming a critical shortage; and production kept pace with design improvement and aircraft requirements.

One of the most striking examples of the Martin policy of concurrent production and improvement is the case of the fire cut-out mechanism. Martin engineers visualized a profile cam cut-out early in the initial design conferences, but such a device required time to perfect; hence the first production model turret came out with a simple arrangement of block cams actuating micro switches in the firing circuit. To be sure, this cut-out protected only the vertical stabilizer. The horizontal stabilizer, the wing tips when flexing under load, and the propeller arcs all fell within the turret's fire. Moreover, the guns, when rotated in the zero azimuth area, forward along the center line, struck their muzzles against the fuselage at minimum elevation.

The profile cam interrupter did not reach Wright Field until April 1942, when it was tested before production. The interim measure proved

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44. Phone transcript, L. G. Milburn, Bellanca Aircraft and Lt. Col. O. R. Cook, PES, 26 Nov. 1941, in ATSC 473.5, General.
45. Phone transcript, J. Hartson, Martin and Col. E. B. Wolfe, PES, 23 Dec. 1941, in Arm. Lab. file, Machine Gun Mounts 1941.

worth while, quite obviously, since nearly a year and a half passed between the time when the first production model appeared and the date of the first turret equipped with a profile fire cut-out and structural interrupter which not only protected all vital parts from gunfire but prevented the gun muzzles from striking the fuselage when slewed low along the zero azimuth area.⁴⁶

Unlike Sperry, the Martin profile cam manufacturer, J. P. Frieze & Sons at Baltimore, did not prepare the cams empirically but employed an ingenious semitheoretical approach. A turret with light beam guns was mounted in the center of a circular room whose walls carried silhouettes of the airplane structure for which the cam was designed.⁴⁷ This technique proved exceptionally successful, although not all the engineering problems of the Martin turret were handled so directly.

Perhaps the most serious difficulty facing the turret manufacturer was the problem of understanding combat or at least attaining an accurate picture of the realities of combat conditions. One of the many Martin models appeared with the main power relay controlled by the deadman switch. Soon afterwards, reports from the field indicated numerous brush failures in the amplidyne drive system. Studies revealed that every stop and start reduced the normal life span of an amplidyne brush from one to ten hours. The condition was corrected by revising the system so that the deadman relay affected only the potentiometer or control circuit and not the amplidyne power circuit. The engineer analyzing this correction noted

46. Memo Rpt., EES, 8 April 1942, in Arm. Lab. file, Martin B-26 Contract ac 13243, folder 2.

47. Memo Rpt., Arm. Lab., 2 April 1943, in Arm. Lab. file, E.O. 553-1-489.

that reports from the field indicated that the deadman switch was operated a good deal oftener than had been anticipated originally.

The case is important because it illustrates one of the most baffling problems of turret manufacturing. After nearly two years of war, Martin engineers were still unable to secure an accurate concept of combat operation. A manufacturer's overseas field representative making periodic personal reports was one solution, and an improved or amplified system of Unsatisfactory Reports was another; but the continued failure of designers to visualize combat realities suggests that no satisfactory answer was found. The appearance of G.E.-built Martin hand controls of plastic construction, with trigger switches which could not be replaced without replacing the whole assembly, graphically illustrated the distance between the industrial drawing board and the armorer's maintenance shop.⁴⁸

Important design improvements incorporating aided tracking and gyro stabilization marked the course of Martin turret development after more than three years of production, but the initial turret concept continued as the foundation for all later improvements.⁴⁹ If the original Martin design proved remarkably successful, such was not the case with every turret manufacturer. The evolution of the Bendix turret, for example, is a case antithetical to that of Martin.

Bendix Aviation Corporation

The experimental Bendix lower turret of December 1940 was followed the next month by a Bendix upper operating with an essentially similar

48. Memo Rpt., MC Equip. Lab., 11 Nov. 1943, in Arm. Lab. file, E.O. 554-1-130, folder 2.

49. Memo Rpt., Arm. Lab., 22 July 1944, in Arm. Lab. file, E.O. 553-1-535.

drive system.⁵⁰ Two turrets, an upper and a lower, both handmade tool-room models, were sent to North American for trial installation in the B-25; but as late as May the fire cut-out cams were still incomplete, pending the arrival of final B-25 structural drawings. Factory trial reports revealed "considerable difficulty" in the new turret ammunition feed system and control circuit, and North American expected to be forced to roll out 15 B-25's in August 1941 without turrets.⁵¹

Despite the fact that the Bendix turrets in their existing state of development represented very imperfect cross sections of the best in turret design, the manufacturer, in compliance with a verbal request from Wright Field, submitted a detailed compilation of technical requirements for a model turret to be of use in amassing data for a turret section in the Handbook of Instructions for Airplane Designers in June 1941.⁵² Bendix turrets were far from being ideal samples.

Flight tests on the new Bendix upper turret at Wright Field revealed, just as in the case of the lower turret tested somewhat earlier, that the speed controls began excessive arcing after a bare 35 minutes of flight, and Experimental Engineering Section engineers predicted that even future models would suffer from abnormally frequent maintenance periods. The hand control system was considered utterly inadequate to the point of requiring immediate modification, and flight tests revealed that current

50. Bendix to MD (AF), 16 Jan. 1941, in Arm. Lab. file, Machine Gun Mounts 1941.

51. Chief, Contract Sec. to North American Aviation, 31 Nov. 1941; and T.X., Maj. I. C. Wolfe to Exec., MD (AF), 12 Aug. 1941, in Arm. Lab. file, North American B-25 Contract ac 13253.

52. Bendix to MD (AF), 18 June 1941, in Arm. Lab. file, Machine Gun Mounts 1941.

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consumption figures ran from 50 to 75 per cent higher than those in other types of turrets because of improper reduction gearing. The report concluded that the Bendix upper turret was inferior to other makes for combat use.⁵³

The Experimental Engineering Section's "689" inspection report of the new B-25 armament listed a number of serious flaws in the Bendix turret. The single control handle was inadequate. It not only impaired smooth tracking but suffered from a serious loss of control across a large dead-spot neutral. The controls had no self-centering attachment. The deadman switch served as the main power switch. Since the B-25 was not equipped with an external battery plug socket, it was not practical to operate the turret on the ground unless the aircraft engine was operating.

Both upper and low^{er} turrets suffered from inadequate sighting facilities; this shortcoming of the lower, in particular, was aggravated by the lack of scanning or pick-up windows. Neither turret was equipped for emergency manual operation. To be sure, the lower turret had a hand crank stowage system, but the cranks were so located and the gear ratios so extreme that manual tracking, even of the crudest nature, was impossible. Both turrets suffered from a variety of ammunition feed difficulties, no boosters were provided, and both drives frequently malfunctioned with brush and relay contacts arcing and burning.

The upper turret was designed without consideration for the size of a man in full flying equipment, and in neither turret had Bendix designers

53. Memo Rpt., EES, 21 July 1941, in ibid.

devoted sufficient attention to slot closure. Open upper turret slots tended alternately to fill the fuselage with a blasting draft when facing forward and to suck all the warm air from the fuselage when facing aft, quite nullifying the value of the cabin heater.

Improper slot closure, however, was a minor problem of modification compared with some of the more intrinsic weaknesses of the turret. Among these more fundamental flaws was the fact that the lower turret required 55 seconds to extend from the fully retracted position. The unsound drive, the inadequate scanning facilities, and the poor sights were to be the source of trouble for months to come.⁵⁴

A Wright Field representative attending a turret training course at the Bendix South Bend plant summed up the Bendix turret as "not satisfactory," commenting that the "general feel, ease of control, ease with which one may become a competent operator, and naturalness of the sighting are not considered satisfactory for efficient gunnery."⁵⁵ These repeated expressions of opinion were not entirely lost on the Materiel Division, but the urgent requirement for turrets in the fall of 1941 made it difficult, if not impossible, to reject the turrets completely, and the division informed Bendix that one of the most important phases of the turret program would be to sell the Bendix turrets to the men who were going to use them. The chief wrote:⁵⁶

It would be to our mutual interests for you to arrange for service engineers to live with these turrets during the next few months to make sure the Service does not receive them with defects and troubles

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54. "689" Inspection Rpt. on B-25B, EES, 16 Aug. 1941, in Arm. Lab. file, North American B-25 Contract ac 13250.
 55. Memo Rpt., Asst. Mech. Eng. G. T. Sixby, 13 Oct. 1941, in Arm. Lab. file, Machine Gun Mounts 1941.
 56. MD (AF) to Bendix, 5 Sep. 1941, in MAG 473.5, Mounts.

which will get them off to a bad start and possibly a bad reputation. . . . If they give the Service trouble at the beginning, they may get a bad reputation which they may never be able to live down.

