United States Army

Aircraft Production Facts

COMPILED AT THE REQUEST OF THE ASSISTANT SECRETARY OF WAR

By

COL. G. W. MIXTER, A. S., A. P.

AND

LIEUT. H. H. EMMONS, U. S. N. R. F.

Of the Bureau of Aircraft Production

JANUARY, 1919

VICTORY CREED

> "*To foster individual talent, imagination, and initiative, to couple with this a high degree of cooperation, and to subject these to a not too minute direction; the whole vitalized by a supreme purpose which serves as the magic key to unlock the upper strata of the energies of men.*"
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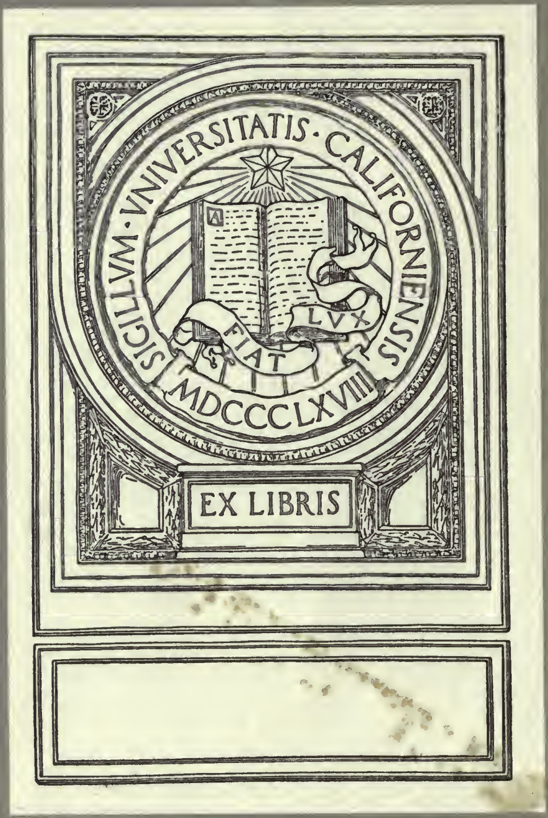
> —*Major General Squier.*

WASHINGTON
GOVERNMENT PRINTING OFFICE
1919



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THE SENTINEL OF THE SKY.

INTRODUCTION.

The Wright brothers, on December 17, 1903, at Kitty Hawk, N. C., made man's first successful sustained and directed flight in a heavier-than-air machine, driven by a gas engine. Wilbur Wright flew 852 feet in 59 seconds, and his four-cylinder gas engine generated 12 horsepower. Thus started the development of the enormous air activity to be later used in warfare.

To fully understand the position of the United States in aeronautics at the time of our declaration of war, one must realize how very little of the development had been carried on in this country; how relatively lacking we were in knowledge of aeronautics, and how completely and absolutely we lacked knowledge of the equipment of military airplanes.

The Army had done some flying at San Diego, using the flying field on North Island, which had been made available by the generosity of the Coronado Beach Co., who loaned the land to the Government, as no funds were available at that time for leasing property for flying fields.

The Air Service had had a struggling and meager existence, working with the old pusher type of planes, until, in 1914, an appropriation of $250,000 was made available for the purchase of airplanes and their equipment.

About this time five officers were sent to the Massachusetts Institute of Technology for a special course in aeronautics. These men constituted the entire technically trained personnel of the Air Service of the United States Army when war was declared in Europe in August, 1914. The total personnel, both military and civilian, numbered 194 men, with a minimum of equipment. At the time of signing the armistice the records showed a total of 195,024 men, to whom had been delivered during the war 16,952 airplanes.

The creation of this personnel, and their equipment, in all its infinite detail, was one of the great problems of the war. This pamphlet presents the story of the production of aircraft in nontechnical language as an aid to a better understanding of the past and future industrial problems of the Air Service.

Air Service, U. S. A., Personnel and Planes, in 1914, 1917, and 1918.

	Aug. 4, 1914.	Apr. 6, 1917.	Nov. 11, 1918.
Air Service officers	[1] 28	[1] 65	20,568
Enlisted and civilian personnel	[1] 166	[1] 1,330	174,456
Flying fields	1	2	48
Airplanes produced in the United States for the Army during the war	....	....	11,754
Airplanes produced by allies, principally in France, to date for the United States Army	....	....	5,198
Total airplanes produced for the United States Army	....	....	16,952

[1] In the Signal Corps.

NOTE.—The figures show total airplanes delivered to the United States Air Service, both at home and overseas. Figures showing the actual quantity of airplanes on hand to-day (January, 1919), can not be obtained, as no figures on losses are available. It is evident that the quantity on hand is materially less than the above figures because of crashes and usual wear and tear.

The best information available indicates that Germany entered the war with nearly 1,000 airplanes, France with about 300, and England with about 250.

To-day, it is almost impossible to realize the utter unpreparedness of the United States in April, 1917. Conditions in aviation at that time may be summarized as follows:

First. The Army had practically no material, personnel nor experience in the designing, producing, or using of aeronautical equipment. The books of the Signal Corps show that during eight years prior to 1916, 59 airplanes were ordered and received, while during 1916, 366 airplanes were ordered and only 83 received. In other words, the total number of airplanes that had been delivered to the Signal Corps prior to 1917 was 142. A large portion of these were already obsolete or destroyed. Not one of them was suitable for use on the battle front.

Second. The country had no accurate knowledge of the aeronautical requirements of modern war; no one knew the engine or plane requirements; no one knew the requirements for instruments, ordnance, and armament. Neither data nor experience existed in the United States from which this vital information could be obtained. No airplane made in America up to this time had mounted a machine gun or carried other than the simplest instruments. Radiotelegraphy and telephony, cameras, bombing equipment, night flying lights, aviators' clothing, suitable compasses, and other instruments were practically unheard of.

Third. Adequate manufacturing facilities for the production of aeronautical equipment of a war type did not exist in this country. Several companies and individuals had been producing very simple planes and engines of limited capacity in a small way. These operations had not passed the experimental stage and had not developed with rapidity, because there existed neither commercial demand nor adequate Government support. These planes and engines were not at all suitable for fighting purposes, although some of them were later adapted and used for training aviators. The 59 planes which were delivered during the eight years prior to 1917 had been supplied by four different makers, the largest number ordered from any one maker being 22.[1]

Fourth. There was no definite understanding as to how much aircraft equipment would be required for the use of the Army or Navy, and therefore no program to work to.

The initial step to meet the situation was taken in April, 1917, when Gen. Squier asked that experts in aeronautical matters be dispatched to the United States from England, France, and Italy. Shortly after this over 100 expert American mechanics were sent overseas to gain experience in European engine and airplane plants. On June 17, 1917, a special technical mission, headed by Col. Raynal C. Bolling, sailed for Europe with instructions to investigate and recommend types of airplane and other aeronautical equipment for production in the United States.

Such was the situation in June, 1917, when the tremendous demands for American-built planes were first laid down. No American-built plane had ever fought over the battlefields of Europe. The development of planes had gone on so rapidly that the machine which was best to-day might to-morrow be relegated to the scrap pile.

We will not enter here into the causes, some military, some civil, of this utter unpreparedness, but the outbreak of the war found the United States with but a handful of fliers and very few training planes. There was no aviation industry in this country, and the number of professional men trained as aeronautical engineers and designers was so small as to be practically negligible. In this respect the problem of developing the air program was unique. The United States had built ships before, had manufactured clothing, guns, munitions, built cantonments, etc., and had a splendid body of men trained in these professions and employments, but outside of a few men there

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[1] The general condition of the industry in the United States is further reflected by the status of Government orders on May 12, 1917. At that time the Government had outstanding orders for a total of 334 flying machines, including both airplanes for the Army and flying boats for the Navy. These orders were placed with 16 different manufacturers, six of whom had probably never built more than 10 machines apiece. These orders called for 10 distinct types of 32 different designs. The largest order placed with any one manufacturer was one for 126 machines of varied design given to the Curtiss Airplane & Motor Corporation. Most of the machines covered by these orders were never delivered, as the manufacturers generally requested release from their contracts.

was no one in the United States with experience in the design or building of even training planes.

After the United States actually entered the war, the pressure from our allies and a sudden realization of our real situation led Congress to grant large sums of money for aeronautics. The act of May 12, 1917, appropriated $10,800,000; the act of June 15, 1917, $43,450,000; and finally the appropriation of $640,000,000 was passed. The latter was the largest appropriation ever made by Congress for one specific purpose; it was put through the House of Representatives Military Affairs Committee in two sittings, the House itself in one, the Senate Military Affairs Committee in 45 minutes, and the Senate itself a week later, becoming a law on July 24, 1917, three months and a half after the outbreak of war.

The first indicated realization of the magnitude of the problem facing the United States is reflected in the program recommended by the Joint Army and Navy Technical Board about June 1, 1917. This called for practically 22,000 airplanes, to be completed by July 1, 1918, of which 10,000 were to be for training purposes, and 12,000 for fighting in France.[1]

With the knowledge then at hand even these figures did not convey a correct idea of the production required to meet this program. The infinite complications of fully equipped battle planes were little understood, neither was the fact fully realized that for each 100 airplanes an equivalent of 80 additional airplanes must be provided in spare parts. In fact, the program laid down in June, 1917, involved the production, not of 22,000 airplanes by July 1, 1918, but rather the equivalent of 40,000 airplanes. A consideration of these enormous requirements in comparison with the available industrial facilities of the country will convey some idea of the magnitude of the task presented to the officers charged with the execution of the air program.

To understand how the situation was handled, the following summary of the vital moves made in the early days of the war should be borne in mind.

1. In April, 1917, Gen. Squier asked that aeronautical experts be sent to the United States from overseas.
2. In May mechanics were sent overseas to learn the details of foreign practice.
3. The design of the Liberty motor was started in the last days of May.

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[1] The entire production of the country for the previous 12 months, consisting principally of training planes and training boats for foreign Governments, was less than 800. In January and February, 1917, it had been thought feasible to build 1,000 planes in a year; in March an annual production of 2,500 planes was discussed; in April it was proposed to build 3,700 planes in 12 months. These figures indicate the rapidity with which ideas changed during this period.

4. The Bolling mission sailed for Europe June, 1917.

5. In August the Signal Corps organized:

The Equipment Division—for the design and production of aeronautical material, including balloons.

The Construction Division—for the preparation and construction of training fields, etc.

The Air Division—for the training of aviators.

6. In August orders were placed in France for over 5,000 planes to cover the American Expeditionary Forces' requirements up to July 1, 1918.

The first problem was the choice of type and design of aeronautical equipment which should be adopted for manufacture in this country. Time was not available for the experimentation required to develop purely American planes. It was also obvious that an intelligent decision regarding types of European planes or engines which should be put into production could not well be made anywhere but in Europe. It was hopeless to attempt to weigh the arguments of different competing representatives of foreign companies.[1] The art was progressing so fast that studies of types of equipment would have to be made on the front by experts aided by the best counsel obtainable from each of the allied countries. The Bolling commission was, therefore, organized in May, 1917, to proceed to Europe primarily for the purpose of investigating aeronautical conditions and requirements among our allies, and of advising us as to the types of planes, engines, and other equipment which we should prepare to manufacture. The commission was instructed to investigate both industrial and military conditions with particular emphasis on the rapid development of requirements at the front. Being at such a distance from the scene of operations, it was clearly essential that developments should be anticipated whenever possible so that by the

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[1] Agents for the various European manufacturers swarmed through the offices of the Aircraft Board. Each of them could produce unanswerable demonstrations of the superior excellence of his article, but it soon developed that practically all of them called for the payment of very considerable royalties. The following tabulation, compiled by Col. S. D. Waldon, illustrates some of these proposals:

	Royalty asked per 1,000 units.
April 10, 1917:	
Short seaplanes	$675,000
Sopwith planes	500,000
Clerget engines	700,000
Sunbeam (including cost of engine and royalty)—	
200-horsepower engines	7,000,000
300-horsepower engines	8,000,000
Apr. 14, 1917: Caproni rights	2,000,000
May 8, 1917: Gnome engines	1,215.000
Clerget	821,250
May 19, 1917: Gnome 100-horsepower engines	500,000
Le Rhone, 80-horsepower engines	1,375,000
May 24, 1917: Handley Page rights	200,000
June 2, 1917: Le Rhone engines	600,000

time material could be put into production, transported overseas, and delivered to the front it would still be of a type which would be useful in service and not obsolete by reason of progress made meanwhile.

The commission sailed on June 17, 1917, under the leadership of Col. R. C. Bolling. It comprised two members from the Army, two from the Navy, and two from civilian life. The Army members were Captains Clark and Gorrell, both able aeronautical engineers, who had been in charge of the very small airplane engineering organization which existed at the beginning of the war as a part of the Signal Corps. The Navy members were Commander Westervelt and Lieut. Childs. The civilian members were Howard Marmon, one of the leading motor experts in the automobile industry and a highly trained all-around engineer, and Herbert Hughes, who was an automobile engineer associated with the Packard Motor Car Co.

The Equipment Division of the Signal Corps, charged with the design and production of all equipment for the Air Service was organized with the following initial personnel:

Edward A. Deeds, an engineer and successful manufacturer of Dayton, Ohio, chief of the division.

Harold H. Emmons, an attorney and manufacturer of Detroit, chief of engine production.

Leonard S. Horner, of the Acme Wire Co. of New Haven, chief of production of instruments and ordnance.

George W. Mixter, vice president and manager of manufacture of Deere & Co., who was placed in charge of inspection.

R. L. Montgomery, a banker of experience in Philadelphia and New York.

Harry L. Shepler, production manager of the Willys-Overland Co., chief of plane production.

Melville W. Thompson, an expert accountant and valuator, of New York City.

J. G. Vincent, vice president Packard Motor Car Co., chief of engine design.

Sidney D. Waldon, formerly vice president and general manager of the Packard Motor Car Co.; later associated with the Cadillac Motor Car Co.; and later in an independent consulting capacity as an automobile expert.

All were commissioned in the Army except Lieut. Emmons, who had for 12 years been an officer in the Naval Reserve and who was detailed by the Navy Department to this work.

In January, 1918, W. C. Potter, of the Guggenheim interests, became Chief of the Equipment Division. When the Air Service was separated from the Signal Corps in May, 1918, John D. Ryan, of the Anaconda Copper Co., was appointed Director of Aircraft Production and later an Assistant Secretary of War and Director of Air Service. Mr. Potter continued as first Assistant Director of the Bureau of Aircraft Production—A. A. Landon, of the American Radiator Co., assisting on production, and C. W. Nash, of the Nash Motors Co., in engineering.

Such were the conditions, the problems presented, and the initial steps taken to meet the situation. The detail of the production development on each class of equipment is presented in the following pages, but it is worthy of note here that at the time of the signing of the armistice there had been produced in the United States 642 kite balloons, 11,754 airplanes, and more than 30,000 aviation engines of more than 7,800,000 horsepower.

AVIATION ENGINES.

Extensive preparation is required for quantity production of engines according to American methods of manufacture; this preparation takes time and involves many varied and intricate engineering problems. These facts, which were recognized from the first, made it essential to select the types and sizes of engines at the earliest possible moment. It was necessary to await information from Europe before final decisions could be reached regarding planes, armament, and equipment, but the selection of engines could be made more promptly. The general problem was to select engines which would be of sufficient capacity and range to cover all requirements, which would comprise the smallest possible number of different types, and which would lend themselves to our methods of manufacture.

Aeronautical engines may be classified under two general heads as follows:

Engines required for training purposes.
Engines required for combat purposes.

It was necessary to proceed with the utmost expedition in the production of both types of equipment, but with the lack of knowledge as to requirements on the front and with the need for equipment for the immediate training of aviators, special attention was demanded by the training program. This, according to the best information, required engines for elementary or primary training and engines for advanced training. It was early determined that the number of types of planes and engines to be used for training purposes should be as limited as possible. Full consideration of the subject and consultations with such representatives of our allies as were available in this country developed a general desire to standardize, if possible, on one, or at the most two, types of equipment for each class of training. This policy would avoid delay both in training the aviator and in preparing him for his actual combat work and also the confusion inseparable from a large number of different types of equipment.

ELEMENTARY TRAINING ENGINES.

The Curtiss JN-4 plane equipped with the Curtiss OX 90-horsepower engine were the most available plane and engine in this country for primary training purposes. The capacity of the Curtiss plant was insufficient to produce the required number of these planes and engines. The production of planes at the Buffalo plant could be largely and rapidly increased, but the capacity for producing engines of the OX type, which were made only at Hammondsport, could not keep pace with the planes and at the same time complete existing orders which it had previously accepted from the English and Canadian aviation authorities. Therefore an additional contract for 5,000 of these engines was placed with the Willys-Morrow company at Elmira, N. Y.

Meanwhile the Air Division was developing its requirements very rapidly. No training equipment was in existence, but many training fields were being prepared and plans were being pushed forward calling for the early training of many thousand student aviators. The great difficulty connected with providing training planes and engines as fast as wanted was the fact that the program laid down for the establishment of new aviation schools and fields called for a very heavy initial equipment, followed by a comparatively low rate of wastage. In other words, during the first six to eight months, while many large schools would be going into operation, the curve of requirements increased rapidly, reaching its peak about January 1, 1918. Thereafter, with schools and fields completed and equipped, a modest production schedule would take care of their requirements for upkeep and wastage.