The British turret authority, wing Commander Spreckley, emphatically stated that "The Bendix lower turret is completely hopeless due to improper control and poor design in general."⁵⁷ This statement, appearing in October 1941 when the new B-24's armament was up for consideration, proved disturbing. The Materiel Division chief wrote the assistant chief, "The question of the turret on the B-24 is one which is getting hotter and hotter daily on account of reports of this nature which are being sent to England. . . . The comment on the Bendix lower being definitely unsatisfactory is news to me . . . perhaps the Bendix is better than none."⁵⁸

Bendix engineers planned to salvage the unsatisfactory turrets by installing amplidyne drive systems. This expedient proved comparatively satisfactory in the upper turret, but apparently nothing could rescue the lower turret.⁵⁹ In May 1942 the Production Engineering Section chief informed North American that the Materiel Center had decided against the lower turret. He summed up service opinion on the turret tersely: "They don't like it." Since a tail gun involved structural changes, and serious weight and balance considerations, he suggested, "Let's stay off the tail gun and see if we can satisfy them with two side guns and

57. Memo, Brig. Gen. Ralph Royce, Military Attaché for Air, London to J. D. Biggers, OPM, 10 Oct. 1941, in ibid.

58. Chief, MD (Wash.) to Asst. Chief, MD (AF), 21 Oct. 1941, in ibid.

59. TX, Chief, PES to Res. Rep., North American, 15 Jan. 1942, in Arm. Lab. file, North American B-25 Contract ac 13258.

. . . the old tunnel gun" as originally designed, although admittedly the tunnel or bottom hatch installation promised to be little more than a "morale gun."⁶⁰ If the Chief of PES seemed to be determining armament policy, however correct that particular decision may have been, he was clearly stepping beyond his delegated responsibilities.

No matter who voiced the opinion, the Bendix lower turret was admittedly a collection of malfunctions. Slight drops in terminal voltage destroyed the effectiveness of the dynamic brake structural limit stops. The kneeling sighting position proved untenable during evasive action, and a large number of other specific mechanical failures cropped up as the turrets reached use. Nonetheless, probably no single weakness was of such critical importance as the inadequate sighting system.

The limited cone of vision which the telescopic sight imposed upon the Bendix upper turret was overcome with the installation of a simple reflex sight comparable to the arrangement in a Martin turret, but all modifications were doomed to failure with the lower turret.⁶¹ Bendix engineers tried to salvage the sight with a number of ingenious devices, but none mastered the basic difficulty. To answer the charge that the lower turret suffered from inadequate pick-up windows, Bendix designed a "direction of attack indicator" to show which quadrant the target appeared in, but the obvious fallacies of such a makeshift device shelved the project as soon as it appeared.⁶²

60. Phone transcript, Lee Atwood, North American and Brig. Gen. K. B. Wolfe, PLS, 6 May 1942, in Arm. Lab. file, E.O. 553-1-452.

61. Chief, EES to Bendix, 29 June 1942, in Arm. Lab. file, E. O. 553-1-119.

62. Bendix to Materiel Center, 23 July 1942, in ibid.

A more promising but little more effective attempt to improve the lower turret sight appeared with the Bendix design to increase the cone of vision to 70° and insert an erecting prism to maintain a normal tracking vision. Hitherto, while tracking through an azimuth arc, the target in relation to the gunner's vision had appeared to roll over in flight. This not only resulted in a loss of orientation but made tracking extremely difficult if not impossible. The proposed improvements did not salvage the turret, however, for as late as January 1943 an Engineering Section report noted that "due to recent criticism an investigation is being conducted to determine the feasibility of modifying the Bendix lower turret in such a manner that the gunner can rotate with the turret in an azimuth direction."⁶³ Turrets equipped with an attack indicator, a 70° cone of vision, and an erect image sight did not provide "adequate combat defensive fire power," according to ^aright Field report of May 1943 which recommended that waist guns be installed until a more satisfactory lower turret could be developed. This course of action had been commended exactly one year before by the Production Engineering Section chief.⁶⁴

The misfortunes which seemed to hinder the Bendix turret began early in the production phase of manufacture. In July 1941 Bendix deliveries were so much in default that the Materiel Division contemplated throwing half of the Bendix contract to Emerson.⁶⁵ To spur on delinquent subcontractors, the Materiel Division wrote directly to 24 Bendix subcontractors.

63. Chief, PES to Bendix, 20 Aug. 1942; and Chief, ES to Bendix, 6 Jan. 1943, in *ibid.*

64. Memo Rpt., PES, 5 May 1943, in Arm. Lab. file, E.O. 553-1-505.

65. Phone transcript, Maj. S. R. Brentnall, Bendix Mes. Rep. and Col. K. B. Wolfe, PES, 22 July 1941, in ATSC 473.5, General. See also Chief, PES to Bendix, 27 June 1941, in AAG 473.5, Mounts.

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Out of 106 in the Bendix complex, only 6 were seriously behind schedule; but these critical 6 were sufficient to wreck production.

The dangers inherent in a policy of subcontracting an abnormal proportion of the turret were many. If the prime contractor became little more than an assembler of components, little design improvement could be expected, for experience showed that a large number of design improvements began with the study of industrial simplification. Furthermore, manufacturing founded largely upon subcontracts left only a tenuous control in the hands of the Materiel Division, whose dealings were necessarily with the prime contractor. A PES report concluded that "the main reason for not getting deliveries on turrets" from Bendix was "the lack of organization and very little effort made to produce parts in the contractor's own plant," and recommended that the manufacturer be notified that unless deliveries were improved, steps would be taken to relieve Bendix of the idle government machinery and to reduce the number of turrets contracted for.⁶⁶

Production difficulties coupled with the problems of design made it necessary to reconsider the entire Bendix production program in September 1941. Although it was decided that the requirement for lower turrets was sufficiently urgent to justify continued production, the chief of PES noted that "difficulties are of so serious a nature that it is unlikely that a completely satisfactory correction can be looked forward to as a probability" and suggested that a "complete redesign be undertaken with a view to substituting entirely new turrets for those now being delivered,

66. Memo Rpt., PES, 29 July 1941, in MISC 473.5, Bendix 1939-1941.

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at some point in the production schedule."⁶⁷ So, somewhat under a cloud, Bendix continued producing lower turrets.

The pattern of Bendix production did not improve in 1942. With B-25 acceptances estimated at 1,288 planes per month, Bendix maximum production, optimistically considered, was not expected to reach 850 units per month. This factor, together with the maintenance problems, the operational training problems, and the steady flow of "Unsatisfactory Reports" from the tactical units to the Materiel Center, led to the decision to delete the lower turret from the B-25C, B-25D, and all subsequent contracts.⁶⁸

In April 1943 the Assistant Chief of Air Staff for Materiel, Maintenance, and Distribution (MM&D) in Washington directed that the surplus Bendix lower turrets be utilized as chin turrets on the B-17F until the newly designed chin turret could be put into production.⁶⁹ Another somewhat later scheme to salvage the surplus lower turrets by inverting the lowers to use as uppers proved mechanically unfeasible.⁷⁰

As far back as July 1942 Bendix had roughed out two experimental chin turrets for trial installations in the B-17F and B-24D. The B-17 version utilized an independently hung sight on a swinging arm free of the turret proper. The B-24 version rotated both the sight and the gunner in relation to the guns moving in azimuth. Since it was obviously inadvisable to manufacture two different types, the B-17 model was selected

67. Chief, PLS to Bendix, 11 Sep. 1941, in Arm. Lab. file, Machine Gun Mounts, 1941.

68. IOM, Chief, PLS to Chief, Airplane Projects, PLS, 7 May 1942, in Arm. Lab. file, E.O. 553-1-425.

69. Daily Log, Production Br., MM&D, 30 April 1943.

70. Memo Rpt., Arm. Lab., 9 July 1943, in Arm. Lab. file, 553-1-486.

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because it could be fitted in either type of aircraft and, in the limited sector of fire available to a chin gun position, there was no need for serious concern about orienting the gunner to his guns.⁷¹

The pressing demands for frontal fire power to defend bombardment aircraft against head-on attack fully justified the earlier British decision to retain nose turrets even though in the early phases of the war only occasionally had attacks been made frontally. Bendix hurriedly improvised a chin turret design, but putting the design into production was quite another problem. By the time the chin turret appeared, Boeing production was rolling; and the chin turret requirement promised to tax Bendix facilities severely. At the Materiel Center it was noted that the "history of the Bendix Company in turret production does not bear out any optimistic assumption as to their capacity to better the delivery schedule."⁷²

Bendix chin production reached approximately 150 units per month by June 1943, but unlike the experimental model, the earliest production turrets utilized the old indirect or remote sighting system.⁷³ After one dry run and one combat mission the Eighth Air Force approved the indirectly sighted chin turret as an "interim measure," but during a subsequent mission, a B-17 equipped with the remotely sighted chin turret suffered 12 frontal attacks in one hour. The nose gunner reported that he had been unable to track more than one target for three bursts "because of the difficulty of picking up targets attacking in rapid succession."⁷⁴

71. Bendix to MD (AF), 2 July 1942; and Memo Rpt., EES, 27 July 1942, in Arm. Lab. file, E.O. 553-1-458.

72. Chief, IC to Chief, P&S, 29 Jan. 1943, in Arm. Lab. file, E.O. 553-1-491.

73. Daily Log, Production Br., M&D, 18 June 1943.

74. Capt. H. C. Montanus, Sth AF Air Tech. Sec. to Aircraft Lab., EES, 19 July 1943, in Arm. Lab. file, E.O. 553-1-569.

The unsatisfactory performance of the indirect-sight chin turret led the Materiel Center to dismantle all such turrets installed in B-17F airplanes, and hand-held guns were continued until a production-version direct-sight chin turret could be procured in quantity.⁷⁵ Too much haste in reaching production and an essentially unsound design seem to have hounded the Bendix lower turret throughout its entire career, at least until the final direct-sight chin appeared on the B-17G.

By the end of 1942, all the major turret manufacturers save Westinghouse had reached the large-scale production phase of turret development. To be sure, G.E. production was delayed because of the retarded progress of the P-61, A-26, and B-29 airplanes; but nonetheless, as a manufacturer of Martin components, G.E. entered production early in 1941. Martin production ran smoothly almost from the very first production contract late in 1940; and Sperry, after a difficult period spent in organizing sub-contractors, hit a production stride by the end of 1941.

Westinghouse, the only manufacturer of the initially interested group who did not make a major bid for a share in the turret business, spent the greater part of 1941 and 1942 perfecting a drive unit. In December 1942 the Armament Laboratory tested a novel Westinghouse power unit in which a silverstat resistor, not unlike the Westinghouse aircraft voltage regulator, controlled the speed of a variable-speed friction drive through a differential follow-up.

75. See under date of 20 July 1943, in ibid.

One particularly interesting feature of the drive was a small gyro sensing changes in the control deflection rate and adding a component of this rate to the control motion to achieve a damping characteristic. The Armament Laboratory believed at the time that the gyro element was unnecessary, but less than a year later the Westinghouse gyro was of such importance that the Armament Laboratory suggested coupling the gyroscopic unit with amplidyne control to form the drive system for a fully stabilized turret.⁷⁶ Stabilized turret control gave much promise for the future and marked a most important departure in the evolution of power turrets, but there were a number of other turret projects being developed by other manufacturers which deserve consideration.

76. Memo Rpt., Arm. Lab., 19 Dec. 1942; and Memo Rpt., Arm. Lab., 13 Aug. 1943, in Arm. Lab. file, A.O. 553-1-476.

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Chapter XI

POWER TURRET DEVELOPMENT: PRODUCTION PHASE, 1941-1944

Among the various turrets manufactured for the Materiel Division, the Consolidated Aircraft Company's tail turret was an anomaly in that it originated as an integral part of the B-24 design rather than as an independent unit of government-furnished equipment. The evolution of the Consolidated tail turret was inevitably influenced by this relationship with an aircraft and probably indicates, as no other illustration could, the importance of perfecting turrets as units apart from specific airplane models.

As far back as May 1937 the Navy's Bureau of Ordnance negotiated contracts with Martin and Consolidated for big, heavy, long-range patrol bombers and expressed a desire to equip these airplanes with some form of power turret. When questioned, the Materiel Division expressed no objection to revealing the "secret" gun mounts of the Air Corps.¹ Just how many "secrets" were learned may be surmised from the fact that the Navy graciously approved Consolidated's sale of the recently developed .50-cal. power mount to the Air Corps in December 1938.²

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1. OCAC to MD (MF), 21 May 1937, and 1st ind., Chief, MD (MF), 28 May 1937, cross reference in ATSC 472.81, Fire Control.
 2. Chief, Navy BuOrd to Inspector of Naval Aircraft, San Diego, 22 Dec. 1938, in Arm. Lab. file, Machine Gun Mounts 1938-1939.

In March 1939 the specifications for Consolidated's XB-24 called for four .30's and three .50's for flexible gunnery installations, .30's in nose and waist, and a single .50 in upper, lower, and tail positions. The type specifications for four-engine bombers as defined in January 1939 expressly stipulated that the number and arrangement of machine guns should be such that "complete protection" could be effectively accomplished by "not more than three members of the crew." It would seem that three men were expected to operate all seven installations. That the contractor was expected to improve on this is apparent, however, in the clause stipulating: "Wherever remotely controlled guns are installed, the contractor shall design and supply the complete sighting and control system."³

Wright Field tests of B-24 and B-24A armament led to the opinion that the upper emplacement would be considerably improved by the application of power, at least for azimuth rotation; and French officials, probably influenced by the success of British armament, urged the development of a tail turret for Consolidated equipment consigned to French military use.⁴

In January 1941 Consolidated was granted \$3,960 for an experimental tail turret for testing at the Armament Laboratory as an installation in the B-24D. The Materiel Division negotiated a contract for 73 such tail turrets in May 1941, but it was not until the following September that the first test model arrived at Wright Field.⁵

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3. Specifications, Consolidated XB-24 Contract ac 12436, in Arm. Lab. file.
 4. Chief, Contract Sec. to Consolidated, 8 Jan. 1940, cross reference in ATSC 473.5, General; and statement of Lt. Col. H. L. Goll, Arm. Lab. to Lt. I. B. Holley, Jr., ATSC Historical Office, 10 Oct. 1944.
 5. A for P No. 175587, 10 Jan. 1941; and Consolidated to AF 62, 4 Sep. 1941, in Arm. Lab. file, E.O. 553-1-357. See also Contract 1535 ac 18522, 3 May 1941, in ATSC (Contract) files.

Because the Consolidated tail turret was an integral part of the B-24, at least in initial concept, the manufacturers scheduled to produce the B-24 were notified that they would be expected to produce tail turrets even though this involved a duplication of tooling. Actually, neither the Ford Motor Company nor Consolidated, the two major B-24 facilities, intended to produce the tail turret in quantity. Consolidated planned to subcontract with the Southern Aircraft Corporation of Garland, Calif., and Ford planned to subcontract with the Motor Products Corporation of Detroit.⁶ The decision to require B-24 prime contractors to assume obligation for the tail turret resulted in little more than a complete duplication of facilities.

The Wright Field tests on the initial experimental tail turret proved disheartening. Not only were there a number of shortcomings of a minor nature, but inadequate attention had been devoted to space considerations, and only a comparatively small man could enter the turret in full flying equipment. Jump card tests showed excessive dispersion, the hydraulic control valve allowed an appreciable creep, and no provision had been made for a heated-suit outlet, hot air duct, trouble lamp, interphone, or oxygen systems. These items could be installed with a minimum of engineering difficulty, but only a complete redesign could overcome the size limitation.

Another fundamental weakness, one which did not appear in the first trials, lay in the azimuth drive. The Consolidated tail turret drive

6. Memo, Chief, Am. Br. (Wash.), to H. E. Boyer, OPM, 9 June 1941; and TXK, Res. Rep. OPD to MD (AF), 16 Sep. 1941, in ATSC 473.5, General.

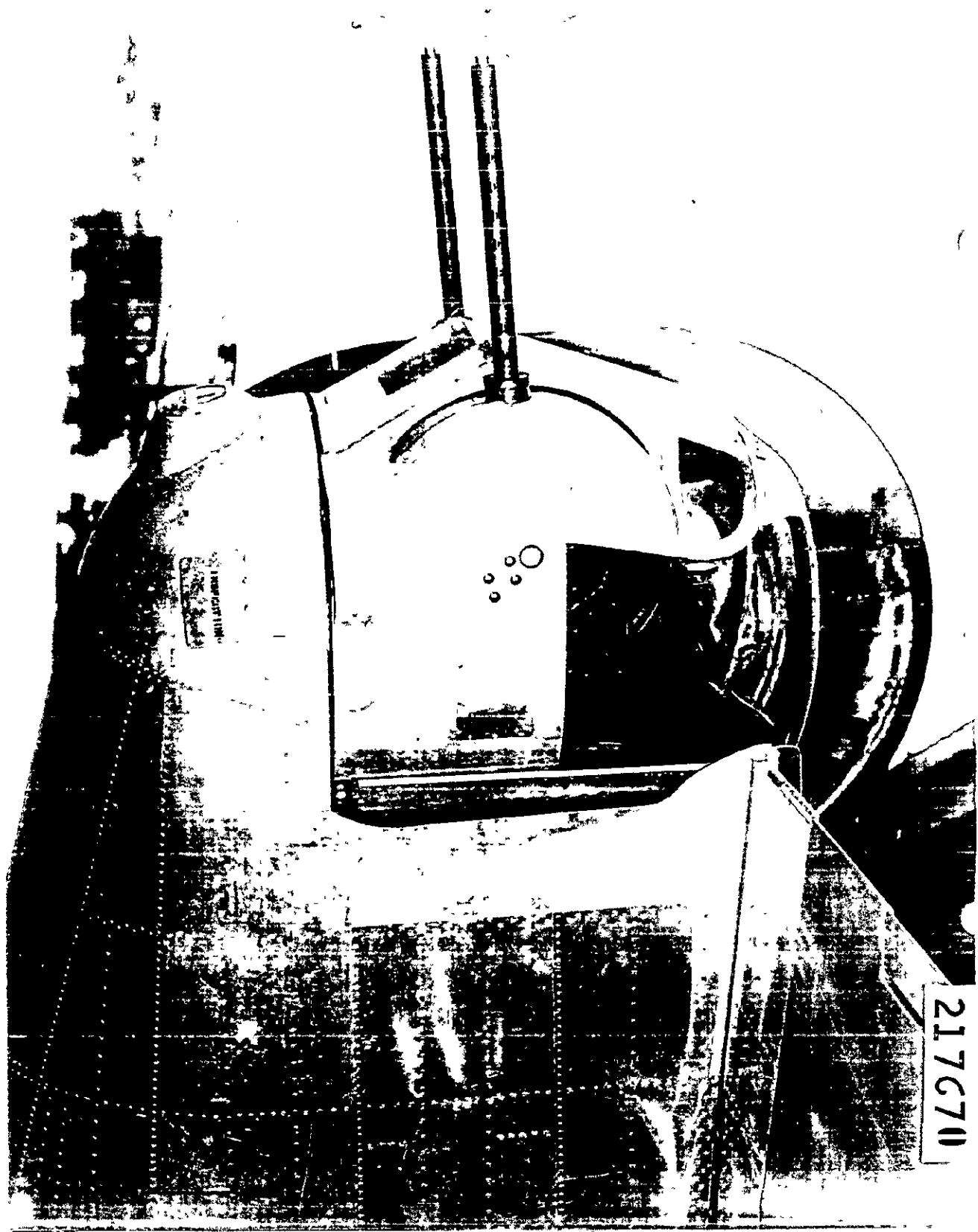
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system consisted of an external hydraulic pressure source, a reservoir, pump, and accumulator with feed and return lines introduced through a swivel joint to the moving turret. A four-way, joy-stick-controlled, hydraulic valve determined the flow to a simple hydraulic jack for elevation and the flow to a simple, fixed-tilt, reversible, Vickers motor for azimuth drive. At this point, however, the difficulty appeared. Instead of gearing the motor directly through a positive gear train to the moving turret, the designer had the motor operate a drum from which steel cables ran in opposite directions about the turret. This arrangement, designed to obviate the use of a ring gear with all its attendant manufacturing difficulties, was ingenious; but it brought more troubles in its wake than could have been anticipated by Consolidated. Every change in temperature changed the tension on the cable system and control became erratic with a disconcerting slackness in the neutral area.⁷