It was therefore essential to procure immediately an additional source of supply for elementary training equipment. The Standard Aero Corporation had, for approximately a year, been developing its Standard J plane and was prepared to proceed with its production. The Hall-Scott Co. had been, with the possible exception of the Curtiss Co., the largest producer of aviation engines in the country prior to midsummer of 1917. It had then actually in production a four-cylinder engine which, while it was known to have a certain amount of vibration common to any four-cylinder engine, was regarded as a rugged and reliable engine. It had been installed in planes made by the Standard Aero Corporation, the Aeromarine Co., and the Dayton-Wright Co. The Joint Army and Navy Technical Board therefore recommended, as the alternate elementary training equipment, the Standard J plane and the Hall-Scott four-cylinder A7A engine. Contracts were at once placed with the Hall-Scott Co. for 1,250 of these engines, and with the Nordyke & Marmon Co. for 1,000 of them; arrangements were also made with the Hall-Scott Co. for assistance in furnishing drawings, tools, etc., to the other manufacturers.

ADVANCED TRAINING ENGINES.

Advanced training called for two types of engine:

First. A rotary engine which would train the student for work in the small speedy fighting planes.

Second. A fixed cylinder engine having upward of 100 horsepower.

ROTARY ENGINE.

To meet the rotary engine requirements there were available the Gnome 110-horsepower engine, which was being built in small quantities by the General Vehicle Co. for delivery on a foreign order, the 150-horsepower Gnome engine, recommended as part of our combat program, and the Le Rhone 80-horsepower engine. The two latter engines had been developed and used in France, but neither had been built at all in this country. The first recommendations received from our aviation representatives in Europe advised the production of 5,000 Gnome 150-horsepower and 2,500 Le Rhone 80-horsepower engines.

The production of 5,000 large Gnome engines was entirely beyond the capacity of the General Vehicle Co., and therefore negotiations were entered into with the General Motors Co. to take this contract. After many weeks of negotiations the General Motors Co. and the General Vehicle Co. agreed to combine, the former bringing to the work its vast resources and numerous factories, while the latter contributed its skilled knowledge and experience in the production of rotary engines. Just at this point cable instructions were received recommending that preparations to produce this engine be discontinued. This instruction was followed and thereafter the General Vehicle Co. was called upon to produce as many of the 110-horsepower Gnome engines as it could with its existing equipment.

Meanwhile the Union Switch & Signal Co., of Swissvale, Pa. (one of the Westinghouse Airbrake chain of factories), had been induced to undertake the manufacture of 2,500 Le Rhone 80-horsepower engines. A sample engine was received from Europe during the first week in September. It, however, was not accompanied with complete or reliable drawings, specifications, and metallurgical instructions. For example, the French specifications called for a crank shaft made from mild steel. It was apparent that this was incorrect, and in fact it was necessary to analyze every piece of the engine to determine the proper material. The drawings had to be carefully checked and corrected, a proceeding which required several months of intensive work on the part of a large corps of draftsmen and engineers. Finally it was necessary to prepare detail drawings; this was done under the direction of Lieut. Col. E. J. Hall and Lieut. F. M. Hawley. During this time the Union Switch & Signal Co. had been procuring its machinery, tools, and equipment. The services of M. Georges Guillot, the French engineer of the Gnome-Le Rhone factories, were procured from France, and he was assigned to the plant of the Union Switch & Signal Co. This company turned out its first production engines in May, 1918, and has now substantially completed its contract. The engines which it has produced have been certified by M. Guillot as being the best constructed rotary engines which have ever been built.

FIXED CYLINDER ENGINE.

A fixed cylinder type of engine suitable for advanced training was already being built in this country for France. This was the 150-horsepower Hispano-Suiza. During the early years of the war it had been one of the most popular engines for both combat and training in England and its dependability had been thoroughly proved. Early in 1916, this engine had been brought to this country and after 13 months of work, the Wright-Martin Aircraft Corporation had actually begun to produce it. By 1917, combat planes were using more powerful engines and the service demand for the Hispano-150 decreased. This engine, however, could be readily installed in the Curtiss JN type of plane, making a combination which became most useful for instruction in bombing, photography, etc.

Contracts for several thousand of these engines were placed with the Wright-Martin Aircraft Corporation and provision was made for increasing its manufacturing facilities to take care of this production.

There had been manufactured in this country a few engines of other types, such as the Curtiss OXX and V type engines, a few of which were used by the Navy, but which were not regarded as first-class engines by either the British or the Signal Corps. Also the Sturtevant Co., had built a small number of 135-horsepower engines and the Thomas Brothers at Ithaca had built a few engines of the Sturtevant type which they claimed to be an improved engine having substantially the same horsepower. Both of these engines were considered to be too low in horsepower to endure for any considerable period of manufacture; they were also too heavy per horsepower. This opinion, held in the United States, was confirmed on July 11, 1917, by cable No. 37, paragraph 7, signed "Pershing," which said: "We consider no need whatever Thomas-Sturtevant 8 cylinder."

The American training program was, therefore, built around the following engines: Curtiss OX-5, Hall-Scott A7A, Hispano-Suiza 150-horsepower, fixed cylinder engines and Gnome and Le Rhone rotaries. The quality of this training equipment may be gauged somewhat by the results obtained from it on the United States training fields. The statistics show that from September 1, 1917, to December 19, 1918, 13,250 cadets and 9,075 students were sent to 27 fields for advanced training. They flew 888,405 hours and suffered 304 fatalities, or an average of 2,922.38 flying hours per fatality. At one field 19,484 flying hours, at another 20,269 flying hours, and at another 30,982 flying hours resulted in but one casualty each. The best unofficial figures obtainable show that the British averaged one fatality for each 1,000 flying hours, the French one for each 900 flying hours, and the Italians one for each 700 flying hours. These figures, however, probably reflect the result of more intense advanced training than do the American figures.

On November 29, 1918, there had been produced and delivered into service 16,286 training engines.

COMBAT ENGINES.

During the time that the production of engines for training was getting under way, careful thought was given to the possibilities of producing combat engines quickly in the United States. An analysis of the situation in May 1917, reflects the following facts:

> *First.* The Joint Army and Navy Technical Board, together with the Aircraft Board, were about to recommend a program calling for the production of 12,000 combat planes for delivery in France by July, 1918.
>
> *Second.* Much time would necessarily elapse before the Bolling Commission could make its report and send back sample engines with drawings and other data required by American manufacturers. Experience in this country with the Gnome and Hispano-Suiza engines also indicated that foreign drawings and specifications would have to be completely revised and remade before any production could start here. This conviction was subsequently verified by the experience with the Le Rhone and Bugatti engines.
>
> *Third.* Engines of increasing horsepower were being demanded at the front; this indicated the early abandonment of sizes and types of engines previously in favor. In fact, up to May, 1917, there was not among the Allies any well-proved engine (with the possible exception of the Rolls-Royce engine, see page 27) of a horsepower sufficiently large to insure its popularity and suit-

ability for two years.[1] American experience with large-scale production of automobile engines had shown that two years would be required to tool up for and to obtain a year's output of a given engine.

Fourth. At that time England was manufacturing or experimenting with 37 different kinds of engines and France with 46. It seemed wise, if possible, for the United States to avoid a similar situation, with its exacting requirements for innumerable repair parts—a situation which would be complicated still further by long distance from the scene of war.

Fifth. There were in the United States extensive facilities for the production of the simpler forms of internal-combustion engine, such as those used in automobiles. American engineers and manufacturers had had wide experience in designing such engines and in producing them in quantity. American engineering talent and ingenuity and knowledge of design was at least equal to that abroad.

Sixth. It was apparent that prompt action was necessary to meet the enormous requirements for engines and spares demanded by the contemplated program. It was also clear that these requirements could not be met unless the automobile-engine industry could be mobilized for that purpose; furthermore, even with the talented organizations and experience of this industry, there was little chance of completing the task unless their efforts could be concentrated on one type of standardized engine designed especially to suit American quantity-production methods.

DESIGNING THE LIBERTY ENGINE.

With the foregoing facts in mind and after many preliminary investigations, Col. Deeds came to the conclusion that it was essential for the United States to concentrate its energies upon the smallest possible number of types of engines and to give special attention to equipment which could be manufactured in quantity, and which would be least affected by the rapid advances in the art.

He considered it entirely possible to design and build an engine suitable for war purposes and adapted to American ideas of quantity production in less time than the Bolling Commission could complete its investigations and negotiations and send us drawings and models of European types that in all probability would be wholly

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[1] This point is further illustrated by the following: In May, 1917, every foreign representative with aeronautical experience, in Washington, agreed that an 8-cylinder, 225-horsepower engine was the right one for the United States to develop for the spring of 1918. Inside of 90 days, it was equally clear and all were equally unanimous that a 12-cylinder, 330-horsepower engine was required.

unsuited to our production methods. He believed that the United States should concentrate its greatest effort on a type of aircraft engine which could be made in powers sufficiently high to assure continued usefulness for a term of years and which would possess the maximum degree of interchangeability between similar parts. Col. Deeds proposed this plan immediately to his associate, Col. S. D. Waldon, who, after giving it careful consideration, agreed entirely with the plan. A few days later J. G. Vincent, of the Packard Motor Car Co., arrived in Washington and proposed substantially the same idea, which had been developed as the result of his experience with aircraft engines, and which had been crystallized by conferences which he had held in Detroit with the French and English commissions which were then touring the United States.

As subsequent investigation proceeded this conclusion received the unanimous support of both the American and European authorities and its wisdom has been absolutely demonstrated by the results which have been attained.

The line of engines finally decided upon was of 4, 6, 8, and 12 cylinders, respectively, all having a bore of 5 inches and a stroke of 7 inches. The 8-cylinder engine rated at 225 horsepower was the one believed to anticipate the requirements for power as of the spring of 1918, and the 12-cylinder rated at 330 horsepower was considered as anticipating the development through 1919 and 1920.

Col. Deeds, Col. Waldon, and Messrs. E. J. Hall and J. G. Vincent[1] met at Col. Deeds's apartment in the New Willard Hotel in Washington and considered in a general way the requirements which this American line of engines must meet. It was determined that they should be built around a 5 by 7 inch individual steel cylinder with aluminum piston, forked rods, and direct-drive propeller, and

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[1] The following notes about Messrs. Vincent and Hall showing their previous experience and training are of general interest:

J. G. Vincent, of the engineering staff of the Packard Motor Car Co., had been engaged in research work for approximately two years, developing several types of 12-cylinder aviation engines, ranging from 125 to 225 horsepower, which, however, were not suitable for military purposes because of their weight per horsepower. This work had resulted in the acquirement of a large amount of data and information which was invaluable in the design of such an engine as the one proposed, and also had resulted in the upbuilding of an efficient experimental organization. He had also had wide experience in designing internal-combustion engines for quantity production.

E. J. Hall, of the Hall-Scott Motor Car Co., for eight years had been developing and latterly producing several types of aeronautical engines, which had been delivered for service to the Governments of Russia, Norway, China, Japan, Australia, Canada, and England. He had also completed and tested a 12-cylinder engine of 300 horsepower, which, however, was of too great weight per horsepower to be suitable for military purposes. He had thus acquired a wide general experience and a knowledge of quantity production; he also possessed a fund of information covering the proper sizes and materials for engine parts, and the proper methods of testing engines. All of this information and experience proved to be of invaluable assistance not only in designing the new engine, but in determining its essential metallurgical and manufacturing specifications.

that nothing experimental or untried should be used. The size 5 by 7 inches was adopted because the Curtiss Aeroplane & Motor Corporation and the Hall-Scott Motor Car Co. had had experience with engines of this size, and also because Maj. Tulasne, of the French mission, ascertained by cable that the new Lorraine-Dietrich, then the most promising French experimental engine, approximated that size.

Messrs. Vincent and Hall set to work on May 29 to combine their knowledge and information, and within two or three days they had outlined the important characteristics of design of the Liberty engine. These preliminary layouts were submitted to the Aircraft Production Board and the Joint Army and Navy Technical Board, who approved the design and on June 4 authorized the construction of five each of the 8 and 12 cylinder sizes.

Detail and manufacturing drawings were begun immediately; this work was done partly by the staff of the Packard Motor Car Co., under Mr. O. E. Hunt, and partly by an organization recruited from various automobile factories and working at the Bureau of Standards under Mr. Vincent. Parts for 10 engines were at once started through the tool rooms and experimental shops of various motor car companies. This work centered in the plant of the Packard Motor Car Co., which most cheerfully and patriotically gave to this work its entire energies and wonderful facilities.

Every feature in the design of these engines was based on thoroughly proven internal-combustion engine practice. The following were some of the features incorporated:

Cylinders.—The design of the cylinders for the Liberty engine followed the practice used in the German Mercedes, English Rolls-Royce, French Lorraine-Dietrich, and others, both before and during the war. The cylinders were made of steel inner shells surrounded by pressed-steel water jackets. The Packard Motor Car Co., by long experiment had developed a practical production method of welding together the several parts of a steel cylinder.

Cam Shaft and Valve Mechanism Above Cylinder Heads.—The design of the above was based on the general arrangement of the Mercedes and Rolls-Royce, but had been improved for automatic lubrication without wasting oil by the Packard Motor Car Co.

Cam-shaft Drive.—The cam-shaft drive was the same general type as used on the Hall-Scott, Mercedes, Hispano-Suiza, Rolls-Royce, Renault, Fiat, and others.

Angle Between Cylinders.—In the Liberty the included angle between the cylinders is 45°. This angle was adopted to save head resistance, to give the crank case greater strength, and to reduce periodic vibration. This decision was based on the experience of the Renault and Packard engines with approximately the same angle.

Electric Generator and Ignition.—The Delco system of ignition, which had been successfully used on hundreds of thousands of internal-combustion engines, was adopted, a special design being produced for the Liberty engine to provide a reliable double ignition.

Pistons.—The die-cast aluminum alloy pistons of the Liberty engine were based upon extensive research and development work by the Hall-Scott Co. under service conditions.

Connecting Rods.—The well-known forked or straddle-type connecting rods as used on the De Dion and Cadillac cars, and also on the Hispano-Suiza and other aviation engines, were adopted.

Crank Shaft.—The crank shaft design followed the standard practice for large-bore engines, every crank pin operating between two main bearings as in the Mercedes, Rolls-Royce, Hall-Scott, Curtiss, and Renault engines.

Crank Case.—The crank case followed the design of the Mercedes and Hispano-Suiza, in which the crank case is a box section carrying the shaft in bearings clamped between the top and bottom halves by means of long through bolts.

Lubrication.—The original system of lubrication combined the features of a dry crank case, such as in the Rolls-Royce, with pressure feed to the main crank-shaft bearings, and scupper feed to crank-pin bearings, as in the Hall-Scott and in some foreign engines. This was subsequently changed to add pressure feed to crank-pin bearings, as in the Rolls-Royee and Hispano-Suiza engines.

Propeller Hub.—The propeller hub design followed that used on such well-known engines as the Hispano-Suiza and Mercedes.

Water Pump.—The conventional centrifugal type of water pump was adapted to the Liberty.

Carbureter.—The Zenith type of carbureter was adapted for use on the Liberty engine.

The parts for the first engine were made in various plants as follows:

> The General Aluminum & Brass Manufacturing Co., of Detroit made the bronze-back, babbit-lined bearings.
>
> The Cadillac Motor Car Co., of Detroit, made the connecting rods, connecting-rod upper-end bushings, connecting-rod bolts, and rocker-arm assemblies.
>
> The L. O. Gordon Manufacturing Co., of Muskegon, made the cam shafts.
>
> The Park Drop Forge Co., of Cleveland, made the crank-shaft forgings. These forgings, completely heat treated, were pro-

duced in three days; this quick work was made possible by Mr. Hall, who furnished dies which he had on hand.

The crank shafts were machined at the Packard factory.

The Hall-Scott Motor Car Co., of Berkeley, Calif., made all the bevel gears.

The Hess-Bright Manufacturing Co., of Philadelphia, made the ball bearings.

The Burd High Compression Ring Co., of Rockford, Ill., made the piston rings.

The Aluminum Castings Co., of Cleveland, made the die-cast alloy pistons, and machined them up to grinding.

The Rich Tool Co., of Chicago, made the valves.

The Gibson Co., of Muskegon, made the springs.

The Packard Co. made all the patterns, and the aluminum castings were made by the General Aluminum & Brass Manufacturing Co.

The Packard Co. used many of its own dies in order to speedily obtain suitable drop forgings, and also made new dies.

The Packard Co., produced all the other parts and did the assembling and testing.

Meanwhile the plans of the engine had been submitted to H. M. Crane, engineer of the Simplex Motor Car Co., and of the Wright-Martin Aircraft Corporation, who had made a special study of aviation engines in Europe, and who for upward of a year had been working on the production of the Hispano-Suiza 150-horsepower engine; also to David Fergusson, chief engineer of the Pierce-Arrow Motor Car Co., and to many of the best experts in the country on the production of motors, including Henry M. Leland and George H. Layng, of the Cadillac Motor Car Co., and F. F. Beall and Edward Roberts, of the Packard Motor Car Co. Representatives of many other companies, including plane and engine makers, machine tool builders, etc., were called in; these men went over the drawings thoroughly and were consulted on many production features of the engine.