As soon as the serious nature of the turret's shortcomings became evident, both Ford and Consolidated were notified to hold up production until satisfactory modifications could be made in the tail turret to produce an acceptable version.⁸ While Consolidated prepared to modify the faulty original turret, the Contract Section of the Materiel Division requested Emerson to estimate the cost of a complete redesign.

An Emerson engineer studied the tail turret at Wright Field and reported that all the existing discrepancies could be removed save the

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7. TX, Chief, MD (MF), to AC Res. Rep., Consolidated, 27 Sep. 1941, in Arm. Lab. file, E.O. 553-1-357; and Memo Rpt., Navy BuAer, 2 Oct. 1941, in Arm. Lab. file, Confidential Correspondence, folder 3, 1941.
8. TX, Chief, PES to Chief, MS (Wash.), 11 Oct. 1941, in Arm. Lab. file, Machine Gun Mounts 1941.



Consolidated tail turret mounting twin cal. .50
machine guns. Installed in the tail of a B-24. 1944.

limitations on size. The original design had been curtailed by weight. The B-24 airplane designers had imposed an arbitrary load limitation, but after the plane took shape and the center of gravity had been found, it was discovered that the weight restriction was set too low.

The limitation on weight not only cramped the tail turret for size, but led to a light construction which impaired the rigidity of the mount. The importance of building a turret around a sight had been reiterated by the chief Frazer-Jash designer, but the Consolidated tail turret sight was so constructed as to transmit a large measure of the vibration set up by the guns in action. Finally, the Emerson engineer pointed out that the excessive dispersion pattern of the twin .50's resulted from the fact that each gun was carried on a pair of trunnions with diverse structural anchors, which fact resulted in a wide variation in degree of yielding and produced the vibrations fundamental to scatter patterns.⁹

In 1940, French purchasing officials, discussing turret designs, had suggested the feasibility of introducing some form of vibrating mechanism to obtain "splatter patterns" increasing the effectiveness of machine gun fire. The Materiel Division, having spent 20 years avoiding dispersion, frowned on this suggestion, but the mere fact that the idea was broached gives some indication of the problems facing Armament Laboratory engineers in groping toward a rational and functionally correct tail turret design.¹⁰ If the theory of turrets, the objectives sought, and the definition of

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9. Chief, Contract Sec., WF to Emerson, 10 Oct. 1941; and Emerson Office Memo, A. R. Lardin, engineer to W. S. Symington, 30 Oct. 1941, in Arm. Lab. file, E.O. 553-1-357.
 10. Memo Rpt., DES, 20 Feb. 1940, in Arm. Lab. file, E.O. 553-1-303.

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performance characteristics remained obscure, how obviously difficult then was the role of the Materiel Division's engineers in conceiving essentially fundamental design standards.

When the diversified manufacturing basis of the tail turret made modification difficult, the Production Engineering Section chief admitted that it probably would have been better had the Materiel Division arbitrarily concentrated the tail turret manufacture in one place.¹¹ Meanwhile, valuable time was slipping away. Liberators bound for the United Kingdom under Lend-Lease needed tail armament desperately. British officials were anxious to accept the airplanes without major modification, and installation of Boulton-Paul in place of Consolidated tail turrets threatened to require many alterations.¹²

Whatever may have been the inadequacies of the production planning on the tail turret, the manufacturers engaged in constructing the Consolidated set about to improve it. Mechanical foot firing, external ammunition feeding, improved accessibility to the guns, and a number of other minor modifications appeared; but, as an Experimental Engineering Section report pointed out after the Motor Products innovation had been tested, "the turret is fundamentally no different from the first Consolidated turret tested." The earlier turrets, the engineers believed, were actually better in some respects; and after all the improvements had been added, the turret was "still an inefficient combat weapon due to the instability

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11. Phone transcript, Lt. Col. Grandison Gardner, Arm. Br., Wash. and Col. K. B. Wolfe, PES, 10 Sep. 1941, in ATSC 473.5, General.
 12. T.X. Chief, MD (Wash.) to Asst. Chief, AF, 15 Oct. 1941; and T.X. MD Exec. (Wash.) to Tech. Exec. (AF), 6 Feb. 1942, in Arm. Lab. file, E.O. 553-1-357.

of the gun mounts, sight vibration, and the lack of room," the major objection to the turret from the start.¹³ A Materiel Division critic was equally emphatic, saying, "After getting a good look at the type of armament work Consolidated is engaged in, I am thoroughly convinced that anything we do is an improvement."¹⁴

The Materiel Division's opinion of the Consolidated turret was confirmed when, despite earlier reports to the contrary, the British Air Commission informed the division that there would be no further requirement for Consolidated turrets on Lend-Lease Liberators, since Boulton-Paul turrets were to be used instead.¹⁵

Despite the fact that the Consolidated turret was far from acceptable, the requirements for its installation continued to increase. The demands from combat theater commanders for frontal turret protection soon made the use of a nose turret inevitable. An experimental tail turret in the nose of a B-24 evoked an Armament Laboratory criticism that the installation "could not be considered as a possible production installation due to the replacing of this type turret by the Emerson . . . improved type tail turret," and, furthermore, the Bendix lower turret, converted to chin use, provided the "required frontal coverage at much less cost than an installation of the Consolidated turret."¹⁶ It is true that the Bendix chin/^{turret}made a much cleaner installation than did the Consolidated;

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13. Memo rpt., III, 5 May 1942, in Arm. Lab. file, E.O. 553-1-429.
 14. J. G. Rogge to Col. P. E. Shanahan, AsC, 19 Aug. 1942, in Arm. Lab. file, E.O. 553-1-373.
 15. T.M., Chief, ED (Wash.) to MC (AF), 27 Aug. 1942, in Arm. Lab. file, E.O. 552-1-350.
 16. ICM, Chief, Arm. Lab. to Chief, Arm. Br., Field Service Sec., ASG, 20 Aug. 1942, in Arm. Lab. file, E.O. 553-1-357.

but neither the Bendix chin nor the new Emerson turret reached quantity production as soon as had been anticipated, and Consolidated tail turrets were mounted as nose turrets to meet the immediate requirement.

The first experimental Consolidated nose installations were made in July 1942, but no definite policy was decided for several months. In January 1943 the Materiel Center complained that the nose turret project was "seriously hampered by lack of a statement as to the extent of protection desired against forward gunfire."¹⁷ The Director of Military Requirements in Washington reduced the whole problem to a few phrases:¹⁸

Several theater commanders have requested the Consolidated tail turret in the nose of B-24 airplanes. . . . In view of the recent losses due to frontal attacks and the long delay before chin turrets are available, it is desired that the feasibility of installing Consolidated turrets on a limited basis as an interim measure be thoroughly explored. It is not impossible that this turret would prove even more desirable than the chin turret. The maintenance and supply and training problems for B-24 units would certainly be simplified if this turret were used instead of the Bendix chin turret.

The Consolidated tail turret, despite its unfortunate origin and confused evolution, came to prove its utility through a much wider span than was originally intended. The fact that the case of the Consolidated tail turret is probably most important as an indication of how not to build turrets, both from the standpoint of design and of production, does not detract from the usefulness of the product. There were a number of other turrets which, like Consolidated, entered the field late and either

17. Chief, Arm. Lab. to Tech. Exec., Eng. Div., AF, 16 Jan. 1943, in Arm. Lab. file, E.O. 553-1-520.

18. Director of Military Requirements to Chief, MC, 21 Jan. 1943, in AAG 452.26, Turrets.

never developed past the experimental phase or came to production only after the major turret manufacturers had perfected their designs and were in full production. Before summing up the pattern of turret manufacture as a whole, it might prove useful to consider these late-comers briefly.

As early as December 1940 Curtiss, one of the earliest turret manufacturers, built a power turret for Navy use, but its design was so inadequate that it received but scant attention by the Materiel Division.¹⁹ Perhaps more typical of the late arrivals was the case of the Norge Division of the Borg-Warner Corporation in Detroit, originally called upon by the Armament Laboratory to consider the possibility of providing a substitute hydraulic drive for the Vickers unit.

After analyzing the various existing turrets--Martin, Sperry, and Consolidated--Norge, assisted by B. B. Henderson, the Frazer-Mash engineer, designed a turret for Air Corps use entirely without reference to the Materiel Division. When the war curtailed refrigerator production, Norge began manufacturing Frazer-Mash turrets mounting twin .50's for use on Navy PT boats and turrets for the Navy's SB2C (the Air Corps A-25). This Navy turret interest was almost certain to influence the Norge turret concept unfavorably in regard to Air Corps requirements.

The Materiel Division interest in Norge centered around the manufacturer's capacity for Pesco hydraulic pump parts and the possibility of large-scale production on the British-used Dowty pump, then manufactured

19. IOM, Chief, Ord. Dept., LF to Chief, Arm. Lab., 5 Dec. 1940, in Arm. Lab. file, Machine Gun Mounts 1941.

by the Dowty Equipment Company of Long Island City, N.Y. Without prior coordination with the Armament Laboratory, Norge prepared an experimental turret, known as the Frazer-Nash Number 78, in the hope that it would warrant consideration. This was "a peculiar procedure to say the least," suggested a Materiel Division representative who was sent to study the development.

However, the Norge turret was undoubtedly worth investigating. The division representative visiting the manufacturer's plant noted that "while it is practically certain that Wright Field will not even consider this turret for installation in the B-24 tail, it does have some very interesting features which might be utilized in future designs." The turret of wood panel construction required no booster system because the ammunition boxes rested on the axis of the guns, which were at knee level.²⁰

There is, of course, no way of proving that the Emerson turret knee-level guns were not independently conceived, but the relationship, real or apparent, is sufficient to suggest the utility of the Armament Laboratory policy of considering every offering, no matter how far-fetched, on the chance that it might contain the germ of some basic innovation. Norge seemed to have exactly this in mind in sending a detailed description of the new turret to the Chief of the Materiel Division "with the hope either in its basic design, or in one or more of its component parts or assemblies, there will be found a contribution of value." Unfortunately for Norge, no Air Corps requirement for the proposed turret ever materialized.²¹

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20. Norge to MD (AF), 22 July 1942; B. B. Henderson to MD (AF), 22 Sep. 1940; and Report on Borg-Larner Turret by Capt. L. E. Elliott to Col. J. T. Murtha, 10 Nov. 1942, in Arm. Lab. file, E.O. 553-1-343.
21. Norge to MC (Nash.), 31 March 1943; and Chief, MD (AF) to AC/AS, PL&D, 24 April 1943, in AAG 452.26, Turrets.

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Another turret which was important to the Materiel Division more as an influence on design than as a production item was that constructed by the Ford Instrument Company of Long Island City, N. Y., not to be confused with the Ford Motor Company's turret on subcontract to the Motor Products company. In July 1941 the Chief of the Armament Branch in Washington informed the Experimental Engineering Section of the Ford Instrument turret being installed in a PBM at Norfolk by the Navy's Bureau of Ordnance. The turret was reported as "novel and very promising," incorporating a gyroscopic control and sight stabilizing element.²²

The Ford Instrument all-electric, gyro-stabilized turret mounted a single .50 and was capable of azimuth speeds up to 90° per second. The Navy declared that the turret had "meritorious features . . . probably not attained with any other turret," and the report was so favorable that the Materiel Division was anxious to continue the project. At the time, however, there were other interests competing for attention.

As late as May 1942 the chief of LES wrote Dr. S. H. Caldwell, a member of the National Defense Research Committee group^{at} Massachusetts Institute of Technology, that the subject of turret stabilization had been discussed at Wright Field and approved for investigation, but noted:²³

There is virtually no possibility of conducting tests at the present time because of the extreme urgency of other tests projects involving equipment now in production. . . . While turret stabilization is considered an important project, all such highly experimental problems are being held up until the present peak of work has passed.

22. ICM, Chief, Arm. Br., Wash. to Chief, ELS, 31 July 1941, in AAG 473.5, Mounts.

23. Memo Rpt., LES, 20 Aug. 1941, in AFSC 473.5, General.

No more graphic proof of the difficulties facing the Materiel Division could be found. When the initial experimental and development phase ran into the production phase, a bottleneck of trained personnel was inevitable. The engineers who might best have been occupied in pushing forward research projects such as stabilization were nearly inundated with the work of testing current production models. The Chief of the Materiel Division, M&D, was fully aware of this problem, but at the time there seemed to be no escape.²⁴

Another Navy project which interested the Materiel Division was the Erco, Engineering Research Corporation, turret. In January 1941 Henry Berliner, an aircraft designer and head of the firm, convinced the chief of the division that Erco would make an "excellent source" for turrets and arranged for a conference of Erco engineers at Wright Field to discuss turret design.²⁵ In October 1941 a Navy test of the Erco upper ball turret revealed the usual defects of experimental turrets, jerky motion, uncomfortable hand grips, and poor accessibility; but it was withal a "very well designed, cleanly constructed, and efficient machine gun turret" with an extremely wide range of travel comparable to that of the Sperry lower ball.²⁶

The Navy ordered the Erco turret in quantity and began a project to build a twin 20-mm. turret with a self-contained gasoline power drive

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24. E&R, Chief, MD (M&D) to Chief, Requirements Div., OC&R, 7 April 1943, in MAG 452.1, Pursuit Planes. See also Case History, XP-71, Oct. 1944, in ATSC Historical Office.
25. T.A., Chief, MD (Mash.) to Asst. Chief, MD (AF), 13 Jan. 1941, in Arm. Lab. file, Machine Gun Mounts 1941.
26. Rpt. No. 1056-41, Ord. Insp., Navy Proving Ground, Dahlgren, Va. to Chief, BuOrd, 31 Oct. 1941, in ibid.

and supercharged cabin for the rBB-1; but the Materiel Division was unable to utilize the Erco design because it was too heavy and was powered with a Vickers unit, which offered no escape from the already critical drive bottleneck.²⁷

There were turret manufacturers or would-be manufacturers other than those working for the Navy with whom the Materiel Division was concerned. The Pioneer Instrument Division, a Bendix Aviation Corporation subsidiary in Bendix, J. J., furnished a case in point. In January 1941 Pioneer informed the Materiel Division of plans to develop a twin-.50 spherical turret for delivery in six months. In May the division approved a \$30,000 experimental contract to procure the turret, an autosyn control drive with external ammunition feed and a computing sight. In February 1942 Pioneer expected to complete the turret the following April. In May 1943 the Armament Laboratory recommended closing out the Pioneer expenditure order after nine months had passed with no word of progress from the manufacturer.²⁸ Not all the late-comers to the turret field, however, dwindled down to such a dismal end. In fact, some of the last to enter the business gave great promise.

The United Shoe Machinery Corporation of Boston, Mass., for example, entered the turret field in the spring of 1941, after a conference at the Armament Laboratory outlining the objectives sought. From the very beginning United Shoe decided to concentrate on the problem of pressurizing turrets rather than enter upon the immediate production models. Even

27. STI-435, 30 Dec. 1941; Memo rpt., MEG, 15 Jan. 1942; and ICM, Chief, MD (ash.) to Tech. Exec., MD (AF), 17 Jan. 1942, in ATSC 473.5, General.

28. Pioneer to MD (AF), 21 Jan. 1941; Contract #535 ac 18767; and Memo rpt., Arm. Lab., 6 May 1943, in Arm. Lab. file, E.O. 553-1-363.

before reaching a contract agreement, it authorized an initial company expenditure of \$2,500 to shape up tentative plans for a pressurized system.²⁹

In September 1941 the Armament Laboratory initiated a series of studies to analyze the problem of turret pressurization and recommended a policy of circulating the results of these studies throughout the tactical units in the field as well as turret manufacturers for criticism before engaging extensively in developmental work. This recommendation marked a forward step toward improved liaison with service units and suggested an important procedure for the future. Shortly afterward, in October, the Materiel Division negotiated a \$50,000 contract with United Shoe for an experimental twin 37-mm. cannon pressurized turret.³⁰ The United Shoe engineers canvassed the possibilities of the turret field, but apart from a few ventures in manufacturing power mounts or assisted-motion mounts similar to the Bell Aircraft Company hydraulic booster for flexible guns, they concentrated their activities on pressurized turrets.³¹

Among the turret manufacturers who never secured large-scale turret contracts with the Materiel Division, one name recurs repeatedly--the W. L. Maxson Corporation of New York. As early as January 1941 the division asked Maxson to consider providing a Maxson drive for turret use. The Maxson unit consisted of a low-torque control motor which

29. United Shoe to MD (I.F), 12 June 1941, in Arm. Lab. file, E.O. 553-1-341.

30. Memo Rpt., EES, 29 Sep. 1941, in *ibid.* See also Contract #535 ac 21870, in ATSC Contract files.

31. United Shoe to Curtiss-Wright, 15 Dec. 1941, in Arm. Lab. file, Machine Gun Mounts 1941.

regulated the speed of a high-torque drive motor by using two hydraulic pumps braking the power drive through differentials.³²

Nothing ever came of the Maxson torque amplifier, but in August 1941 the Armament Branch in Washington informed Wright Field of a Maxson control "considered to be the most interesting development yet made," designed for the Brewster X332A aircraft destined for export to the Dutch. Originally Brewster had relied upon Tucker for a power turret, but when Tucker's turret failed to materialize, Maxson undertook the development.³³

Perhaps the most appealing feature of the Maxson turret drive in October 1941 was the fact that it did not require a large ring gear, the bugbear of almost every turret manufactured at that time. Furthermore, Maxson anticipated a capacity of 1,000 drive units per month, with a mere \$150,000 tool expansion. In the fall of 1941 almost any drive with such a production promise might have been worth considering in view of the desperate need for drives for Bendix, Emerson, and Sperry products when both the amplidyne and Vickers units became critical.