From the foregoing statements it is clear that the Liberty engine was not developed by any species of magic nor by any single individual or company, but was a well-considered and carefully prepared design based on much practical aviation engine experience. The promptness with which the design was completed and the samples built was the result of complete cooperation between all interested parties.

This engine so designed proved in actual operation to satisfy the controlling requirements of the highest type of aviation engine. These requirements, roughly speaking, are as follows:

(*a*) Maximum power and efficiency combined with minimum weight. The average automobile motor weighs from 6 to 10 pounds per horsepower; an aviation engine should weigh not more than 2 pounds per horsepower.

(*b*) Ability to run at practically maximum power and speed during a large percentage of operating time. An automobile motor, except in racing, rarely runs at its maximum power or speed for more than a few moments at any one period.

(*c*) Reasonably low consumption of fuel and oil. This is necessary to conserve space and weight in the plane.

Very early in the Liberty engine program it became apparent that one of the great stumbling blocks to volume production would be the steel cylinder if it were necessary to machine it out of a solid or partially pierced forging, as is done in making shells. Col. Deeds and Col. Waldon laid this problem before Henry Ford and the engineering organization of the Ford Motor Co. and they developed a unique method of making the cylinders out of a piece of steel tubing. One end of the tube was cut obliquely, heated, closed over, and then expanded into the shape of the combustion chamber and with all bosses in place on the dome. The lower end was then heated and upset in a bulldozer until the holding-down flange had been extruded from the barrel at the right place. By this method a production of 2,000 rough cylinders per day was reached and the final forging was very nearly the shape desired. The development of this cylinder-making method was one of the important contributions to the quantity production of Liberty engines; it saved much labor and millions of pounds of scrap.

Fundamentals of the design of the Liberty engine have not been altered from the date of its original layout, with the single exception of the scupper feed system for lubricating the crank pins which was abandoned in favor of the full pressure feed system of lubrication. Numerous manufacturing changes in materials, limits, clearances, etc., have been made to facilitate production, exactly as such changes are made in the production of any piece of machinery. As time went on it became necessary to increase the horsepower of the 12-cylinder engine from 330 to 375 and later from 375 to 440. These increases made it necessary to increase the size and strength of certain parts of the engine.

By the method outlined above the first 8-cylinder engine was delivered in Washington and set up at the Bureau of Standards on July 4, 1917, and the first 12-cylinder engine was built and successfully passed a 50-hour endurance test by August 25, 1917.

PRODUCTION OF LIBERTY ENGINES.

At first it was believed that both 8 and 12 cylinder engines would be required and negotiations were started looking to the production of both sizes. The Ford Motor Co. agreed to produce 10,000 of the 8-cylinder engines, but before the contract had been made information from abroad indicated that efforts should be concentrated on the 12-cylinder engine. Contracts were therefore let for 22,500 Liberty 12-cylinder engines as follows:

Packard Motor Car Co	6, 000
Lincoln Motor Co	6, 000
Ford Motor Co	5, 000
Nordyke & Marmon	3, 000
General Motors Corporation (Buick-Cadillac)	2, 000
Trego Motors Corporation	500

This number was sufficient to take care of the requirements of both the Navy and the Army. The first of these contracts was signed in August, 1917, and production work started immediately. It was at once apparent that, to avoid delay and confusion, the engineering and standardization required for developing and maufacturing the engine must necessarily be done in close proximity to the production plants. A district office was therefore established in Detroit, and James G. Heaslet, formerly vice president and general manager of the Studebaker corporation, an engineer and manufacturer of wide experience, was appointed district manager. At the request of the Chief of the Engine Production Department an order was issued in October, 1917, which placed all engineering, inspection, and production of the Liberty engine in charge of a committee of engineers and manufacturers composed of Lieut. Col. E. J. Hall, Maj. James G. Heaslet, Henry M. Leland, C. Harold Wills of the Ford Motor Co., and Messrs. Beall and Roberts of the Packard Motor Car Co. With them were associated D. McCall White, engineer of the Cadillac Motor Co., and Walter Chrysler, general manager of the Buick Co. Presided over by Maj. Heaslet, these men in their respective plants and in joint meetings pushed forward the development and production of Liberty engines. Each without reservation revealed all the trade secrets and processes which they had developed in their plants during the preceding years. The Packard Motor Car Co. gave to this developmental work all of its equipment and personnel. The wonderful organization of the Ford Motor Co. was devoted to solving the problems presented by the production of this engine. The unique method of making a rough cylinder from a piece of steel tubing, also a new method of making durable and satisfactory bearings, were among the extraordinary results of the work of the Ford Motor Co., and its highly skilled organization.

Difficulties which ordinarily would have been well-nigh insuperable, or which at least would have prevented rapid progress, were immediately encountered; for example:

> The existing motor-building plants had practically no machinery of sufficient size to handle the parts of the Liberty engine; it was therefore necessary to build and frequently to design the machine tools for this purpose.
>
> Between 2,500 and 3,000 small jigs, tools, and fixtures are required to produce all the parts of a Liberty engine. For large outputs much of this equipment must be duplicated many times. This made it necessary to requisition practically the total capacity of all the tool shops east of the Mississippi.
>
> It soon developed that men who were able to make the comparatively simple automobile motors did not have the skill required to machine the parts of a Liberty engine; it therefore became necessary to educate thousands of men and women to do this work.
>
> A large amount of unfriendly influence was encountered, a considerable portion of which was doubtless pro-German. This was manifested in the tool shops, where many of the tools made for this work were found to be incorrect and had to be remade before they could be used in the engine-building plants. In the engine-building plants tools mysteriously disappeared or became injured, cans of powder were found in the coal, fire-extinguishing apparatus was plugged up, and numerous other treasonable acts were committed.
>
> As rapidly as skilled men were developed they were requisitioned by nearly every department of the Government. The draft took a great many men, and their return was either impossible or was secured only after great delay.
>
> The materials required for the engines were frequently of a much higher grade than the corresponding materials in automobile motors and much patient work was required to secure their production.
>
> The procurement of necessary transportation and fuel during the winter of 1917–18 presented difficulties which at times were almost insurmountable.

Notwithstanding the difficulties encountered, production actually started with the delivery of 22 engines during December, 1917.

The Liberty engine as originally manufactured was of approximately 330 horsepower. Information received from overseas led to the conclusion that a higher horsepower would be desirable. Therefore, after about 300 of these engines were in production, the engineers stepped up the horsepower to 375. Under the additional stresses induced, certain parts of the engine, particularly the crank shaft, required strengthening. This was done and several hundred engines were delivered at this horsepower. Then final and definite information arrived from abroad to the effect that if an engine of 400 horsepower or more could be produced, the United States would lead the combatant nations in size and power of engine during 1918 and 1919. The engine was therefore stepped up by the engineers to 440 horsepower. This enormous increase in power necessarily required an increase in strength of practically all the working parts of the engine. This required changes in a very large percentage of the jigs, tools, and equipment used in manufacture. It also required certain metallurgical changes in some of the parts, which in turn involved the development of new and better methods of producing steel for them. These changes in equipment were required in the engine plants, the parts plants, and the forging shops; in like manner they affected all manufacturers throughout the production line, including the producers of the raw metal.

These changes were made with such speed and energy that by May 29, 1918, one year from the date when the design of the engine was begun, 1,243 Liberty engines had been produced and delivered for service.

The magnitude of this accomplishment may be realized when it is compared with the development of automobile motors. Practically no automobile motor of any size or importance has ever been put into production and into service without at least one year being devoted to its design and development. This time was not required for the Liberty engine, because its original design required substantially no change and also because the best ability in the country was devoted without stint to its development and production.[1]

Much incorrect and misleading comment has been published to the effect that many changes were made in the engine.

The changes arranged themselves in three groups:

1. Design.
2. Increase of power.
3. Manufacturing limits.

Design.—There was but one fundamental change in design in this engine after it was laid out in May, 1917. This was to change the oil system from the so-called scupper feed to a pressure feed. Either system worked properly on the engine, but the

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[1] The following extract from the report of the British war cabinet for 1917 is interesting in this connection: "Experience shows that, as a rule, from the date of the conception and design of an aero engine to the delivery of the first engine in series by the manufacturer more than a year elapses."

latter system is foolproof while the former is not. The latter system was therefore substituted.

Increase of power.—The changes due to increasing the horsepower twice are covered above. They were made solely to meet the demands of American and foreign aviation authorities.

Manufacturing limits.—As the engine was used in service and as the manufacturing progressed, it became evident that some of the limits might be changed, and these changes were made. This is common practice in all manufacturing establishments. It has always been so on automobile motors and will always be so on any manufactured product. As manufacturing processes are developed and as experience is gained, changes in limits are always expected and are always made, both to expedite production and to improve quality.

During six months, from May 29 to November 29, 1918, the production of Liberty engines increased by leaps and bounds; during October, just preceding the armistice, 150 12-cylinder engines were being produced and delivered into service on each working day. The record of monthly deliveries of these engines is as follows:

December, 1917	22
January, 1918	39
February	70
March	122
April	415
May	620
June	1,102
July	1,589
August	2,297
September	2,362
October	3,878
November 1–29	3,056
Total	15,572

These engines were distributed as follows:

American Navy	3,742
Plants manufacturing airplanes	5,323
Aviation fields for training purposes	907
American Expeditionary Forces in France in addition to those which went over installed in planes	4,511
Allies—England, France, and Italy	1,089
Total	15,572

In January, 1918, three of these engines were shipped to the American Expeditionary Forces. In March, 10 engines were shipped to the British, 6 to the French, and 5 to the Italians. By June 7 tests abroad had proceeded so far that the British air minister cabled to

Lord Reading that the excellent results obtained from the Liberty engine had placed it in the first class of high-powered engines, and that they were convinced that it would be a most valuable contribution to the allied aviation program. On September 26 the British air ministry reported that the Liberty performed at least as well as the Rolls-Royce, in identical airplanes, and that their opinion of June was fully confirmed.

Birkight, the designer of the Hispano-Suiza engine in France, advised Count Poinatowski that the Liberty engine was superior to any high-powered engine then developed on the Continent.

The British placed an order for 1,000 Liberty 12-cylinder engines and subsequently stated their desire to increase this to 5,500, to be delivered by December 31, 1918. The French made inquiry as to the possibility of their securing 20 per cent of all of these engines produced. The Italians also indicated their desire to purchase a large number for immediate delivery.

The original program of 22,500 engines was designed only to take care of the requirements of the American Army and Navy, and rendered impossible the delivery of any such quantities to our allies. Orders for engines were, however, immediately increased with all the existing Liberty engine builders; arrangements were made to utilize the manufacturing facilities of the Willys-Overland Co. at its plants in Toledo and Elyria, Ohio, and Elmira, N. Y., and the entire productive capacity of the Olds Motor Works at Lansing, Mich., was also contracted for. About this time plans were developed for the production of several small fast planes which required a smaller engine than the Liberty-12. Eight thousand 8-cylinder Liberty engines were therefore included in the contracts mentioned above. The total number of Liberty engines contracted for was 59,100.

The English, French, and Italians promptly arranged their plans for the installation of the Liberty engine. When Mr. Ryan was abroad in September, 1918, he verbally arranged for the delivery to the French of 1,500 engines by December 31, and 750 per month during the first six months of 1919. He also arranged for the delivery of several thousand additional engines to the English during the early part of 1919; the British Government requested a supply of 1,000 engines per month.

The vision of Col. Deeds and the decision to develop an American aviation engine has been fully and completely justified by the results obtained. The engine which approaches nearest to the Liberty in power and efficiency is the English Rolls-Royce. However, this weighs approximately 100 pounds more and delivers approximately 100 horsepower less than the Liberty. The maximum production of the Rolls-Royce engine in England has never exceeded 70 per week; the average production has ranged from 40 to 45 per week.

OTHER COMBAT ENGINES.

ROLLS-ROYCE.

During the spring and early summer of 1917 consideration was given to the production of the Rolls-Royce engines in this country. One of the principal objections to this plan was the extremely complicated nature of the Rolls-Royce as compared with the Liberty. Other difficulties connected with the negotiations for the production of this engine have been recorded by Col. Waldon as follows:

> "Arrangements had been made through Lord Northcliffe to have Claude Johnson, managing director of the Rolls-Royce Co., come to the United States with competent assistance, samples, drawings, etc., and prepare to arrange to manufacture in this country. When Claude Johnson first arrived it was recommended that we make arrangements with the Pierce-Arrow Motor Car Co. to build his engine, but Mr. Johnson preferred not to have anything to do with a company, which, after the war, might derive any commercial benefit from an association with Rolls-Royce production. He insisted upon the United States Government securing and turning over to him a factory fully equipped in accordance with his ideas and those of his assistants, in a labor market that would meet their approval, and within what he considered a suitable radius, so far as transportation of raw materials was concerned, from Pittsburgh.
>
> Numerous factories were suggested and investigated. Those that were satisfactory to the Signal Corps were not satisfactory to Mr. Johnson; and those which met his approval were not approved of by the Signal Corps. There was also difficulty in determining the features of a contract which would be acceptable to both parties, providing the matter of facilities could be arranged. Weeks dragged along into months and the Liberty engine was designed, built experimentally, and tests made, with still no settlement having been reached with Mr. Johnson. The success of these tests and the comparison of possibilities of output as between the very limited number of Rolls-Royce and the large number of Liberties that might reasonably be expected within 12 months, tended to make the Aircraft Production Board much less anxious to obligate a large part of their appropriations for the Rolls-Royce engines and the facilities for making them.
>
> Another factor in reaching a decision against the Rolls-Royce was the fact that the type of motor upon which Mr. Johnson wanted to start manufacture was what is known as the 190, developing about 250 to 270 horsepower. On this type of motor he agreed to bring over to this country a complete set of jigs and fixtures, and, according to his schedule, to deliver something like 500 engines before the end of the fiscal year, July 1, 1918. During these negotiations the need for increased horsepower became apparent and the negotiations were changed to the 270-horsepower Rolls-Royce, but for this engine jigs and fixtures would have to be made new in this country and the schedule of deliveries reduced correspondingly."

These were the reasons why the Rolls-Royce engine was not built in the United States.

BUGATTI.

The Bolling mission early considered the Bugatti engine, which was a new French design. It was a 16-cylinder engine, weighing approximately 1,100 pounds, and it was asserted that it would develop 510 horsepower. Col. Bolling and Maj. Gorrell purchased the first of these engines which had been built in France and sent it to the United States with a very strong recommendation that it be put into production immediately, and that it be pushed as energetically as the Liberty. Work on the Liberty engine by the Duesenberg Motor Corporation, of Elizabeth, N. J., was immediately stopped and this plant was prepared for the production of the Bugatti engine. Arrangements were also made for the manufacture of parts of the Bugatti engine at the Fiat plant, Schenectady, N. Y., and at the plants of the Herschell-Spillman Co., North Tonawanda, N. Y., and other concerns in the same region. When the engine arrived, accompanied by several French mechanics and engineers, it was not in condition to run. During its test in France a soldier had been struck by the propeller and the crank shaft bent. Furthermore, it was immediately admitted that the design and development of the engine had not been thoroughly completed, and that a great deal of work would be required on it. For example, the oiling system needed a complete readjustment. Mr. Charles B. King, one of the Government engineers, was immediately assigned to this work. After months of effort the engine was redesigned so that it successfully passed a 50-hour endurance test and was just getting into production when the armistice was declared. It is probable, however, that only a comparatively small number of these engines would have been produced even if the war had continued.

HISPANO-SUIZA 220 HORSEPOWER AND 300 HORSEPOWER.

During 1917 advices were received from France to build the Hispano-Suiza geared engine of 220 horsepower, and the Wright-Martin Aircraft Corporation immediately arranged for its production. After preparations had progressed for a considerable period of time the American representatives in France reported that this engine was not successful and advised that work upon it should be discontinued, principally because of trouble with the gearing.

During the summer of 1918 it became apparent that the existing contracts for engines could not meet the American and foreign demands quickly; it also became apparent that an engine of 300 horsepower could be used advantageously on small planes. Contracts were therefore placed for the production of ten thousand 300-horsepower Hispano-Suiza engines. Five thousand of these were ordered from the Wright-Martin Aircraft Corporation, who immediately leased the Government-owned plant in Long Island City, formerly known as the General Vehicle Co. Contracts for the remaining 5,000 were placed with the Pierce-Arrow Motor Car Co., of Buffalo. To assist these companies in getting into rapid production, practically the entire manufacturing facilities of the H. H. Franklin Co., of Syracuse, N. Y., were placed under contract. Production on these engines was expected to begin in January, 1919, but was stopped by the armistice.

SUMMARY OF ENGINE PRODUCTION IN THE UNITED STATES.