The Maxson turret drive, a V-belt control with infinite speed variation, derived from adjustable pulley sheaves determining the linear speed of the belt proportionally to the radius at which it turned, held considerable promise as a turret drive. The Maxson experimental turret built around the V-belt drive was, however, a heavy, extremely bulky

32. Maxson to MD (AF), 10 Jan. 1941, in Arm. Lab. file, E.O. 553-1-343.

33. T.X., Chief, Arm. Br. (Wash.) to Chief, EES, 18 Aug. 1941, in Arm. Lab. file, Secret Correspondence, folder 2, 1941; Memo Rpt., EES, 6 Oct. 1941, in Arm. Lab. file, Machine Gun Mounts 1941.

apparatus which had about as much chance of survival in the Air Corps as the AMB turret.³⁴

Still another Maxson enterprise appeared in December 1941, when the Armament Laboratory arranged to purchase an electric drive for \$13,425. This unit, like its predecessor, received an initially enthusiastic approval by Emerson engineers, who regarded it as being³⁵

as promising as any of the electrical drives encountered to date. It has a number of advantages over the amplidyne drive in that it is much simpler, can be made of substantially standard parts, and its weight is in the order of one-half that of the amplidyne. Its sensitivity is not as great as the amplidyne, but it is believed that it will be satisfactory for the turret application.

Unfortunately, the Maxson electric drive, a pulsation field control system, did not prove very adequate when tested, and the type was limited to use in trainer turrets built by the Crocker-Weeler Electric Manufacturing Company of New Jersey.³⁶

One of the most interesting of the many turrets which never came into production was the project of Airarms, a Vega Airplane Company subsidiary. In July 1940 a Western Procurement District engineering officer reported the development of an armored, pressure-cabin power turret. The Engineering Section chief requested further information, commenting that this turret "looks pretty good." In October the Materiel Division pushed Airarms for a proposal; but the manufacturer replied that

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34. W. L. Maxson prospectus, Brewster-Maxson turret control, Model 313, in Arm. Lab. file, E.O. 553-1-343 (Oversize); Chief, EPD to Chief, PDS, 2 Oct. 1941, in Arm. Lab. file, Confidential Correspondence, folder 3, 1941.
35. A for P No. 181571, 9 Dec. 1941; and Emerson to MD (J.F.), 21 Dec. 1941, in Arm. Lab. file, E.O. 553-1-410.
36. Memo rpt., EES, 13 Jan. 1942; and Emerson to MD (J.F.), 28 Feb. 1942, in Arm. Lab. file, E.O. 553-1-410. See also #535 ac 19444, in ATSC Contract files.

the turret was still in the experimental stage, with engineering bugs to be ironed out. Airarms was so confident in the essential soundness of the turret design that the company was perfectly willing to invest a large amount of money in the unremunerative stages of development in the hope of future contracts.³⁷

In January 1941 the Materiel Division warned Airarms that it would be necessary to make a quotation to permit procurement in the current fiscal year. In March the manufacturer claimed to be 100 per cent tooled for production, but the first turret did not reach Wright Field for testing until May.³⁸ After such a prolonged build-up the Armament Laboratory could do little but anticipate a remarkable turret.

The Airarms turret was indeed remarkable, for it represented an attempt at a single-handed solution of most of the major problems facing turret designers. The basic ball design gave a wide range of elevation as well as azimuth movement, the gas recoil-operated ammunition booster system was a novel approach to a vexing problem, and the prismatic double-ended sight for aiming past obstructions, in appearance not unlike a naval range finder, were all ingenious even if not entirely satisfactory solutions to fundamental turret requirements.

Above all, the Airarms drive was an unusual contribution. It consisted of a constant-speed motor with two opposed friction clutches for two-directional speed controls. The opposed clutches prevented coasting

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37. Eng. Officer, WPD to MD (AF), 18 July 1940; and Airarms to MD (AF), 3 Oct. 1940, in Arm. Lab. file, Machine Gun Mounts 1940.
38. TX, Chief, MD (AF) to Airarms, 9 Jan. 1941; and Airarms to MD (AF), 26 March 1941, in ibid.

after disengagement, for movement past neutral introduced a reciprocal motion. One of the advantages of the drive lay in the fact that it delivered maximum torque without regard for clutch positions approaching low speeds. The Materiel Division considered the Airarms project sufficiently worthy to promote and negotiated an experimental contract for \$15,000 to continue development by Airarms.³⁹

Airarms engineers tried to remodel the turret to overcome the major objections noted at Wright Field. The turret sheathing obscured large areas necessary for scanning, the drive motor was improperly ventilated and overheated after five minutes at full load, the maximum azimuth slewing speeds were too slow, and the minimum tracking speeds were too fast.⁴⁰ When Airarms had little success in ironing out these difficulties, the Armament Laboratory turned the project over to the Emerson facility in the hope that Emerson might have more success in converting the turret into a production prototype.

Unfortunately for the future success of the Airarms project, Emerson engineers were little more successful at improving the turret than Vega had been. Despite careful theoretical and empirical redesign of the clutch system, it was impossible to secure azimuth speeds low enough to track efficiently. A gear reducer on the clutch output, a planetary gear reducer between drive and clutch disks, and idler disks in the clutch were all ineffective. There were, however, enough features of interest and value in the Airarms design to make it worthy of continued study.

39. Technical Description of Airarms Drive, 13 Jan. 1941, in Arm. Lab. file, E.O. 553-1-343. See also AEC Contract File 535 ac 201040.
40. Memo Rpt., EAS, 25 June 1941; and Memo Rpt., EAS, 21 Aug. 1941, in Arm. Lab. file, E.O. 553-1-376.

The Airarms turret was heavily armored, the prismatic sight promised to be a remarkable contribution when perfected, and the turret possessed an unusual degree of down fire, a low drag coefficient, and an ingenious arrangement for lever action charging. All these items notwithstanding, the basic drive design was far from acceptable.⁴¹

Emerson decided that only a completely new drive would ever rescue the Airarms turret from the junk heap, so an agreement was negotiated securing the rights to manufacture G.L. amplidyne at Emerson for a sum of \$25,000. The fate of the Airarms project was probably sealed when the standard 530-watt amplidyne proved insufficiently powerful to drive the turret, and G.E. anticipated a five-month delay in developing a heavier amplidyne with increased output. The critical need for turrets in January 1942 induced the Materiel Division to press the Airarms project in spite of all its obvious defects, but by June increased turret output by other manufacturers made even the promise of future improvement in the Airarms turret seem insufficient justification for continuing the project.⁴²

Firing tests of the Airarms turret with alternate amplidyne and Maxson electric drives revealed the usual accessory troubles, inadequate boosters, etc., as well as excessive power consumption. Early enthusiasm for the Airarms design had led to tentative procurement plans in a letter contract to Emerson for 500 units in January 1942, but by October of that year Emerson was doing an "absolute minimum" in development work because the project had been shelved for more promising designs.

41. Memo Rpt., EES, 8 Nov. 1941; and Emerson to MD (WF), 14 Nov. 1941, in ibid.

42. G.L. to Emerson, 7 Jan. 1942; and Emerson to G.E., 28 Jan. 1942, in ibid.

The original Authority for Purchase on the Airarms turret called for a \$10,000 allocation of funds, but by June 1942 Emerson reported expenditures totaling more than \$94,000.⁴³ The Production Engineering Section pointed out that a quantity contract on the Airarms turret would be based on the assumption that the turret would be suitable for use in production aircraft. Furthermore, predicting the use of central-station fire control by June 1944 and allowing nine months tooling time, a margin of but nine months remained for production, which seemed inadequate justification for pushing the Airarms project further. The Experimental Engineering Section disagreed with the PES viewpoint. The section chief was convinced that the Airarms turret represented an engineering achievement: "As of this date, the Vega turret is superior to any of the present production turrets." Furthermore, the chief of EES doubted that local control turrets would be outmoded by June 1944, and, if successful, the Airarms turret would be of tremendous value in relieving the Vickers unit shortage.⁴⁴

When the 750-watt amplidyne project ran into protracted delays at G.E. and Martin-Omaha anticipated a delay in Martin turrets, the Materiel Division shelved the Airarms project entirely and turned Emerson capacity to Martin production. The Contract Section chief estimated that the development costs of the abortive Airarms project would reach \$400,000 by December 1942. Against just such a contingency, Airarms sought to

43. Emerson to LD (AF), 15 June 1942; Memo Rpt., PES, 30 May 1942; and Emerson to LD (AF), 23 Oct. 1942, in *ibid.*

44. ICM, Chief, PES to Chief, Prod. Div., 15 June 1942; and ICM, Chief, EES to Chief, PES, 24 June 1942, in *ibid.*

reach a settlement with Emerson. That this money was not utterly wasted was attested by the appearance of Emerson's nose ball in the B-24G.⁴⁵

Vega, representing Airarms, claimed more than \$153,000 for development costs prior to the time Emerson took over the project, but the Western Procurement District contracting officer held the opinion that the Vega claim was not allowable and recommended that the Air Corps settle with Emerson and leave the Vega claim for direct negotiation.⁴⁶ Regardless of the outcome financially considered, the whole Airarms project is a worth-while study. It raises a number of problems of policy for future consideration, such as the contractual relationship between such elements as Emerson and Airarms, the fair control of design rights between competing manufacturers, and the utility of pressing development, in the face of successful production in other lines, to perfect a novel design. All these questions of policy were especially significant with regard to Emerson, since that facility, unlike any other, played a complex role in relation to almost every other turret manufacturer, both as a prime contractor and as a subcontractor, building turrets for Sperry and Lartin, Grumman Navy turrets, and Emerson turrets incorporating G.E. drives.

Of all the turret facilities, Emerson was in an exceptionally favorable position to foster development, for as work-horse to the other

45. Memo, Capt. L. S. Robinson, to Chief, Contract Sec., 10 Dec. 1942; and Emerson to MD (AF), 9 Feb. 1943, in *ibid.*

46. WPD Contracting Officer to MD (AF), 14 Dec. 1943, and Emerson to Vega, 9 Feb. 1943, in *ibid.*

manufacturers turning out Martin uppers, Sperry uppers, and ball turrets on a production line basis, Emerson could study large-scale production methods at first hand and translate this information into design data. In addition to production contracts for Sperry and Martin, the engineering role of Emerson in developing the ANS and the Miremas turrets helped to train a capable staff in the idiosyncracies of turret design.

In August 1941 the evolution of Navy patrol planes gave indications of a future requirement for 20-mm. and four-gun machine-gun turrets. Efforts to arrange an Army-Navy standardization meeting led to the usual bickering as to where the meeting should take place--with the Navy in Washington or at Wright Field. On this particular occasion the Materiel Division won the argument inasmuch as the larger part of the turret business was in division hands.

A joint Army-Navy committee agreed to project a four-gun pressurized turret with a computing sight, 2,000-round ammunition capacity, one-inch armor plate, and possibly a 120-volt electric system. Tentative requirements for this turret were sent to Emerson, which embarked on a long period of turret development.⁴⁷

Utilizing the anthropological analysis of turret designs made by Professor E. A. Hooton, the Harvard anthropologist, Emerson set out to perfect a pressurized turret.⁴⁸ The original Emerson turret facility

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47. T.X., Chief, Arm. Br. (Wash.) to Chief, EMS, 13 Aug. 1941, in Arm. Lab. file, Secret Correspondence, folder 2, 1941; T.X., Exec., Navy BuOrd, to Tech. Exec. (A.F), 6 Sep. 1941, et seq., in Arm. Lab. file, Confidential Correspondence, folder 3, 1941.
48. "Preliminary Report on adaptation of certain types of gun turrets to various sizes and builds of gunners," by E. A. Hooton, Harvard University, 24 Sep. 1941, in ibid.

had been designed for production rather than experiment, and the Armament Laboratory chief objected to Emerson's application for funds to construct an experimental laboratory. However, the relationship between production method studies and experimental design was so close that the plan seemed entirely feasible even if it did represent a certain duplication of existing facilities. Laboratories on Long Island were useless if they could not improve production methods in St. Louis.⁴⁹ Meanwhile, with the existing facilities, Emerson engineers worked along several lines of development. Inasmuch as it was apparent that the pressurized turret was largely experimental, possibly nothing more than a hedge against the future failure of central-station fire control, Emerson perfected a production item, an entirely new nose or tail turret, to replace the intrinsically ill-designed Consolidated product.

The Emerson turret, an amplidyne drive, twin .50, incorporated many of the best features of turret design known at the time and some entirely novel elements. It had accessible guns, external feed ammunition, boosters with emergency manual operation, manual operation for both azimuth and elevation movements, a lever-action charging mechanism, and a plate of bullet-resisting glass on a chain and sprocket drive so constructed as to remain always at an angle to the guns. The initial Emerson turret appeared in February 1942 but did not begin to reach production until the summer of 1943, when a maximum of 250 turrets per month was anticipated for the following September.⁵⁰

49. Memo by W. S. Symington, 5 Nov. 1941, in Arm. Lab. file, Machine Gun Mounts, 1941.

50. Chief, MD (TF) to Chief, Navy BuAer, 25 Feb. 1942, in AIG 473.5, Mounts. See also Daily Log, Development Eng. Sr., 122D, 17 July 1943.

A little more than a year after the nose and tail turret appeared, Emerson perfected another turret, the nose ball, to provide a low-drag turret for the E-24G nose position. The new design indicated, perhaps more than any other illustration, the utility of coordinating manufacturing with experimental work and the value of prolonged experience in turret development work.⁵¹ However, the perfection of turrets as the war progressed was inevitable. The real battle of the Armament Laboratory fell in that period when the power turret was leading up to production.

By January 1943 Emerson had undertaken production on nine different contracts which, consolidated into a single Air Corps contract, totaled more than \$93,000,000.⁵² Martin production contracts in February 1943 exceeded \$50,000,000, and in the following month Sperry, Briggs, and Steel Products together held production contracts totaling more than \$25,000,000. Bendix and Bendix subcontractors held contracts in the neighborhood of \$100,000,000.⁵³ Even as early as May 1942 the battle of turret production had really been won; the Production Engineering Section could report that "in most cases . . . the production of gun turret assemblies is ahead of actual requirements."⁵⁴ By the end of 1944 the Armament Laboratory had accumulated a total of more than 70 turrets, some of them production models and many experimental models. The

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51. Emerson to Chief, Ara. Lab., 22 Oct. 1943, in Ara. Lab. file, E.O. 553-1-569.
52. See W535 ac 31692, W535 ac 2643, and supplement 1, in ATSC Contract files.
53. See W535 ac 21966, W535 ac 30482, W535 ac 36126, W535 ac 16147, W535 ac 22712, W535 ac 3692, and W535 ac 37859; see also W535 ac 15773, W535 ac 18906, W535 ac 21976, W535 ac 24631, W535 ac 30436, among others, in ATSC Contract files.
54. Chief, PDS to Chief, Production Control Sec., 15 May 1942, in ATSC 473.5, Gun Turrets 1942.

power turret had reached the point where it was an accepted fact. The B-26 carried a single upper turret, and a powered tail mount. The B-17 carried upper and lower turrets, a chin turret, and a powered tail mount. The B-24 carried an upper and a lower turret, a nose turret, and a tail turret; and the B-29 was to appear with two upper and two lower turrets and a power mount in the tail. While requirements increased, and many problems remained to be solved, the task became largely one of applying engineering talent and industrial capacity to meet specific situations. The critical problem in turrets occurred not during production, which was essentially similar to any other industrial project, but rather during the period of initial development.

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Chapter XII

CONCLUSIONS

This study has been written as a critical analysis of a representative armament problem and not as a record of achievement, however remarkable that record may have been. The summary of power turret evolution presents a recurring pattern of problems which, when extracted, isolated, and investigated, may prove of utility as a body of administrative experience for the future guidance of those charged with directing armament development for the Army Air Forces.

The record of the past 25 years seems to indicate conclusively that, more than any other organization, the Armament Laboratory must carry the burden of armament development during the years between wars. Commercial rivalry will, in a large measure at least, insure the continual, if gradual, perfection of commercially useful engines and airframes. But armament, unstimulated by peacetime requirements, is almost certainly destined to fatal neglect unless emphasized from within the air force. The inferior position of the Armament Laboratory with regard to funds, personnel, and equipment in contrast to the other Wright Field laboratories in the 20 years after World War I seems to indicate that the Materiel Division did not recognize this necessity.

If the Armament Laboratory, more than any of the other laboratories, is going to carry the burden of responsibility for a specific line of

development, it follows that there must be a detailed definition of the Armament Laboratory's role in relation to that development. During the power turret's evolution the exact nature of the Laboratory's responsibilities were vaguely and inadequately defined. Before launching into a new era of engineering enterprise which will thrust a large measure of responsibility for the Army Air Forces' combat effectiveness upon the Armament Laboratory at Wright Field, the record of the past should be considered as an aid toward the formulation of a highly detailed elaboration of the Laboratory's future responsibility.

Perhaps the greatest single failure which is apparent in the development of power turrets lay in the fact that there was never any adequate system for analyzing the basic aircraft armament problem. On occasion visionary individuals or boards of spirited officers did grapple with the philosophical or theoretical aspects of the immediate problem in hand, attempting to generalize on the ends desired; but no formal machinery existed to insure a systematic and periodic analysis of the ultimate objectives sought. For years the prevailing doctrine of flexible gunnery was that the majority of pursuit attacks would come within a narrow cone to the rear; yet each successive bomber down to the very outbreak of war appeared without tail gun installations. In short, the record reveals that the actual armament provision for bombardment aircraft was an inherent contradiction of prevailing doctrine. Before the Armament Laboratory can hope to establish a rational plan of development there must be a definition of objectives. These objectives must be subject to re-evaluation and questioning at definitely prescribed, and periodic intervals. Without such a definition of objectives and a perpetual revision of the definitions

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to keep abreast of the times, even the most remarkable technological achievements may be relatively fruitless.

There remain a number of other factors to consider. Among the several primary limitations retarding the evolution of power turrets was the prevailing inadequate liaison between the Materiel Division and the tactical units in the field which used the equipment being developed by the division. Without an understanding of tactical requirements, the division was admittedly at a loss to understand the immediate requirements of the service. It follows that the division cannot expect to fulfill its role effectively unless it continues to perfect the machinery of liaison with the operating units.