Prior to the declaration of the armistice, contracts had been placed for the following engines:

OX-5	9, 450
A7A	2, 250
Gnome	342
Le Rhone	3, 900
Lawrance	451
Hispano-Suiza:	
150 horsepower	4, 500
180 horsepower	4, 000
300 horsepower	10, 000
Bugatti	2, 000
Liberty 12	56, 100
Liberty 8	8, 000
Total	100, 993

From August, 1917, when the Equipment Division of the Signal Corps was established, to November 29, 1918, the following engines had been produced and delivered into service:

July, 1917	66
August	139
September	190
October	276
November	638
December	595
January, 1918	705
February	1, 004
March	1, 686
April	2, 214
May	2, 517
June	2, 604
July	3, 151
August	3, 625
September	3, 802
October	5, 297
November 1-29	3, 911
Total	32, 420

This production was divided between different types of engines as follows:

OX-5	8,458
Hispano-Suiza	4,100
Le Rhone	1,298
Lawrance	451
Gnome	280
A7A	2,250
Bugatti	11
Liberty	15,572
Total	32,420

All together contracts were placed for 100,993 engines, of which about one-third were completed. The total cost of all the engines ordered, together with their spares, would have been about $450,000,000.

The combined horsepower of the engines produced was approximately 7,800,000, of which the Liberty engines accounted for somewhat over 6,000,000 horsepower.

The distribution of the engines produced was as follows:

Type.	Plants manufacturing airplanes.[1]	American Expeditionary Forces.	Navy.	Allies.	Aviation fields.	Total.
Training engines:						
OX-5	4,325				4,133	8,458
A7A	1,599			1	650	2,250
Gnome	182				98	280
Le Rhone	620	325			353	1,298
Lawrance	301				150	451
Hispano-Suiza	2,042		515		992	3,549
Total	9,069	325	515	1	6,376	16,286
Combat engines:						
Liberty	5,323	4,511	3,742	1,089	907	15,572
Hispano-Suiza E	4	515	1		23	543
Hispano-Suiza H				1	7	8
Bugatti		4	3		4	11
Total	5,327	5,030	3,746	1,090	941	16,134
Grand total	14,396	5,355	4,261	1,091	7,317	32,420

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[1] The engines delivered to airplane manufacturers were promptly shipped with planes either abroad or to aviation fields in this country.

The results of the engine-production program may be summarized as follows:

> There was designed, developed, and put into production during one year a 400-horsepower engine giving a perfectly satisfactory performance and which met with enthusiastic recommendation and approval from all the allied nations.
>
> Over 15,000 of these engines were produced within 18 months.
>
> 32,420 engines of all types, with a combined horsepower of over 7,800,000, were produced during 18 months.

The officers charged with the execution of the program are proud of this record, which is the direct result of the energy and ability of all the engine contractors.

Four Liberty–12 engines have, as this pamphlet goes to press (May 31, 1919), just successfully driven the NC–4 Navy seaplane from America to Europe on the first trans-Atlantic flight.

AIRPLANES.

The building of the fully equipped airplanes with their necessary spare parts in the quantities required by even the most conservative programs required a vast industrial development. The manufacturing problem was serious in itself; the engineering situation was still more serious. How fully the officers of the Equipment Division realized these difficulties is best told by reviewing the facts.

First. Primary training machines were needed for use in the United States. These were at once ordered from 11 different contractors, the principal type being the regular Curtiss training machines previously furnished the British.

Second. Training and fighting machines were needed for the earlier requirements of the American Expeditionary Forces in France. The impossibility of meeting this requirement with machines built in the United States was recognized.

In August, 1917, orders promised for delivery by July 1, 1918, were placed with French factories for 5,875 planes of regular French design, a sufficient quantity to meet the estimated requirements of the United States Air Service in France until July 1, 1918. In other words, it was fully realized that machines of United States manufacture could not be provided on the front until the summer of 1918, and that any machines to be used by the American Expeditionary Forces previous to that time, must be secured in France.

That the French factories failed to meet the promised delivery is only too clearly shown by report of Supply Section, Air Service, American Expeditionary Forces, Chart B, dated May 23, 1918. This report showed 45 Breguet, 74 Spads, 1,180 Nieuports, and 532 planes of various other types, or a total of 1,831 machines delivered by May, 1918. This quantity was substantially increased through June, but not to a degree to approximate the original promise.

Third. The program for building fighting planes in quantities in the United States was initiated, involving the creation of sources of raw materials, engines, armament, accessories, and finally the planes themselves.

To understand airplane production, one must understand what an airplane is, and how the inside of the airship is really made.

An airplane flies, and does not drop to the ground because it moves through the air. The front edges of the wings are raised above the line of flight and when the propeller driven by the engine forces the wings through the air, the airplane is lifted and flies.

So an airplane must have wings and an engine with a propeller to make it go, and like a bird it must have a tail to make it fly straight, and a body (fuselage) to hold all together. Part of the tail (the rudder) moves sidewise and steers the airplane to right or left. Part moves up and down (the elevators) and makes the airplane go up or down. Part of the wings (ailerons) move up and down and make the airplane tip from side to side. All of these things must be connected to the "controls" in the hands of the pilot.

There are many types of airplane, such as monoplanes, biplanes, triplanes, pushers, tractors, etc. All of the airplanes built in quantity for the United States have been "tractor biplanes," that is, the propeller or air screw is in front and pulls the airship, which has two planes or wings. The biplane has been most largely used for two reasons: First, the struts and wires between the planes form a truss and this gives the needed strength; second, this type of design permits better vision.

The power of the engine and area of the wings can only lift a limited weight. So every part of the airplane must be as light as possible.

An airplane engine weighs from 2 to 3 pounds per horsepower, whereas an automobile engine weighs from 8 to 10 pounds per horsepower.

The airplane skeleton is made of wood, mostly spruce, with sheet steel fittings to join the wood parts together, and steel wires and rods to make every part a truss. This skeleton is covered with cloth, and the cloth is stretched and made smooth by "dope."

Wood, sheet steel, wire, cloth, varnish, all seem easy to obtain in America. Yes, common materials in peace time. But every piece of an airplane is uncommon material, perfect to a degree never before demanded. A man's life hangs on every piece. Not only had America to furnish materials for her own air program, but all of the spruce, and later much of the fabric and dope for our allies.

The problem involved in securing spruce in quantities was realized relatively early in the program.

Slightly later it developed that England could not furnish as much linen as necessary. Then came the question of dope and the castor oil supply. During the latter months of the war when industrial conditions became more tense, it was necessary to follow the production of all classes of raw materials, but broadly speaking, the great creative work on raw materials was confined to spruce, fabric, and dope, with some later developments, never fully worked out, to provide a suitable supply of steel tubing.

LUMBER SUPPLY.

Nothing better illustrates the newness of aircraft production work in the United States than the vast industrial and technical problems that had to be solved before the lumber problem was understood. The knowledge of airplane requirements had to reach to the loggers, to the sawmill, to the cut-up plants and follow through the processes of drying, sawing, and utilization of the lumber in the aircraft factories. Too much credit can not be given to the lumber industry of the Pacific Northwest for the way they helped solve these problems.

The work done by the Forest Products Laboratory at Madison, Wis., and by the Wood Section of the Inspection Department of the Bureau of Aircraft Production has had a lasting influence. Great credit must be allotted to the Forestry Service and to the Forest Products Laboratory for creating the underlying basis of technical knowledge which made it possible to meet the situation. Recent investigation of conditions in France and England indicate that, new though this country was to all questions of aircraft lumber, it is fair to state that at the signing of the armistice, practice was better in this country than in either France or England.

There are two distinct lumber problems connected with the air program. First, spruce and similar lumber for wing beams and other plane parts; second, mahogany and other hardwoods for propellors. In each case, the problem involved both securing the lumber and educating manufacturers to handle it properly.

SPRUCE AND FIR.

The principal lumber problem in the airplane itself was to procure suitable material for the wing beams and struts. In an ordinary biplane there are two beams in each wing, or eight beams per machine, which form the basis of the strength for the wings. Because of the high stresses developed in an airplane during normal flight and especially in the performance of acrobatic stunts, only the most perfect straight-grain wood is suitable for the major parts. This means that all cross-grain or spiral-grain material, as well as material too coarse in structure, is useless. On our entry into the war practically the only lumber accepted in this country for wing beams was spruce from the Pacific Northwest.

To properly understand the problem, it is only necessary to consider the supply of lumber for wing beams and struts, as practically all the other pieces can be made from cuttings from the wing-beam stock. At the start the American practice was to make wing beams out of one piece, and this meant that suitable lumber must be extra long, thick, and perfect.

It was necessary to provide spruce, not only for the much discussed air program of the Army, but also to provide for the Navy and all our allies.

The problem was further increased by the known fact that only a small portion of the lumber actually logged for this purpose was ultimately found to be satisfactory for airplanes. A typical biplane uses less than 500 feet of lumber. Under good practice, this can be worked out of 1,000 feet of rough lumber. In the earlier days of the air program as high as 5,000 feet per machine was actually used because of the imperfections in the lumber, difficulties of securing proper inspection at the mills, and because of the faulty handling in transit and in the airplane factories. Ultimately, an allowance of 1,000 feet per machine, without spares, appeared to be essentially correct.

Understand that at the beginning of the war spruce was practically the only accepted material, and wing beams made from a solid piece of lumber were insisted on. The problem presented was met in two ways—first, by securing vast additional quantities of spruce; second, by using fir or other substitutes and also by building up wing beams from small pieces of lumber by splicing and laminating. It is felt that the latter methods will in the future solve the problem of spruce supply, unless a much greater demand than the past requirements is encountered. The future plans for meeting possible aircraft demands should look toward the technical knowledge of lumber and laminating in order to design planes to meet the lumber problem rather than to enormous lumbering operations.

CREATION OF THE SPRUCE PRODUCTION DIVISION.

During the summer of 1917 it became evident that extraordinary efforts should be made to secure sufficient supply of aircraft spruce. Almost immediately it was decided to use certain species of fir in training planes. The fact that spruce and fir came from the same territory further assisted in meeting the situation. Broadly speaking, these woods are used because of lightness, toughness, and strength. Investigation proved that practically the only great source of supply was the Pacific Northwest, with a modest quantity in West Virginia, North Carolina, and New England, the latter being used principally by the Navy.

The logging problem was intensified by the small portion of the lumber actually cut that was of aircraft grade.

Various efforts were made to get lumbermen of the Pacific coast together, but without great success. The logging problems involved were extremely difficult and the large virgin stands of spruce occurred only at intervals and often at a long distance from existing railroads. On the recommendation of the Aircraft Board, the chief of staff approved October 17, 1917, the formation of a military organization to handle the situation. On November 6, 1917, Col. Brice P. Disque took command of the Spruce Production Division of the Signal Corps, which later became the Spruce Production Division of the Bureau of Aircraft Production.

The labor situation was in chaotic condition, due principally to the strength of the I. W. W. in that territory. The mills were not equipped to cut the straight-grained lumber needed nor had they men sufficiently skilled in the selection and analysis of the logs to secure the maximum footages. Men had been trained to work rather to a large-quantity production and, in general, desired to avoid the high-grade requirements of the Government.

The Spruce Division met the labor situation by organizing a league called the Loyal Legion of Loggers and Lumbermen, including manufacture representatives. The principles of the L. L. L. L. were—no strikes, fair wages, and the production of Government war requirements. On March 1, 1918, an agreement was entered into by the operators and 75,000 lumbermen which placed in Col. Disque's hands, without reserve, the power to decide all labor disputes. Specifications were standardized and modified as far as practicable to meet manufacturer's needs, financial assistance was arranged for, methods of instruction were agreed upon, and a price was fixed by the Government for aircraft spruce, thereby stabilizing an industry and definitely providing against delays from labor disputes.

The existing stands of spruce timber were studied, railroads built and planned far in the future. The splitting or riving of logs by farmers in small operations was initiated. The organization of the Spruce Division contained a large number of men who had had a lifelong experience in the industry and the efficiency of operations gradually increased.

Over 180,000,000 feet of aircraft lumber was shipped. To our allies went 120,000,000, to the United States Army and Navy, 60,000,000.

UTILIZATION OF THE SPRUCE.

It was early realized that outside of a few of the existing aircraft plants but little knowledge existed as to the proper methods of drying aircraft lumber. The problem involved the drying of lumber so as to preserve its strength, whereas the vast majority of woodworking plants of the country, such as furniture and piano makers, had always dried lumber simply to assure its retaining its shape. Based on the data secured from the Forest Products Laboratory the Wood Section of the Inspection Department of the Bureau of Aircraft Production practically took over the entire technical problem of drying the aircraft lumber. The facts were that ordinary commercial drying had seldom been carried on scientifically. The factories did not realize that definite results could be obtained by prearranged drying schedules. It is felt that the instruction in drying practice, which has been spread broadcast over the country, will have a lasting effect in many unforeseen directions.

In addition to the drying problems, the training of manufacturing organizations to saw the lumber to obtain maximum results and the education of inspectors, as well as manufacturers, has involved a most extensive and consistent campaign.

FUTURE SPRUCE SUPPLY.

In the latter months of the production of airplanes, spliced beams were universally used; that is to say, beams composed of two short lengths glued together. Laminated beams—beams whose section was made up of two or more pieces glued together—were coming into use both here and abroad, and would have been universally used in the spring of 1919. The effect of laminating reduces the size of the stock required and if the gluing is properly done the strength is satisfactory. The shorter and thinner sizes meant that many sources of lumber and many varieties of lumber not heretofore considered could be used in the future and if we were to start to-day to initiate another enormous air program the problem should be attacked in this way.

FABRIC.

What are known as the flying surfaces of an airplane are made by stretching cloth over a frame. At the time of the declaration of war in Europe practically all airplane fabric had been made from linen, and at the time of the entry of the United States into the war linen was still almost exclusively used, although it is understood that Italian manufacturers had made some effort to develop a cotton fabric.

The principal countries producing the flax from which the linen was made were Belgium, Russia, and Ireland. The Belgian supply was immediately cut off from the allies, Russian flax was at all times difficult to obtain, and became unobtainable after the Russian revolution. This left Ireland as the only source from which to obtain the flax for airplane linen.

The situation was further complicated by the fact that Great Britain used large quantities of flax in the manufacture of duck sheets and other materials.

As late as August, 1917, Great Britain continued to assure the United States that sufficient linen would be made available. However, it rapidly became evident that deliveries from Ireland could not be depended on. America was facing an enormous air program—one airplane of the typical training or JN-4-D type, or of the fighting type like the DH-4, required about 250 yards of fabric for one machine. Night bombers required in excess of 500 yards. Furthermore, provision was necessary for the covering of spares, and the frequent recovering of machines in the field.

PRODUCTION OF FABRIC.

The United States entered the war on April 6, 1917, but for several months prior to that time experimental work on airplane cloths had been under way at the Bureau of Standards. A large variety of fabrics were tested out, and in the spring of 1917, a number of very promising experimental cloths were produced. At first there was a decided prejudice against the use of cotton because its application was not thoroughly understood, and the dope which gave satisfactory results when applied to linen failed to work with uniformity on cotton. The development of the new dope was in itself a big undertaking.

As the result of experiments, two grades of cotton airplane cloth were finally evolved, the so-called grade A, with a maximum weight of 4½ ounces per square yard, and minimum tensile strength of 80 pounds per inch, and grade B, with a maximum weight of 4 ounces per square yard and minimum tensile strength of 75 pounds per inch. As these cloths got into production it was shown that the grade A, instead of having a strength of 80 pounds, ran, for the most part, from 85 to 90. This was the grade that was universally adopted after February, 1918, because the additional strength far more than compensated the slightly increased weight.

The first orders for 20,000 yards of cotton airplane fabrics were placed in September, 1917, and from that time on the use of linen decreased. By March, 1918, the production of cotton cloth had increased to about 400,000 yards per month; in May, production reached about 900,000 yards; and at the time that the armistice was signed the production was approximately 1,200,000 yards per month. About 2,600 looms were engaged, each loom turning out about 120 yards per week. Up to January 11, 10,248,355 yards had been woven. August, 1918, saw the complete discontinuance of importations of linen.

The only practical limit to the production of cotton airplane cloth is the available supply of long staple sea-island and Egyptian cotton. To guard against a shortage of this material, the Signal Corps in November, 1917, purchased 15,000 bales of sea-island cotton so that there was at all times an adequate reserve of the raw material from which to make the new fabric.

The substitution of cotton for linen which was regarded with skepticism for a long time has now been universally recognized as not only feasible but as actually desirable, and it is unlikely that linen will ever again be used in large quantities for the manufacture of airplane wings no matter how abundant the supply of flax may be.

The appreciation of the fabric situation, the promptness in purchasing the necessary cotton, and the instant starting of production of cotton fabric marked a great decision promptly taken, that made possible the allied air program.

DOPE.

The function of the dope which is used on all the fabric surface of airplanes is twofold: First, it helps to stretch the cloth tight; second, it fills the fabric and creates a smooth, waterproof surface. Ordinary spar varnish is used to protect the surface created by the dope.

There are two broad classifications of dope:

> *Nitrate*, made from cellulose nitrate and wood chemical solvents (alcohols, etc.). This produces a surface similar to a photographic film and burns rapidly.
>
> *Acetate*, made from cellulose acetate and wood chemical solvents (acetone, etc.). This is slow burning.