The "Unsatisfactory Report" offered one possible avenue of coordination between the Armament Laboratory and the tactical unit, but the hitherto limited application of the principle makes it obvious that only an aggressive policy will perfect that administrative mechanism to the point of primary utility. The manufacturer's field representative in the combat zones in wartime proved to be a useful direct line from field to factory. The record of field-representative achievement in design modification suggests the value of a careful study of the representatives' contribution to power turrets.

Quite obviously there is no definitive answer to the complex problem of improving liaison between the tactical units and the Materiel Division, but the case of the power turret suggests that more attention should be devoted to the specific questions of coordination technique. If no one system of liaison is the whole answer, surely then it would prove profitable to study all the methods of liaison and devote as much time and

attention to perfecting liaison methods as to the technical questions of armament. The definition of the duties of small boards of officers selected to evaluate a mock-up, the training of such boards, the preparation and circulation of questionnaires throughout the service—these are all responsibilities of greater long-range importance than the fate of any one specific technical item.

Not only do the requirements of liaison impose an obligation to perfect the machinery of coordinating the activities of tactical units and the Armament Laboratory in peacetime, but they stress the need for establishing a system for highly efficient combat liaison with both air forces and allied units. This raises the problem of insuring an adequate system for garnering and evaluating every possible outside source of armament information.

The prevailing lag of Air Corps armament doctrine and practice behind that of the RAF at the outbreak of World War II, clearly illustrates the limitations existing in the Armament Laboratory's methods for studying foreign developments. When the war came in Europe, General Arnold stressed the necessity of adequate armament intelligence, but the time for establishing active foreign information services was a full 20 years past. The military attaches in foreign capitals had performed excellent service in recording foreign trends; but few attaches were armament conscious, and little or no formal organization existed in the Armament Laboratory or elsewhere at Wright Field to benefit from their labors. Success in the perpetual competition for armament supremacy could never be expected until at least some effort had been made to improve attaché technical reports, to provide for systematic search of international patent files, and to improve the degree of coordination with naval and industrial innovations.

Even the finest reporting services available would be to no avail if no effort were made to improve the research technique employed by the Armament Laboratory. The record of Materiel Division turret development bolstered by British practice seems to indicate that the best results are obtained if research projects are delineated, subdivided into workable units, and assigned to individuals or small groups of individuals devoting their entire attention to the projects in hand. The success of such a system leans heavily upon frequent coordination of all groups and periodic evaluation to consider whether progress justifies continuance or rejection and whether or not the objectives initially delineated continue to fulfill a tactical necessity.

The concept of the research team raises the major problem of defining the role of the Armament Laboratory at right field. Exactly what is the role of the laboratory? It is the monitor of projects in industry and a clearinghouse for ideas and requirements derived from foreign reports and the comments of tactical units. Ideally, the Armament Laboratory should focus its planning toward its ultimate wartime role, remaining always ready to expand without dislocation to meet the pressure of the emergency for which it exists.

Organizational flexibility sufficient to cope with the task of monitoring the projects of a large-scale industry in wartime implies a wide range of advance peacetime planning. The record of power turret development gives ample evidence of the necessity for establishing contact with and educating manufacturers long before the time for quantity production arrives. Small peacetime experimental contracts give a higher order of assurance of results than do wartime contracts because the

leaner the prospect of production, the more zealous will be the designer to perfect his project.

Not all educational efforts need be contractual. The Secrecy Agreement doubtless curtails the process of industrial familiarization; but even within the framework of that limitation, carefully organized design competitions would go far toward familiarizing industrial designers with the realities of MF requirements. Likewise, the process of industrial education carries with it the absolute necessity of a frequent and periodic revision of the Handbook of Instructions for Airplane Designers and of type specifications to insure minimum standards entirely in line with the most progressive existing practices.

A realistic approach to future wartime expansion and acceleration requires advance planning for contract and subcontract patterns. The time lost in building up subcontracting complexes on combinations of the sort behind the Sperry organization suggests the necessity of correlating such an organization long before the production phase begins.

Similarly, the wartime experience of the Emerson facility demonstrates the utility of research and experimentation in direct conjunction with large-scale industrial production and suggests that the period of active experimental fabrication at the Armament Laboratory itself is past. Increasingly the Armament Laboratory must shift its emphasis to technological supervision and method analysis. If the complexity of modern armament development involves a scale and scope of industrial facilities far beyond the physical research and experimental resources at Wright Field, the Armament Laboratory must mold its function to meet the new situation. In short, by way of graphic illustration, if the trend toward

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electronic control of armament apparatus involves the necessity of coordination with the Aircraft Radio Laboratory, then the analysis and perfection of the system of coordination with that laboratory becomes a function of the Armament Laboratory of equal importance with the technical perfection of the apparatus being designed. The record of power turret evolution up to World War II shows the necessity for the periodic re-evaluation of the existing organization and of the objectives sought, parallel to the routine perfection of technical equipment.

It is too easy to explain away shortcomings and insufficiencies on the basis of inadequate funds. The remarkable achievements of the Armament Laboratory in World War II become proportionally less surprising as the available funds increase. Technological advances, granted unlimited resources and engineering talent, become little more than a question of time. During the years of peace between wars, when time is less critical and funds are more critical, the organization's technique must be perfected to extract every possible element of usefulness from the available resources.

NOTED

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G L O S S A R Y

AAF	Army Air Forces
AAG	Air Adjutant General
AC	Air Corps; also alternating current
AC/AS	Assistant Chief of Air Staff
AIF	American Expeditionary Force
A for F	Authority for Purchase
AMH	Assistant Military Attache
ANB	Army-Navy-British
Arm.	Armament
AS	Air Service
ASC	Air Service Command
AS.	Assistant Secretary of War
ATSC	Air Technical Service Command
BAC	British Air Commission
Br.	Branch
BuAer	Bureau of Aeronautics, U.S. Navy
BuOrd	Bureau of Ordnance, U.S. Navy
C/AC	Chief of the Air Corps
CFC	Central-station Fire Control
CG	Commanding General
CO	Commanding Officer
C.P.	Circular Proposal
CFD	Central Procurement District
CTI	Classified Technical Instruction
DC	Direct Current
Dir.	Director
DPC	Defense Plant Corporation
EES	Experimental Engineering Section
Eng.	Engineering
E.O.	Expenditure Order
EFD	Eastern Procurement District
ES	Engineering Section
G	Force of gravity
G.E.	General Electric
GFE	Government Furnished Equipment
GHQ AF	General Headquarters Air Force
GO	General Order

IDM	Inter-Desk Memo
IOM	Inter-Office Memo
JAC	Joint Aircraft Committee
Lab.	Laboratory
LI	Letter of Instruction
MA	Military Attaché
MAP	Ministry of Aircraft Production
MC	Material Command (also Materiel Center)
MD	Materiel Division
Memo Rpt.	Memorandum Report
MID	Military Intelligence Division
MMAD	AC/AS Materiel, Maintenance, and Distribution
NA	Naval Attaché
NACA	National Advisory Committee for Aeronautics
NDAC	National Defense Advisory Commission (Advisory Commission to the Council of National Defense)
CCAC	Office of the Chief of Air Corps
CPM	Office of Production Management
Ord.	Ordnance Department
PES	Production Engineering Section, AF
Prod.	Production
R&R	Routing and Record Sheet
Res. Rep.	Resident Representative
Rpt.	Report
Spec.	Specification
Tech.	Technical
TI	Technical Instruction
TWX	Timed Wire Exchange (teletype)
UK	United Kingdom
UR	Unsatisfactory Report
USN	United States Navy
USW	Under Secretary of War
W/C	Wing Commander
WD	War Department
WF	Wright Field
WPB	War Production Board
WPD	Western Procurement District

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The value of the materials in these several locations varies considerably. The AAG files, including both open and closed sections, are a most useful source of information regarding the nontechnical aspects of turret development—that is, over-all policy on production, tactical use, etc. The Pentagon Library, AAF Section, may prove of great value in the future, but it is still too recently organized to be a fruitful source in turret materials.

The ATSC Central files at Wright Field contain many excellent files regarding aircraft armament policy, board reports, etc., but the materials on individual turret manufacturers are superficial as compared with the Wright Field Armament Laboratory files, where the most extensive source of turret development documents, especially with regard to technical aspects, is to be found. Unfortunately, the Armament Laboratory files are catalogued not by subject matter but by Expenditure Order. This system makes research exceedingly laborious because oftentimes a single Expenditure Order covers a multitude of developments and the trail of a single project cuts across the filing system.

The ATSC Contract files at Wright Field provide an excellent source of technical information in the specifications attached to contracts, but the contract correspondence files do little more than duplicate the materials in Central files.

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The ATSC Technical Data library's document collection proved exceptionally valuable for details on the evolution of aircraft armament from the first world war onward. The attaché reports in the document collection provided the only available accurate, detailed, technical study of foreign armament. Comparable files do exist, however, in Washington, in the files of the former OJAC Information Division (filed in the AAF Historical Office) and, for the period after 1939, in the files of the Air Intelligence Library.

There is almost no published literature of aircraft armament other than that of an extremely popular and superficial nature. Even the technical publications and aviation periodicals seldom treat the general topic of armament, and turrets have proportionally less emphasis. Quite obviously the restricted status of armament equipment discourages published articles, but there have been almost no nontechnical discussions. In view of the tremendous volume of material published about aircraft in general, it is surprising to discover the utter neglect of armament and armament policy articles.

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