The greatest danger in the air is fire. Nitrate dope was fairly satisfactory for training planes not subject to enemy incendiary bullets. In fighting planes acetate dope was a vital necessity.

Up to our entry into the war dope—mostly nitrate—was furnished by various chemical and varnish manufacturers.

PRODUCTION DEVELOPMENT.

The development of a great air program necessitated quantity production of an acetate dope. To produce the acetate dope, acetone and other chemicals had to be obtained, and a careful canvas of the situation showed that it was impossible to obtain the necessary increase, or anything like it, without developing absolutely new sources.

The allied Governments had previously been absorbing a large part of the acetone and kindred products. The British Government, in particular, looked with the greatest concern upon the added requirements of the American Air Service, because acetone is the basis of cordite, an explosive on which the British were absolutely dependent.

It was estimated that the Bureau of Aircraft Production requirements, based on the airplane program for 1918, would be 25,000 tons, and the British war mission submitted figures showing that irrespective of the demands made by the United States Air Service, the allied and necessary domestic requirements would in themselves be greater than the total available supply. It, therefore, became obvious that the Government must assume the necessary control over the matter of arranging for increased production.

The selection of the new dope to be used opened up a wide field of research, because not only was there a shortage of acetate of lime but also of the refined ingredients going into the dope, such as cellulose acetate, acetic anhydride, and glacial acetic acid.

Acetate of lime is the base from which acetone is made, and in December, 1917, steps were taken to commandeer all of the existing supply in the United States, as well as supplies of kindred products.

Steps also had to be taken immediately to increase the productive capacity of the country of these necessary chemicals, and this resulted in the Government taking an active interest through cash advances and otherwise in establishing 10 large chemical plants located at Collinwood, Tenn.; Tyrone, Pa.; Mechanicsville, N. Y.; Shawinigan Falls, Canada; Kingsport, Tenn.; Lyle, Tenn.; Freemont, Mo.; Sutton, W. Va.; Shelby, Ala., and Terre Haute, Ind.

A policy was developed whereby the interests of the United States and allied Governments were pooled in order that the supplies of chemicals, which it was anticipated would be short prior to the completion of the new plants, should be allocated between the different countries according to the urgency of the war demands. The disposition of the pooled material was put under the control of the Wood Chemical Section of the War Industries Board. The British war mission arranged with the European allies a plan whereby their purchases of material should be handled and paid for through the British Government, and this method greatly facilitated matters.

An arrangement was also agreed to between the Signal Corps and the British war mission whereby the American and British Governments should share equally any losses occurring as a result of the erection of new Government plants or through the working out of the commandeering order. The basis of the plan was that each Government should pay exactly the same for its supplies, neither having any advantage of prices in the long run.

Up to the time that the armistic was signed, 1,324,356 gallons of dope had been manufactured, and this proved adequate to meet all requirements. The shortage of dope in France was not because of shortage in available supply in this country. Had the war continued the output from the new enterprises in which the Government was a partner would have proven sufficient in itself to take care of all American and allied requirements, and it would probably not have been necessary to further commandeer the chemical output of privately owned plants.

ENGINEERING RESOURCES.

The talent in the United States having experience with aeronautical engineering, and therefore qualified in some measure to undertake parts of this work, was extremely limited. There were probably a dozen men who had had more or less experience in the designing of flying machines, but none who even remotely comprehended the progress that had been made in Europe and were competent to design a *complete fighting machine.* No airplane had been built in the United States equipped to carry a machine gun, nor was there an aircraft machine gun of the fixed type being produced in the United States. Some of the too rosy estimates of accomplishment were caused by this lack of comprehension of the multitudinous detail and complication of the engineering problem.

The Curtiss Co. had Mr. Curtiss and several engineers who had worked with him for a number of years. The Curtiss Co. also had the benefit of contracts from the British for training machines, as well as assistance from them in improving the type. In distributing the engineering work the Curtiss Co. was immediately thought of as possessing more knowledge and experience available to apply to the most difficult part of our program than any other company. It was for this reason that it was decided at the start to put the duplication of the French Spad into the Curtiss plant.

Orville Wright had not been in the best of health for some time and was devoting his entire time to laboratory work for the Dayton-Wright Co. There was Willard, who had designed the L. W. F. and was then with the Aeromarine Co.; Charles Day, formerly with the Sloane Manufacturing Co., and then with the Standard Aero Corporation; Starling Burgess with the Burgess Co. of Marblehead; Grover C. Loening of the Sturtevant Co.; D. D. Thomas with the Thomas-Morse Co.; Vought, of Lewis & Vought, of New York City; Glenn L. Martin, of Cleveland; and Lieut. Commander Hunsaker, of the Navy, who while not as old in experience as some of the men mentioned above, was considered among the best in this country.

The man in the Signal Corps corresponding to Lieut. Commander Hunsaker was Capt. V. E. Clark, who had transferred from choice from the Coast Artillery into the Signal Corps to the engineering section, and was in charge of all matters connected with Army airplane designs.

About this time it was mutually agreed between the Army and Navy that the Burgess factory at Marblehead, the Aeromarine plants at Nutley and Keyport, N. J., and the Boeing Airplane Co. at Seattle would be turned over to the Navy exclusively for their work. This made it necessary for the Signal Corps in considering plans for developing their engineering work to eliminate these exclusive Navy contractors and the aeronautic engineers connected with them. Lieut. Commander Hunsaker, of the Navy, was out of consideration except for consultation work, as his hands were full with the development of the Navy's program.

As the vastness of the engineering problem developed it was realized that the entire aeronautical engineering resources of the country must be applied to the program, and a tentative division of the work was determined on as follows:

Curtiss Aeroplane & Motor Corporation (Glenn Curtiss) to furnish the designs of the JN-4-D primary training plane and to develop the drawings and manufacture the French Spad (single place chasse machine).

Standard Aero Corporation (Charles Day) to furnish the drawings of the J-1 training plane, and develop a rotary motor advance training plane. Later Mr. Day supervised the engineering on the Handley-Page work.

Dayton-Wright Airplane Co. (Orville Wright) to develop the American drawings of the De Haviland-4.

Signal Corps Engineering Department to develop the Bristol Fighter.

Thomas-Morse Aircraft Corporation (D. D. Thomas) to develop a rotary motor advance training plane, and later a chasse machine.

Grover C. Loening to develop a two-place fighter.

Glenn L. Martin to develop a two-engine bomber.

Lewis & Vought (C. M. Vought) to develop an advanced training plane.

In addition to the above, several other orders were early placed for sample machines from various sources.

The engineering confusion which followed the program throughout the first year must be frankly admitted. This confusion was due primarily to a lack of knowledge of the exact requirements, and the necessity of determining on and designing accessories at the same time the planes were being designed.

MANUFACTURING FACILITIES.

Manufacturing men who viewed the proposed production of planes at once realized that the manufacturing facilities available in the country must be enormously developed, and their organizations trained for the manufacture of airplanes. The idea of creating facilities for airplanes seemed to be uppermost at the start. The Government organization to correlate facilities was neglected, and there was certainly no realization of the magnitude of the engineering detail involved in order to bring the various items of production together into a workable, assembled whole.

In considering the manufacturing problem, the responsible airplane plants were first divided, by mutual conference, between the Army and the Navy, the general principle being to confine the work of a given factory to the requirements of one Government department only.

This made available for the Army the following plants: Curtiss Aeroplane & Motor Corporation, Buffalo, N. Y.; Standard Aircraft Corporation, Elizabeth, N. J.; Thomas-Morse Aircraft Corporation, Ithaca, N. Y.; Wright-Martin Aircraft Corporation, Los Angeles, Cal.; Sturtevant Aeroplane Co., Boston, Mass.

And for the Navy: Curtiss Aeroplane & Motor Corporation, Buffalo, N. Y.; the Burgess Co., Marblehead, Mass.; L. W. F. (Lowe, Willard & Fowler) Engineering Co., College Point, N. Y.; Aeromarine Engineering & Sales Co., New York, N. Y.; Gallaudet Aircraft Corporation, New York, N. Y.; Boeing Airplane Co., Seattle, Wash.

Curtiss, Standard, Burgess, L. W. F., Thomas, and Wright-Martin are the only ones in the above lists who had ever built over 10 machines.

It was evident to the manufacturing men in the Government organization that the resources of the existing plants, either in equipment or in organization, were insufficient to meet the program.

As principal producers of airplanes, in addition to the existant plane plants, two principal plants were created; the Fisher Body Co. at Detroit, Mich., admittedly the largest producers of automobile bodies in the world, were asked to create an airplane factory. It should be noted that the Fisher organization brought not only machinery and buildings, but a skilled organization, trained in the manufacture of accurate interchangeable wood and sheet steel parts.

At Dayton, Ohio, the Dayton-Wright Airplane Corporation was created. With this company was associated Orville Wright, and their engineering airplane force was built up around the old Wright group. Great buildings recently finished for other purposes were at once utilized.

In addition to these two large sources of supply the Springfield Aircraft Corporation at Springfield, Mass., was put together by Messrs. J. G. White & Co. and J. G. Brill & Co.

Certain interests on the Pacific coast also created several plants in California, some of which ultimately became satisfactory producers of training planes.

In addition to the principal plants for the manufacture of airplanes, it was thought necessary to initiate the production of spare parts in many relatively minor plants. This was done for two reasons; first, to increase the capacity of the regular airplane plants, relieving them of the burden of making spares, and, second, to start to educate the other manufacturers up to the point where they might wisely undertake the manufacture of complete airplanes.

The manufacturers called upon to undertake the production of spares were largely makers of automobile bodies. To a lesser extent orders for spare parts were placed with the smaller airplane companies. Among the principal producers of spares were:

The Metz Co., Waltham, Mass.; Sturtevant Aeroplane Co., Jamaica Plains, Mass.; Wilson Body Co., Bay City, Mich.; West Virginia Aircraft Corporation, Wheeling, W. Va.; The Rubay Co., Cleveland, Ohio; Engel Aircraft Co., Niles, Ohio, and Hayes-Ionia Co., Grand Rapids, Mich.

The record of adaptability, energy, and drive with which the manufacturers attacked the plane program is worthy of the best production traditions of this country. The ultimate results attained both in quality of workmanship and speed of production exceed the world's best records. Delays in reaching quantity production were due to the lack of drawings, specifications, and accessories resulting from the previous inexperience of the United States in aeronautics.

TRAINING PLANES.

TYPES.

A primary training plane carries the student and the instructor, generally placed one behind the other. Each has a full set of controls and these are interconnected, enabling the instructor either to do the flying, or correct the student's false moves, or let the student do all the flying. Primary training planes are relatively slow (75 miles per hour) and especially require an engine so reliable that little skill or attention is required.

Evidently the first requirement of the Air Service was training planes, and the decision to use the Curtiss JN-4, with the OX-5 motor as the standard, primary training plane, has been proved wise, especially as the delay in securing rotary engines would have prevented prompt deliveries of planes using that type of engine.

A few Penguins, a kind of half airplane that never really leaves the ground, were built, but this (French) method of training was never adopted.

The Standard J–1 plane, with the Hall-Scott A–7–A engine as a secondary source of primary training plane, has been criticized, but it is fair to state that the difficulties encountered were not with the planes themselves, and not with the original engine, but rather due to the modification of the intake of the engine, which made the machine uncertain under cold weather conditions.

Advanced training machines are faster (about 105 miles per hour) and carry various equipment to train observers, gunners, photographers, radio men, etc. The plane chiefly used in this country for this work was the Curtiss JN4–H and JN6–H, substantially the same as the slower Curtiss training plane, but with a 150-horsepower Hispano-Suiza engine.

The final training in France was in French-built Nieuports and regular fighting machines.

PRODUCTION OF TRAINING PLANES.

The airplane plants were, without exception, all started on training machines. The reason for this was twofold: Training machines were wanted first, and in addition to this fact, neither engines nor approved designs were available for fighting machines. In general the production of the training machines kept up with the engine production, and particularly the Curtiss plant produced JN4 machines at a pace far beyond anything previously obtained.

The supply of spare parts was for a long time insufficient for the needs of the training fields. The importance of spare parts had not been realized, and when proper quantities were ordered many manufacturing difficulties were encountered. The lack of a proper supply of spare parts may be charged to:

The lack of a proper realization of the quantity required at the time of requirement; placing orders with new companies; the lack of proper drawings.

As the supply of training planes met the demands of the fields, the production was reduced. The maximum production of JN4–D and SJ–1 (primary training) was 756 in March, 1918. The maximum for advanced training machines—JN4–H, JN6–H, S4–C—was

427 in July, 1918. The actual production of training planes may be summarized as follows:

Month.	Primary training planes.[1]	Advanced training planes.[2]
June, 1917	9	....
July	56	....
August	103	....
September	193	....
October	340	....
November	331	1
December	423	20
January, 1918	700	29
February	526	199
March	756	178
April	645	81
May	419	166
June	126	313
July	236	427
August	296	193
September	233	132
October	212	320
November	186	297
December	162	259
Total	5,952	2,615

[1] SJ-1, JN4-D, Penguin.

[2] JN4 and 6-H, S4-B and C, E-1, SE-5.

FIGHTING OR SERVICE PLANES.

DE HAVILAND—4.

The reports of the Bolling mission furnished most of the information on which were based the early decisions as to types of fighting or service airplanes to be manufactured in the United States. Both the authorities in this country and the Bolling mission recognized the fact that the development of the single-place machine, which type represented the principal chasse machine on the western front, was going on with extreme rapidity. It was felt that by the time the best machine in use on the western front could be sent to the United States, placed in production, and delivered in quantity in France, such a machine would be hopelessly out of date. French manufacturers, with the approval of their Government, were anxious to furnish the needed machines, and accordingly the orders were placed in France for single-place fighters. For production in the United States it was decided to give precedence to the two-place observation type, and to follow with the two-place fighting machine as rapidly as possible. In the light of conditions in 1917, this decision appears to have been correct.

When Col. Bolling's mission began to cable from Europe and recommend types to be adopted, samples were sent of the planes so recommended. On July 18, 1917, the De Haviland 4 was received in New York. This was the then accepted type of British two-place observation machine. It arrived in Washington on July 27, and after review by various officers at Washington was sent to Dayton, arriving August 15. This plane arrived without its engine and ordnance and lacking many other accessories which were later recommended as essential to a fighting machine. The plane had to be redesigned and altered to take our machine guns, our instruments, and our accessories, and fitted to receive the Liberty engine, as well as much additional equipment above that with which the sample was furnished or designed.

The first DeHaviland plane was flown at Dayton, October 29, 1917, and this identical plane was flown by Mr. Rinehart, of the Dayton-Wright flying force until March, 1919, and known all over the country as the *Canary Bird*. It is now a part of a permanent exhibit in the Smithsonian Institute.

Howard M. Rinehart's part in developing the American air program is known to the few. Trained by Orville Wright himself in 1912, and after an extensive experience in radio work, he became a military flier for Gen. Villa in 1915, flying the Wright Model H–S machine.

Later in the Wright Flying School he trained over 200 fliers. After connecting himself with the Dayton-Wright Airplane Co. he did the major portion of the development flying with the DeHaviland–4 machine. Only those who went through the DeHaviland problems of the winter of 1917–18 realize the degree of Howard Rinehart's devotion to the work.

During the months of December, January, and February the infinite problems surrounding the installation of the equipment demanded on the DeHaviland–4 were struggled with, and on the 8th day of April the machine known as *No. 31* was completely finished, and established as the model for the future DeHaviland–4.

The characteristics of the DeHaviland are as follows:

Endurance at 6,500 feet, full throttle	2 hours 13 minutes.
Endurance at 6 500 feet, half throttle	3 hours 3 minutes.
Ceiling	19,500 feet.
Climb to 10,000 feet (loaded)	14 minutes.
Speed at ground level	124.7 miles per hour.
Speed at 6,500 feet	120 miles per hour.
Speed at 10,000 feet	117 miles per hour.
Speed at 15,000 feet	113 miles per hour.
Weight, bare plane	2,391 pounds.
Weight loaded	3,582 pounds.

The actual production of service planes, airplanes built in this country and fully equipped to fight in France, was confined to DeHaviland–4 machines, which is an observation two-place biplane with Liberty motor.

The following table of production of DeHaviland–4 machines from all sources is of interest:

Production of De Haviland–4 Machines.

November, 1917	0	August (100 as spares)	224
December	0	September (100 as spares)	757
January, 1918	0	October	1,097
February	9	November	1,072
March	4	December	436
April	15	Total	4,587
May	153		
June	336		
July, 1918	484		

Criticism of the DH–4 and Development of the U. S. D.–9–A.

Opinions as to the wisdom of the original selection of the widely used British DH–4 as the most desirable model for an observation machine and of the general utility of the machine are varied.

Much of the detailed early criticism of construction and workmanship was unwarranted. On the other hand, the machine lacked several desirable characteristics in comparison with other machines in use on the western front during the latter part of 1918.

The first machines delivered in France were immediately erected, such imperfections as existed were corrected then and there, and the machines put into the air and delivered to the training fields. The constantly changing and increasing demands of the service indicated the wisdom of some detailed changes which were made in August, 1918.

The principal points of criticism of the machines were as follows:

1. Unsatisfactory visibility.
2. Distance between the pilot and the observer.
3. Location of the gas tank behind the pilot.
4. Pressure system on the gas tank, increasing the fire risk.
5. Lack of leak-proof covering of the gas tank.
6. Insufficient radius of action, especially on the original machines, which had only 66 gallons of gas against 88 on the later machines.

In response to the demand for something better, the U. S. D.–9A, with Liberty–12 motor was designed, and 4,000 ordered from the Curtiss Co. The main differences between it and the DH–4 are different locations for pilot and tanks, their positions being interchanged, increased gasoline capacity, no pressure on the gas tank, leak-proof tanks, and increased wing surface. The machine is a cleaner, more finished design, of about the same speed, but with greater range of action, and was planned to succeed the DeHaviland–4.

THE SPAD.

Single-seater pursuit machines have not as yet been manufactured in the United States, and no work looking toward such production has been under way since December, 1917. There has been much criticism of the cancellation of the Spad order.

The Spad sample arrived in New York, September 12, 1917 and was received at Buffalo, September 25. Work on this plane, however, was finally stopped some time in December, based on recommendations from Gen. Pershing that the United States should leave production of single-place fighters to Europe. Cable No. 375, paragraph 2, dated December 14, 1917, indicates clearly the instructions of the American Expeditionary Forces, with respect to the single-place fighter of which type the Spad was a leading example. "United States should leave production single-place fighter to Europe" (quotation from Cable P–375, pr. 2).

This opinion was later changed—partly because of a growing confidence in American airplane manufacturers and partly because of inability to obtain prompt and adequate deliveries of chasse planes from European manufacturers. At the time of signing the armistice, several single-place fighters were being developed in the United States by both American and foreign engineers. It was planned to choose the best two of the planes for production in this country; this production could not have started until late in 1919 or early in 1920.

THE BRISTOL.

The necessity of a two-place fighter was understood from the start. The Bristol fighter sample arrived in New York on August 25, 1917, and in Washington on September 5, 1917. Government engineers at once began redesigning the machine to take the Liberty–12 engine and ordnance and other accessories of American manufacture. There has been much criticism of redesigning the Bristol fighter to take the Liberty–12. In other words, to equip it with a 400-horsepower engine rather than a 275-horsepower engine. Later development of two-seater fighters around the Liberty–12 indicates the fallacy of criticizing the Bristol program from this point of view. It is true that there were repeated changes in the engineering management of the Bristol job, beginning with purely Government engineers, then Government engineers combined with the drafting force of an airplane factory, then placing the entire responsibility on the factory without, however, offering the manufacturer an opportunity to correct the basic principles involved, then completing the machine under the direction of Government engineers. Result in brief was that in June, 1918, the Bristol fighter with Liberty–12 engine was definitely abandoned.

THE LEPERE WITH LIBERTY–12 ENGINE.

At the same time, other brilliantly successful efforts were under way to design the two-place fighter around the Liberty–12. On January 4, 1918, Capt. Lepere, a French aeronautical engineer, formerly with the French Government at St. Cyr, started designing such a machine. On May 18, 1918, a contract was made with the Packard Motor Car Co. to provide shop facilities for the production of 25 experimental planes, under the direction of Capt. Lepere.

The result of Lepere's efforts from the very start met with the approval of manufacturing men because of the clean-cut perfection of the design. The plane was really being created around the Liberty–12 engine rather than an attempt to fit the engine to some existing plane.

The actual results in the air are only partially shown by the following figures:

Altitude.	Climb.		Speed.	
	Time.	Revolutions per minute.	Miles per hour.	Revolutions per minute.
Feet.	*M. S.*			
0		1,500	136	1,800
6,000	5 35	1,540	132	1,740
10,000	10 35	1,520	127	1,680
15,000	19 15	1,500	118	1,620
20,000	41	1,480	102	1,550

	Feet.
Theoretical ceiling	22,000
Real ceiling	20,800

("Technical Orders" No. 1, October, 1918, p. 17.)

The brilliant performances in the air and the possibilities of manufacturing led to the placing of orders for 3,525 of these machines. No actual shipments, however, of regular production machines had been made at the time of the signing of the armistice, November 11. Twenty-five samples were ordered, of which seven had been turned out and were being used for every conceivable kind of test of the machine. It is the feeling of those in authority that at last the training and technique of the best engineers in France had been combined with the Liberty, admittedly the best of all aviation engines, and it was felt that the spring of 1919 would see the American air forces equipped with two-place fighters from America superior to anything they would be required to meet.

NEW DESIGNS.

The extent of this work being carried on in this country by the best of both American and foreign engineers is little understood, even by the men in the Air Service. Comment by officers of the A. E. F. confirms the thought that America had attained results in design comparable to or exceeding the best in Europe.

The following is a list of experimental machines which have been delivered; many of which give brilliant promise:

SINGLE-SEATER PURSUIT.

Thomas-Morse MB-3—300 Hispano engine.
Vought VE-8—300 Hispano engine.
Ordnance Engineering Model D—300 Hispano engine.
Pomilio—Liberty 8 engine.
Pomilio—Liberty 12 engine.
Verville—300 Hispano engine.

TWO-SEATER FIGHTER.

Lepere—Liberty 12 engine.
Lepere (armored—C-21), Bugatti engine.
Lepere Triplane (day bomber)—2 Liberty engines.
Curtiss Triplane—Kirkham engine.
Curtiss Ground Harassment Biplane—Bugatti engine.
Loening 2-place monoplane—Liberty 12 engine.
Loening—300 Hispano engine.
USD-9-A and B—Liberty 12 engine.
USXB-1—300 Hispano.
USXB-2—Liberty 8 engine.
Thomas-Morse MB-1, and 2—Liberty 12 engine, geared.

NIGHT-BOMBING MACHINES.

Glenn Martin—2 Liberty 12 engines.
J. V. Martin—2 Liberty engines with transmission.
Caproni—3 Liberty engines.

NIGHT BOMBING MACHINES.

The problem of night bombing machines presented from the first greater uncertainties as to design than any of the other types. These relatively slow, weight-carrying machines were enormously big and required either two or three engines with the complications attendant thereon and really presented the most difficult manufacturing problem of any of the airplanes required by the program laid down in June, 1917.

The problem of selection of types throughout practically the entire years following July, 1917, was limited in choice to the Handley Page machine, or rather a copy of the Handley Page machine but equipped with two Liberty-12 motors, or to the Caproni biplane, also to be equipped with Liberty motors.

The complications of negotiations for the right to construct the Caproni machine dictated the decision to put the Handley Page into production, not because it was necessarily as perfect as the Caproni, but because we could get the drawings for it and could not get the drawings for the Caproni. It was well known that the ceiling of the Handley Page was low and that 12 months' development might leave it of doubtful value because of the increasing range of anti-aircraft guns.

BUILDING HANDLEY PAGES.

A set of drawings, supposedly complete, was finally secured in August, 1917. Twice during the following winter new sets of drawings were sent from England, and few, if any, of the parts remained unaltered.

From the start it was evident that machines of the magnitude of the Handley Page (spreading over 100 feet) could not have the fuselage, wings, etc., made up in this country and shipped complete to Europe. However, the decision was reached to manufacture the parts in this country and to assemble machines in England. When it is realized that each machine involves 100,000 separate parts, the magnitude of the manufacturing problem presented may be somewhat understood. Packing of these parts, particularly delicate members made of wood, so that they would reach England in proper shape was in itself a very great problem.

To secure the erection of these machines in England, on January 26, 1918, contract was made in London with the British air ministry for the creation of a factory in Lancashire district of England at Oldham.

At the same time contracts were placed for the making of the parts in the United States. Liberty engines of standard type were to be used. The fittings, extremely intricate pieces of pressed steel work, were practically all produced by the Mullins Steel Boat Co. at Salem, Ohio. The wood parts contracts were placed with the Grand Rapids Airplane Co., a combination of furniture manufacturers of Grand Rapids, Mich.

All of the parts were to be brought together previous to ocean shipment in a warehouse created for this purpose at the plant of the Standard Aircraft Corporation at Elizabeth, N. J. The Standard organization was retained to erect 10 per cent of the machines complete. These machines were to be used for training in this country.

Here again in the case of the Handley Page, as in the case of all other fighting machines for overseas, the engineering details proved a serious source of delay. Installations of Liberty motors was a serious source of delay. At the time of the discontinuing operation on the Handley Page work, 100 sets of parts complete had been shipped to England, and 7 complete machines had been built in this country.

Reports just received from overseas indicate that the perfection of fabrication and packing of parts sent to England reflected great credit on American manufacturing methods. Preparation by the

British for the erection of machines had been long delayed and the work had only started in England at the time of the signing of the armistice.

The characteristics of the Handley Page as built in this country with two Liberty–12 engines, taken from unofficial trials made by the manufacturer, are as follows:

Speed at ground level	97 miles per hour.
Climb to 7,000 ft.	18 minutes 10 seconds.
Climb to 10,000 ft.	29 minutes.
Ceiling 14,000 ft.	60 minutes.
Total weight	11,270 pounds.

On these tests 390 gallons gasoline, 20 gallons oil, and seven men were carried. No guns, ammunition, or bombs carried.

CAPRONI NIGHT BOMBER.

About January 1, 1918, tentative arrangements were made with the Caproni interests looking toward the production of Caproni biplanes in this country; these machines being for night bombing work, but having a ceiling and speed in excess of the Handley Page. Capt. de'Annunzio, with 14 expert Italian workmen, with designs and samples, came to this country and initiated the redesigning of the Caproni biplane to accommodate three Liberty engines. The cause of delay in the production of the Caproni was due to a large extent, to the changes in Signal Corps organization, together with the difficulties in securing the desired cooperation between the Italian mission and all American plants in which the work was being done. It was not until the last half of 1918, with Capt. de'Annunzio at the Fisher plant, that it looked as if real progress were being made. These facts, together with the multitude of engineering problems involved, limited the actual production of Caproni planes in this country to a few samples which were under test at the time of the signing of the armistice. Many of the tools required for the production of this machine had been made and had the war gone on, Caproni biplanes would have been available in liberal quantity.

Preliminary Tests of American-Built Caproni at Mineola, Sept. 21–22, 1918.

	Test No. 1.	Test No. 2.
Speed at ground level	100 miles per hour	103.2 miles per hour.
Climb to 6,500 feet	16 minutes 18 seconds	14 minutes 12 seconds.
Climb to 10,000 feet	33 minutes 18 seconds	28 minutes 42 seconds.
Climb to 11,200 feet	49 minutes	
Climb to 13,000 feet		46 minutes 30 seconds.
Total weight	12,904 pounds	12,350 pounds.

("Technical Orders" No. 2, November, 1918.)

MARTIN NIGHT BOMBER.

In discussing the night bombing program, attention has been repeatedly drawn to the complications of foreign machines. In the fall of 1918, Glenn L. Martin submitted to the Government for test a night bomber equipped with two Liberty 12's. The spread of this machine was 75 feet, which carried a capacity comparable with that of the Handley-Page. The speed of 118 miles at ground level exceeded that of the Caproni and Handley-Page, and it was evident that the ceiling would exceed the Caproni, the Glenn L. Martin probably exceeding 18,000 feet. The Martin machine never reached a state of actual quantity production, but several experimental machines were built and tested. It reflected such clean-cut principles of design with such remarkable resulting performances that it was confidently believed it was the basis for the coming type of night bombing machine.

Preliminary Tests of Martin Bomber.

Test No. 1 held at Wilbur Wright Field, October 10, 1918.
Test No. 2 held at McCook Field with machine equipped with stream line wires.

	Test No. 1.	Test No. 2.
Speed at ground level	113.3 miles per hour	118.8 miles per hour.
Climb to 6,500 feet	10 minutes 45 seconds	7 minutes.
Climb to 10,000 feet	21 minutes 20 seconds	14 minutes.
Climb to 15,000 feet		30 minutes 30 seconds.
Total weight	9,663 pounds	8,137 pounds.

("Technical Orders" Nos. 2 and 3, November and December, 1918.)

PRODUCTION REVIEW.

RESULTS IN THE UNITED STATES.

The actual production in the United States for the Army for the year ending July 1, 1918, was 6,391 airplanes. At the time of signing the armistice the figures showed a total of 11,754 airplanes (exclusive of 15 secured by Engineering Department), together with a reasonable quantity of spare parts.

BRITISH AND UNITED STATES PRODUCTION COMPARED.

The only figures of allied airplane production available are the British. In considering this comparison it should be remembered that a large proportion of the British production was service planes, and that the major portion of our production was made up of the simpler training machines. In the following comparison the British figures from the Lockhart report of November 1, 1918, are of interest:

Comparative rate of airplane production—British and United States Army.

Calendar year.	British Army and Navy.	United States Army.
1915, Jan. 1 to Dec. 31	2,040	20
1916, Jan. 1 to Dec. 31	6,000	83
1917, Jan. 1 to Dec. 31	14,400	[1] 331 [2] 1,476
1918, Jan. 1 to Dec. 31	[3] 30,000	[4] 11,950 [5] 12,837

[1] Experimental.
[2] Last seven months only.
[3] Estimated.
[4] Inclusive of 135 secured by Engineering Department.
[5] If October production had continued through November and December.

Broadly stated, these figures mean that the United States produced for the Army as many airplanes in her second year of the war as did England in her third year for army and navy.

In October, 1918, the United States produced 1,651 planes, which is at the rate of 20,000 per year.

DETAILS OF FRENCH ORDERS.

Orders for training planes, deliveries to meet United States training program in France:

100 Nieuport 23 meter dual control, 80 LeRhone.
75 Nieuport 25 meter single control, 80 LeRhone.
100 Neuport 18 meter single control, 80 LeRhone.
350 Nieuport 15 meter single control, 80 LeRhone.
100 Nieuport 15 meter single control, 110 LeRhone.
150 Spad (or equivalent service machine), Hispano.

Orders for service planes, with deliveries as follows:

1917–18.

	November.	December.	January.	February.	March.	April.	May.	June.
1,500 Breguet (Renault and Fiat)	60	60	460	460	460	....	....	....
2,000 Spad (200-horsepower Hispano)	....	....	....	135	300	400	550	615
1,500 New Spad [1] (150 Gnome)	....	....	50	100	200	300	350	500
or								
Nieuport [1] (150 Gnome)	....	....	300	400	400	400	....	....

[1] Decision between New Spad and Nieuport was to be made as soon as tests of New Spad were completed. There was time to await this because both types took same engine.

Orders for service engines.

1917–18.

	November.	December.	January.	February.	March.	April.	May.	June.
1,500 Renault [1] (300-horsepower)	60	60	460	460	460			
4,000 Hispano (200-horsepower)			135	375	565	755	945	1,225
3,000 Gnome (150 horsepower)			400	400	400	600	600	600

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[1] It was necessary to secure Fiat 300-horsepower engines for some of the Breguet airplanes unless Renault could increase his output or deliver spares rapidly after March. The Breguet takes either Renault or Fiat.

Much of the raw material required for these machines was furnished from this country, and Messrs. J. G. White & Co., of New York City, were retained to procure and ship it. The actual procurement of $10,000,000 worth of the multitude of items required for the fabrication of airplanes and in addition about 5,000,000 feet of lumber and much necessary machinery was on the whole creditably carried out by J. G. White & Co., although certain of the items, notably semifinished engine parts, were much delayed.

There was supplied on this contract 7,500 tons of lumber and 15,000 tons of materials and supplies, consisting of steel, brass, copper, and aluminum tubing; steel, copper, lead, and aluminum sheets; bar steel; tool steel; structural steel; ball bearings; crank shafts; turnbuckles; radiator tubes; wire; cable; bolts; nuts; screws; nails; fiber; cloth; felt; and rubber. There was also purchased and shipped approximately 1,000 machine tools, such as motors, lathes, grinders, etc.

Production progress on the French contracts is shown in the report of Supply Section, Air Service, American Expeditionary Force, Chart B, as of May 23, 1918.

Total orders.

Nieuport training	725
Spad training	150
Breguet service	1,500
Spad service	2,000
New Spad or Nieuport service	1,500
Total	5,875

Total production to May 23.

Breguet, all types	45
Spad, all types	74
Nieuport, all types	1,180
Total	1,299

In addition to the above the French had delivered 532 planes of various other types during same period, making a total deilvered of 1,831 planes as of May 23, 1918. After this date deliveries increased.

This phase of the situation is reflected from another angle by stating that at the time of the signing of the armistice, the United States forces in France were using 3,002 foreign-made planes. These include the above French machines, some from the English, and a few from the Italians.

CONCLUSION.

At the time of the signing of the armistice there had been delivered for use of the Army 16,952 airplanes from the following sources:

United States contractors	11,754
From England	258
From Italy	59
From France	4,881
Total	16,952

Above figures as shown by the Bureau of Aircraft Production and by American Expeditionary Force Air Service report as of November 11, 1918.

According to report dated July 30, 1918, from Chief of Air Service, American Expeditionary Force, the central powers had the following planes on the front July 30, 1918:

German	2,592
Austrian	717
Total	3,309

The relative standing of the allies as expressed by planes on the front is variously estimated, because of the uncertainty of the actual number of planes in a squadron. Two views are given below, the smaller figure probably reflects nearer the actual facts:

	Lockhart's report as of Oct. 1, 1918.	Air Service estimate as of Nov. 11, 1918.
France	3,609	3,000
Grear Britain	2,641	2,100
United States	1,032	860
Italy	1,017	600
	8,299	6,560

These figures represent fully equipped machines ready for fighting service and do not include replacement machines at the front or in depots or training machines in France.

Officers from overseas agree that the above figures are probably representative. They, however, believe that the German service on spares, simplicity of equipment, and better organization based on long experience gave the German command much more service per plane, and essentially overcame the numerical difference.

At the time of signing the armistice the status of American-built service planes for use in France is reflected by the following figures:

2,091 planes had actually been shipped to France, 1,885 of which were De Haviland 4 with engines, 204 De Haviland 4 without engines, and 2 were Leperes.

1,040 more planes were at ports of embarkation or were in transit from American factories to ports.

1,440 planes had actually been received in France.

960 U. S. A. built planes were actually in service in France, 667 at the front and 293 at A. E. F. training fields.

There had also been delivered to an assembling plant in England 100 sets of parts for night bombing planes for assembly in England and to be flown to France.

Source of information: Statistics Branch, General Staff, Report No. 91.

AIRCRAFT MACHINE GUNS.

NOTE.—The production of machine guns is handled by the Bureau of Ordnance on requisition of the Air Service.

Fighting in the air is entirely a development of the present war, and the adaptation of machine guns for all types of aircraft has practically all taken place since the declaration of war in Europe. During the first year of the war the application of machine guns was being developed, but not until the summer of 1915 was it possible to send out on active service flights airplanes with armament consisting of one or more machine guns.

Records show that a machine gun was successfully fired from an airplane in this country in 1912; also that the French had a few heavy airplanes equipped to carry machine guns at the beginning of the war.

Until almost a year after the war began machine guns were not carried by airplanes on active service, but they were armed with various weapons, such as service rifles, automatic rifles, automatic pistols, shotguns shooting large shot held together by wire, and also equipped with grenades and darts, which were intended to drop on their adversaries. Needless to say, the damage done by these weapons was slight, owing to the great difficulty of one moving object hitting another.

Maj. Eric T. Bradley, United States Army, in August, 1915, was a flight sublieutenant in the British service. He regularly flew over the lines in a B. E. plane, armed with a Lee-Enfield rifle or sometimes with a 12-gauge double-barrel shotgun loaded with buckshot tied together by wire that swished through the air and occasionally hit something. Regular service automatic pistols were carried, and there are many stories of frightening the Hun with Very pistols, which shot Roman candle balls. Later Lewis ground guns were taken didectly from the trenches and worked from the observer's shoulder.

GUN CONTROL OR SYNCHRONIZING MECHANISM.

The development of methods of so controlling machine guns that they could be fired through the area traversed by the propeller has had a vast effect on aircraft armament, and an understanding of this problem is necessary to a proper understanding of the story of aircraft armament. What the device under discussion actually does is, fire the gun only at such times as the bullets will not strike the propeller blades, that is, the device used must time the gun with the engine.

The various devices utilized for controlling the fire of a machine gun so as to cause the bullets to miss the blades of the propeller are commonly known as synchronizing gears or interrupter gears. However, both these terms are somewhat erroneous, as it is only occasionally that the speed of the propeller is equal to the rate of fire of the gun, which is the condition of synchronization; also, the gun is not interrupted, but caused to fire at the proper instant so that the bullet will not strike the blade of the propeller. The term "gun control" is a much better name for these devices than either synchronizing or interrupter gears.

Tractor airplanes which have the engine and propeller in front, were found early in the war to be better suited for active service work, owing to their having better maneuvering powers and being more easily able to defend themselves. With these planes were developed the fixed aircraft machine gun. This gun is fixed rigidly to the plane, pointing straight forward, parallel to the line of flight.

The first fixed guns were mounted on the top plane so as to shoot over the arc described by the propeller; but these were not satisfactory owing to the difficulty in reloading the gun. To evercome this difficulty the gun was lowered, which brought its line of fire inside the circle described by the propeller.

Thus arose the difficulty of shooting into the propeller, and various attempts were made to solve this problem. The blades of the propeller were armored at the points where the bullets would strike, with steel of a shape calculated to cause the bullets to glance off, but this system was never very satisfactory. In other cases linen fabric was wrapped around the propeller at points where the bullets would strike to keep it from splintering, as it was found that several shots could pass through the propeller without causing it to break.

This was the condition on all fronts early in 1915. All of the Nieuports had their fixed guns literally shooting through the propeller; that is to say, if the bullet hit the propeller it went through it if it did not wreck it. As late as February, 1917, Maj. Eric T. Bradley, United States Army, at that time flight commander in the British service, flew 40 miles over the Bulgarian lines, fighting with Lewis guns and no synchronizing device.

Who first invented the device for controlling the fire so as not to strike the blades of the propeller is uncertain, but it is an admitted fact that the Germans first extensively used such device on their

Fokker monoplanes, which caused so much damage on the western front in 1915. It was some time after this date that the allies used similar devices.

The introduction of the so-called synchronized gun was an improvement which made aerial combat a large factor of the war. It seems to be credited to several people. It is difficult to state to whom the credit of this invention is due. Some give the credit to the famous Frenchman, Roland Garros.

CONDITIONS IN THE UNITED STATES, APRIL, 1917.

Neither the Ordnance Department nor the Aviation Section of the Signal Corps had had any experience worthy of the name with aircraft guns. None of the airplanes used at the time of the mobilization on the Mexican border were equipped with machine guns. In short, the Army was essentially ignorant. The Army was entirely lacking in experience in these matters.

There had been manufactured by the Savage Arms Co. in this country Lewis flexible aircraft guns for the British Government. No aircraft guns of the fixed type had been manufactured in this country, and nothing was known of the mechanism of gun control, sometimes called the synchronizer.

None of the gun mounts or other special details connected with the installation of aircraft armament had ever been produced in this country.

SPECIAL REQUIREMENTS OF MACHINE GUNS IN THE AIR.

The operation of the guns must be reliable to a degree. To have a gun jam may be fatal, and little can be done to overhaul the guns in the air. If a jam or malfunction occurs at a critical moment, the gunner is left at the mercy of his adversary. The gun must function perfectly in any position in which it is liable to be placed by the maneuvering of the plane. The guns are subject to extreme variations of temperature and must be certain to function in intense cold, often below zero, as found at high altitudes. The ammunition must be superperfect to still further avoid the possibility of the gun jamming.

An intensely high rate of fire is essential. On the ground 500 shots per minute is reckoned as sufficient for the machine gun, but aircraft guns have now been brought up to 950 to 1,000 shots per minute. This high rate of fire is important because of the great speed at which airplanes move. The gunner can only train on his target for a few seconds at a time, and every possible shot is essential. When one considers that if an airplane fires at right angles at a fixed target with the plane moving at 100 miles per hour and the gun shooting

880 bullets per minute the bullets will be spaced 10 feet apart on the target, the necessity for extreme rapidity of fire is evident.

Aircraft guns are never fired continuously for any length of time, therefore water cooling is not required. No special cooling devices are provided for machine guns when especially designed for aircraft use.

TWO DISTINCT TYPES, FIXED AND FLEXIBLE.

Single-seater machines carry only fixed guns, which are attached with the barrel parallel to the axis of the airplane. These guns are controlled or synchronized so as to shoot through the circle traversed by the propeller. They are put in action by a trigger on the joy stick of the airplane and are aimed by pointing the entire airplane at the enemy.

Flexible guns are used with two-place machines and are operated by the observer or gunner. They are carried on the universal mount, which permits the gun being pointed in any direction.

FLEXIBLE GUNS.

All the flexible aircraft guns used by the allies are based on the principle of the Lewis machine gun, originally invented by Col. Isaac N. Lewis, United States Army (retired). The Lewis gun as used by ground troops has been especially modified to make it practicable for aircraft use. Modifications particularly include the elimination of the cooling radiator and addition of a gas check to reduce the recoil. The Lewis aircraft gun at the time of the entry of the United States into the war was being manufactured by the Savage Arms Co. for the British Government. It is of particular note that the Lewis gun principle of a drum magazine is more desirable for the flexible guns than any type of belt feed, for evident reasons. The German flexible gun, known as the Parabellum, had the belt feed, with its attendant troubles.

FIXED GUNS.

At the time of the entry of the United States into the war the Vickers was essentially the only type of fixed gun used on either English or French planes and was used on all the planes early delivered by the French manufacturers for the use of squadrons of the American Expeditionary Forces.

When the Equipment Division of the Signal Corps faced the machine gun situation in September, 1917, it was found that the entire Vickers production in the United States had been previously contracted for and were depended on to supply the early requirements of the ground troops. As a matter of fact, 4.325 Vickers had been supplied on May 4, 1918—all the types suitable for ground troops and not suitable for airplanes.

The continued personal efforts of the officers of the Equipment Division secured the development of a fixed type of aircraft gun by the Marlin-Rockwell Corporation of New Haven, Conn. The original reason for this move was because the Marlin gun was the only gun available. The wisdom of this move was reflected by the fact that on June 24, 1918, the Chief of Ordnance presented cable No. 1168, demanding 7,220 machine guns for tank use. Within 24 hours 500 guns were shipped from the Air Service Depot at Fairfield, by express, to the American Expeditionary Forces. The remaining 6,720 guns were forwarded by freight in the next two weeks from the same source.

The order for Marlin guns was placed in the fall of 1917 in the face of marked opposition, but resulted in providing sufficient fixed guns for the American Air Service, and for other purposes as noted above. At the time of the signing of the armistice no other fixed aircraft guns were available from production.

PRODUCTION OF LEWIS FLEXIBLE AIRCRAFT GUNS.

The first order for Lewis aircraft guns was placed on December 19, 1917, and up to November 11, 1918, 32,957 of these guns had been delivered for use by the American Air Service. The deliveries commenced in February, 1918, with about 1,500 guns per month, and in the month preceding the signing of the armistice—that is to say, in October, 1918, about 6,000 Lewis aircraft guns were delivered.

A notable accomplishment of American manufacturing was an increase in the depth of the magazine pan so each magazine held 97 cartridges in place of the previous 47 cartridges.

PRODUCTION OF MARLIN FIXED GUNS.

The Marlin aircraft machine gun, which has been developed and manufactured by the Marlin-Rockwell Corporation, New Haven, Conn., has been adapted to all American-built planes which carry fixed or synchronized guns as part of their armament. The first order for Marlin aircraft machine guns was placed September 25, 1917, and over 37,500 were produced before December, 1918. Quantity production of 2,000 per month began in January, 1918, and increased rapidly until as many as 7,000 guns were produced in one month. Our aviators report that this gun compares favorably with the best machine guns used by our allies, and is entirely satisfactory in every respect. This machine gun shoots .30 caliber ammunition at the rate of 600 to 650 shots per minute, and is fed from a belt which is of the disintegrating metal link type.

PRODUCTION OF "CC" GEARS.

There are two distinct types of gun control, both in use at the time of the signing of the armistice. These are the hydraulic and the mechanical.

The operation of both these types is somewhat similar. In each case a cam mounted on the engine shaft actuates a plunger when the device is in operation, which in turn operates the rest of the mechanism. In the mechanical gun control the impulse of the cam is transmitted through a series of rods to the gun, causing the gun to fire at the proper moment. In the hydraulic gear the impulse of the cam is transmitted to the gun through a system of copper tubes containing oil under high pressure.

The hydraulic type of gun control, known as Constantinesco control (CC), was copied for American planes, particularly the DeHaviland 4, which carries two fixed air-craft machine guns (Marlin, each firing at the rate of 650 shots per minute. At maximum fire, 1,300 shots per minute could be fired between the blades of the propeller revolving at a rate of as high as 1,600 revolutions per minute without any of the bullets striking the blades of the propeller. Four guns have been successfully fitted to one plane and timed with these devices so that none of the bullets struck the blade of the propeller.

At the time of signing the armistice 6,827 "CC" gears had been shipped.

AIRCRAFT AMMUNITION.

Generally speaking, all aircraft ammunition used is of regular service caliber. All ammunition is especially gauged so as to eliminate, as far as possible, the chances of the guns jamming. Even the regular-service ammunition furnished for use of aircraft guns is special in the sense that it is picked out for accuracy.

The production of ammunition for aircraft guns has increased very rapidly, not only because of the increase in use of airplanes, but because many of the observation machines to-day carry four guns and the consumption of ammunition per plane has radically increased.

The fact that two fixed guns and two flexible guns are often carried still further reflects the necessity of perfect ammunition. The primary reason for carrying two of each kind of gun is to immediately have another gun available in case the first gun jams.

Efforts to make the bursts of fire from airplane guns of maximum effectiveness have led to the development of three distinct types of ammunition. This special ammunition not only requires the extreme care in gauging that is applied to service ammunition for aircraft use, but also involves the special types of bullets.

Enormous quantities of this special ammunition were being produced at the time the armistice was signed; the rate of production exceeding 10,000,000 rounds per month.

The *tracer type of ammunition* has a projectile containing a smoke-producing charge which ignites when the cartridge is fired and leaves a trail of smoke for about 600 yards. This type of ammunition was developed to assist the gunner in aiming his gun, and is equally useful at night or day, as the white smoke can be seen in the daytime and a bright spark at night.

Armor-piercing ammunition has a projectile which consists of a hard steel core with a soft nickel casing. As the name implies, the object of this type of ammunition is to pierce any of the metallic parts of the airplane, particularly the engine or gasoline tanks. The soft nickel casing acts as a lubricant and prevents the steel core from glancing off.

Incendiary ammunition has a projectile containing a charge of yellow phosphorus, and when the cartridge is fired the rifling of the machine-gun barrel causes a small hole in the case of the projectile to open and allows the phosphorus to come in contact with the air and it ignites immediately. This will set fire to any inflammable part of the airplane which it may hit.

It is customary to load the ammunition belts or containers with these three types of special ammunition in certain sequences. First, the tracer cartridge, which assists the gunner in correcting his aim; then two or three armor-piercing cartridges, which possibly will injure the engine or pierce the gasoline tank; then one or two incendiary cartridges which, if by chance the gasoline tank has been pierced, will ignite the leaking gasoline, thereby setting fire to the machine. This sequence is repeated throughout the belt or ammunition container as the case may be. Different pilots use different sequences in loading special ammunition, according to what they consider the most effective method.

For the fixed guns, the ammunition is carried in belts carrying a maximum of 500 rounds for each gun. This belt, as furnished to the American Expeditionary Forces, is made of small metallic links held together by the cartridges themselves. As the gun fires, the links fall apart. Chutes are provided so that the links fall clear of the airplane. This type of belt was developed especially for aircraft use to eliminate the problem of taking care of the empty belt or furnishing a container for the empty belt. The links of the disappearing belt must, of course, equal in number the cartridges consumed. The actual production in this country up to the signing of the armistice consisted of 59,044,755 links. These links appear to be extremely simple, but the extreme accuracy required created a difficult manufacturing situation necessitating extreme care. The production and inspection of these links involves over 36 separate operations.

ARMAMENT SUNDRIES.

The details of fitting the guns to the planes and providing for proper sights and gun control involve many pieces of work, each minor in themselves, but as a whole presenting a very material problem.

The sights are simple excepting the so-called unit sight, which was copied exactly from the English design. The primary difficulty was in securing the necessary optical glass. Unit sights to the number of 12,621 had been produced at the time of the signing of the armistice, and 1,550 had been sent overseas to equip foreign-built planes that had been furnished the American Expeditionary Forces.

The extreme altitude and the difficulty of keeping the gun oil from congealing makes it necessary to keep the guns warm. A small electric heater is provided for this purpose. These are small resistance grids fastened to some convenient part of the gun.

TYPES.

The Marlin aircraft machine gun, made by the the Marlin-Rockwell Corporation, and the Lewis aircraft machine gun, made by the Savage Arms Corporation, are the two American-built machine guns actually used on American-built planes up to the time the armistice was signed. In this type of gun a small amount of the explosive gas is allowed to act on the head of a piston which operates the action of the gun, being returned to position by a strong return spring. The operation of both guns was very satisfactory.

The Browning aircraft machine gun was just coming into quantity production. This gun embodies the best principles of every known machine gun, and would probably have replaced all fixed machine guns of other types in use. It had the high rate of fire of more than 950 shots per minute and was very accessible and extremely reliable in every respect. This is a belt-fed gun of the recoil type.

AIRPLANE BOMBS.

NOTE.—The production of airplane bombs is handled by the Bureau of Ordnance on requisition of the Air Service.

One branch of aerial warfare which was steadily increasing in effectiveness and magnitude was aerial bombing. Bombs of a sort were dropped from airplanes in Italy's war in Africa, and also by American soldiers of fortune in the Mexican trouble in 1914. The huge Zeppelins of the enemy were the first aircraft to attempt systematic bombing, but their early efforts were not accompanied by much success, owing to the general ignorance of the design of an effective aerial bomb. The lowering effect on the morale of the enemy was, up to the last year and a half of the war, probably as great a result of bombing as the actual damage caused by the explosion of the bombs.

No one who has not tried it can realize the extreme difficulties in dropping a bomb from an airplane so that it will hit a desired target. Owing to the great speed at which an airplane travels through the air, a bomb when released does not drop vertically but falls to the ground in a curve. For this reason the bomb must be released some little time before the airplane is directly over the target and the ability of an aviator to determine this point accurately is only acquired through experience.

The line of flight of a bomb from the point of release is influenced by the speed of the airplane, the height of the airplane above the ground, the shape of the bomb itself and cross currents of air acting on the bomb on its way down.

The Bombs themselves are shaped so as to offer the least possible resistance to the air and have fins on the tail to hold the bomb steady and keep it from tumbling.

Quick-release Mechanisms are provided on all bombing airplanes, which hold the bombs firmly in a vertical or horizontal position by hooks or bands around the body of the bombs. Release mechanisms are usually placed underneath the lower wings or fuselage of the smaller types of bombing planes such as the De Haviland–4. On the large types, such as the Handley-Page, the bombs are carried inside the fuselage. The bombs are usually released by the observer who has a small lever in a convenient position for that purpose.

Bomb Sights constitute part of the equipment of all bombing planes. These sights have numerical scales mathematically calculated so that when adjusted for height, air speed as shown by air speed indicator, calculated strength of wind with or against the airplane, two sighting points are moved into such a position that if the bomb is dropped, when the desired target comes in line with them, it will reach its objective providing the sight has been set correctly.

Practically all bomb sights produced were an exact copy of the English high altitude Wimperis. On November 11, 8,371 had been produced.

American Demolition Bombs are made in different weights, 50 pounds, 100 pounds, 250 pounds, 500 pounds, and 1,000 pounds. The 100 and 250 pound sizes are used mostly. These bombs consist of a light steel casing filled with T. N. T. or other high explosive, and a detonator held apart from the explosive charge by a safety pin. When the bomb is released from the airplane the safety pin is pulled out, allowing the detonator to slide down into such a position that the bomb will explode as soon as it strikes the ground. These demolition bombs are for use against buildings and all sorts of heavy structures where a high explosive charge is desired.

Fragmentation Bombs are smaller, the size most commonly used weighing 20 pounds. They have a thicker case than the demolition bombs and are constructed to explode a few inches above the ground. These bombs are for use against personnel on the ground or in trenches and depend upon the scattering of the fragments for effect.

Incendiary Bombs weigh about 50 pounds and contain charges of oil emulsion, thermit, and metallic sodium, which burn with intense heat for several minutes. The purpose of the metallic sodium is to discourage the efforts of anyone trying to put out the fire, as it explodes violently if water is poured on it. Incendiary bombs are used against ammunition depots and any structure of an inflammable nature.

AERIAL PYROTECHNICS.

The part played by pyrotechnics in modern aerial warfare is an important one and one which must not be overlooked in a discussion of the various and innumerable accessories and equipment applicable to the up-to-date airplane. It is interesting to consider that almost identical forms of the fireworks we burn on Fourth of July and similar celebrations are utilized for aerial warfare, and form a valuable and often vital asset for the aviator.

The principal use to which pyrotechnics are put is that of signaling from the airplane to the ground and vice versa, also from one plane to others in the air at the same time.

VERY PISTOL.

For signaling every active service airplane is equipped with one or more signaling pistols, depending on the number of the crew. These rather formidable appearing weapons are similar to the Very signaling pistols used in the trenches, and their ammunition consists of cartridges very similar to a shotgun shell but larger, containing different colored stars and a sufficient charge of powder to eject the stars a good distance into the air. Three colors, red, green, and white, are furnished, and the color of the star is painted on the end of the cartridge, also the base is serrated differently for each color so that the aviator can tell the color by the feel, for use at night. By different combinations of these three colors a great variety of signals may be conveyed. The stars are quite visible in the daytime and are used for many purposes, such as indicating position of enemy troops, presence of hostile aircraft, requests for assistance from other airplanes, as a method of transmitting orders from the leader of a squadron to other machines in formation, etc. At night the signaling pistol is of exceptional value in enabling the pilot to make a safe landing. When approaching the home landing ground the pilot fires a light of a predetermined color and, if answered by a light from the ground of the proper color, he is assured that the landing field is clear of obstruction and other machines and safe to land on.

It is the duty of every pilot to destroy his machine in case of being forced to land in enemy territory, and these signaling pistols have in many cases been used effectively for this purpose by firing into the body of the machine or any inflammable part and thereby setting fire to it. There are also a few cases on record of the pilot being able to hold the enemy at bay with the signal pistol long enough to prevent them from any chance of extinguishing the fire.

All Very pistols actually furnished for use of the American Expeditionary Forces were purchased abroad.

WING TIP FLARES, OR HOLT FLARES.

Night flying is one of the most hazardous duties of the aviator, the chief danger being in the difficulty of making a safe landing. Night landing fields as a rule are well illuminated by flood lights, but near the front this is not always advisable and owing to the difficulty of judging the distance of the machine above the ground at night, accidents are not uncommon.

This condition of affairs has been greatly improved by the use of the wing tip flares which is adapted from the Holt landing flare of British design. These flares consist of a small cylinder of magnesium material held in a metallic holder, one of which is fitted under each lower wing of the plane.

The wing tip flares are ignited by an electric current furnished by a battery or by the generator which supplies the lighting and radio apparatus, and are controlled by push buttons, one for each flare in the pilot's cockpit. In making a night landing, when the pilot judges the plane to be but a few feet above the ground, he presses one of the push buttons. The flare immediately ignites and burns with a brilliant light of approximately 20,000 candle power for about 50 seconds. This light is reflected on the ground by the under surface of the wing and thereby enables the pilot to judge his landing perfectly.

AIRPLANE FLARE WITH PARACHUTE.

The requirements of aerial warfare have led to the development of a very interesting form of pyrotechnics known as the airplane flare. This flare weighs 32 pounds and is contained in a cylindrical sheet-iron case 46 inches long and 5 inches in diameter. The flare consists of an illuminating charge, capable of giving 32,000 candle-power for approximately 10 minutes, which is attached to a silk parachute 20 feet in diameter. The flare is attached to the airplane by a light release mechanism similar to those holding the bombs. When released a pin wheel on the end of the flare case is revolved by the rush of air and ignites the illuminating charge, at the same time detonating a black powder charge sufficient to eject the flare and its tightly rolled parachute from the case. The parachute immediately opens and the burn-flare descends very slowly, brightly lighting up the territory in a large area under it.

These flares are used particularly for night bombing raids. The flares are dropped over the objective, thereby illuminating it and enabling the bomber to more accurately drop his bombs. It has been found in many cases when violent antiaircraft fire is encountered at night that one of these flares will so dazzle the eyes of the antiaircraft gunners as to make their aim very inaccurate. Recent experiments have proven that with the aid of these flares it is possible to obtain aerial photographs of good detail on the darkest of nights. Production on these flares was just starting.

PHOTOGRAPHIC EQUIPMENT.

The story of the production of photographic equipment for the Air Service of the United States is a story primarily of the rapid copying of models used by the Allies, followed later by unique American developments.

It has been truly said that "the airplane is the eye of the army," and it is equally true that the camera is the eye of the airplane. Contrary to general belief outside of military circles, the principal function of the airplanes is the securing of information, and the camera secures and retains this information with fatal accuracy.

The importance of the pictures taken from the air, showing the progress of the battle, is emphasized by the comparatively large number of pictures which were used by the intelligence officers during combat. Illustrative of this point, and as an example of the work done by the American photographic forces, it might here be well noted that during the drive in the Argonne district, the American photographic sections made 100,000 pictures of the battle lines in four days' time.

The equipment required for the photographic work of the Air Service can be best understood by having in mind a general classification of the work to be done.

Mapping is the primary and most important work of aerial photography. These mapping cameras all provide that when once started, a new plate or film will be automatically put in place and exposed, and the speed of this action is so controlled by the observer in relation to the speed of the airplane over the ground that a series of pictures making a continuous photograph of a given strip of territory is obtained.

Hand cameras, differing from ordinary cameras primarily because they have much greater focal length. These cameras are for single exposures used to photograph other airplanes, or perspectives of ships at sea, or scenes on the ground.

Gun cameras, installed in place of machine guns and used for target practice. These are either "single shot" cameras that indicate the spot held on when the gunner pulled the trigger, or are continuous motion-picture cameras that make an exposure corresponding to each shot of the gun. This again is used for checking the marksmanship of the gunner.

Photographic trucks, or traveling dark rooms, and endless supplies and equipment are required for handling the work after the exposed plates or films are delivered on the ground.

CONDITION IN EUROPE IN 1914.

As aerial photography was an entirely new military subject at the outbreak of the war in 1914, there were no precedents to go by, nor had any special apparatus been designed for this purpose. Consequently the entire subject of aerial military photography was developed by the allied armies during the period from August, 1914, till the cessation of hostilities, and as trench warfare made aerial photography extremely important, the changes and improvements in apparatus came with incredible rapidity.

At the outset it was possible to fly at low altitudes and secure satisfactory pictures with such cameras, plates, and lenses as were then available. As antiaircraft guns were developed, the planes were forced to attain a higher altitude, and photographic observations in turn had to be made from increasingly higher altitudes, making necessary the use of longer focus lenses, special plates, and special color filters to overcome the haze existing between the camera and the ground.

MAPPING CAMERAS.

Some work had been done in this country by Arthur Brock, jr., of Philadelphia; the G. E. M. Engineering Co. of Philadelphia and the Eastman Kodak Co. of Rochester had given the matter considerable attention; and the Engineer Corps, together with the Bureau of Standards, had given some thought to mapping cameras.

All technical information concerning these highly technical subjects developed in Europe during the war had been most carefully guarded, and most meager and conflicting information was all that was available in April, 1917.

In June, 1917, the photographic division of the Signal Corps was organized, large purchases were made of cinematograph cameras, hand cameras, and view cameras, and at once attention was given to training the organization necessary to handle this equipment.

Aerial photography received little attention until October, 1917. At that time attention was stimulated by much valuable information imparted by the Italian and French High Commissions, and particularly by the arrival of Maj. Campbell of the Royal Flying Corps, who brought with him from England a complete equipment of photographic apparatus as then used on the British front.

Maj. Campbell at once made clear the amazing volume of accurate information brought in by aerial photographic observers. He stated that in April, 1917, approximately 280,000 prints had been issued to the British service. He also made clear that, due to the importance of the work and the very rapid development, practices employed one week at the front were obsolete the next.

The fact that neither the British, French, nor Italians were using films for aerial photography, backed by Maj. Campbell's very decided opinion that films were unsuitable, lead to the decision to discontinue experimental work then underway with automatic film cameras. In fact, it was not until August, 1918, that this line of work was resumed.

A survey of the situation indicated that the British system differed but slightly from the French. Both used cameras mounted in the planes in various types of vibration-reducing suspensions.

The French cameras made a relatively large negative, on glass plates, using cameras fitted with 20-inch focus lenses. Contact prints were made direct from these negatives.

The British used 4 by 5 inch plates and cameras equipped with lenses of from 8-inch to 12-inch focus. Instead of making contact prints from these negatives, enlargements 6½ by 8½ inches were made on glossy paper. It was claimed that this process gave greater control in printing, and it is undeniably true that the lenses for the smaller cameras were more easily obtained.

The British system was adopted and was followed throughout the earlier development of production in the United States.

All mapping cameras are attached by spring suspension to the fuselage. The cameras point straight down toward the earth and were originally placed on the outside of the airplane, but the more modern designs are placed inside, and point directly through the floor of the fuselage. Cameras are always mounted with a rubber cushion or other device to minimize the bad effect of the vibration of the plane.

All of the cameras discussed are designed to take a series of pictures that, together, make a continuous photograph of a given strip of territory. The earlier cameras were hand operated, followed by spring-driven instruments, which later were followed by designs driven from a small air screw exposed to the passing air. The latest type of full automatic camera uses an electric motor drive.

The first camera submitted by Maj. Campbell—type C—carried eighteen 4 by 5 inch plates, 12-inch focus, and was hand operated. This was rapidly followed by type E, which was of a similar design, but of metal, and in December, 1917, the type L camera, of which

750 were delivered by the Eastman Co., was put in production. This instrument was superior, not only because of numerous details in design, but because an air propeller was used to drive the mechanisms of the camera—that is to say, the plates were changed and the shutter set automatically, leaving the operator nothing to do but press the release.

18 BY 24 CM. (FRENCH SYSTEM FOR CONTACT PRINTS).

In January, 1918, Mr. G. S. Dey, of the Eastman Kodak Co., returned from overseas and assisted in reviewing the general situation. It was agreed that the type L camera, previously mentioned, should be manufactured with all possible speed. At the same time, the necessity for a camera of longer focal length, carrying a greater number of plates, and of a size suitable for contact printing, was presented by Mr. Dey. He had with him a model of the De Ram camera, a machine of French design. This machine carried 50 plates 18 by 24 centimeters, the lens was of 20-inch focal length, and the whole outfit weighed about 90 pounds. None of these machines were actually produced in this country.

About the same time the Folmer & Schwing Division of the Eastman Kodak Co. developed an 18 by 24 centimeter film camera, also of 20-inch focal length; weighing, however, only 35 pounds, accommodating a roll of films on which 100 successive exposures could be made. The particularly novel feature of this camera was the "vacuum back." This was a perforated sheet which extended across the top of the chamber and over the face of which the film passed. A slight air suction through the perforations served to hold the film sheet absolutely flat. This air suction was produced by a Venturi tube, placed where it would catch the rush of air past the airplane.

This automatic Folmer film camera was driven by an electric motor, and all that was required of the observer was to start the camera and regulate its speed according to the ground speed of the airplane. Only six of these cameras were delivered at the time of the signing of the armistice, but apparently they reflected a marked step in advance.

CAMERA SUSPENSION.

The vibration of the airplane caused by the motor and the rush of the plane through the air would be fatal to good photographic results unless the vibration be effectively eliminated in the camera. This dictates the necessity of a spring or cushion suspension, in itself a new development in America, but the British practice was largely followed in the production in this country. This matter is of great importance when it is realized that pictures taken from an altitude of over 10,000 feet indicate where one soldier has walked across a field.

PRODUCTION OF AERONAUTICAL CAMERAS.

At the time of the signing of the armistice there had been delivered 1,164 aeronautical cameras complete with their spring suspensions, motors, and other accessories. This was accomplished primarily through the extremely energetic action of the Eastman Kodak Co. and also of Arthur Brock, jr., of Philadelphia, and the G. E. M Manufacturing Co., of Philadelphia.

GUN CAMERAS.

Camera guns are used to train aerial gunners. Target practice with a machine gun in an airplane is not only difficult but also dangerous, and the towing of a suitable target is impracticable. Thornton Pickard, of Altringham, England, had devised a camera which was being used successfully in training gunners. This instrument imitated as closely as possible an aircraft model Marlin machine gun, and in order to make a picture it is necessary to go through the same movements as in firing a Marlin gun. The picture is made through a circular graticule synchronized with the sight on the fixed machine gun and, if the film shows that the gunner scored a hit with the camera, he would have been equally successful with an actual gun.

This "single-shot" gun camera, known as the Mark III, used a typical Brownie film, which took one picture each time the trigger was pulled. This could be used to replace either the fixed gun usually operated by the pilot of the airplane, or in place of the flexible gun operated by the observers, but only one picture was taken at a time.

It is interesting to note that in August, 1917, a sample of the single-shot camera (Mark III) was obtained from Canada, and a copy thereof made in one week by the Eastman Kodak Co.

At the time of the signing of the armistice 150 Mark III gun cameras had been delivered.

In September, 1917, the Eastman Kodak Co. started work on an experimental model camera gun Mark I, which would give a "burst" of exposure with a rapidity approximating that of the machine gun firing a burst of shots; this was a great improvement over the Mark III, which made but a single exposure with each pressure of the trigger. A model was submitted and shortly after the Navy ordered a number, and Gunnery Training Branch, Signal Corps, placed orders for these instruments, which orders were increased from time to time until in November, 1918, 1,057 Mark I camera guns had been delivered.

The Mark I camera was, in common language, a moving-picture camera, and exactly replaced the magazine on a Lewis gun; that is to say, it was used for training gunners in the handling of their flexibly mounted Lewis guns. The resulting film, or bromide print, was a string of silhouettes of the supposed enemy plane, each with an image of the gun sights superimposed to show where the gun was held, with reference to the target, at the instant the picture was taken.

LENSES AND RAY FILTERS.

It must be remembered that the camera is only a mechanism to hold the optical devices. The development and procurement of lenses was a matter of importance, and as the altitude at which photographs must be taken increased, the development of ray filters to overcome the haze effect produced by the moisture in the intervening atmosphere became essential. The solution of these optical problems was in itself a matter of vital importance in which America played no mean part. The success of this work and the importance of ray filters is shown by two photographs of the same subject, one taken without a filter and the other taken with a ray filter.

GENERAL EQUIPMENT.

Particular stress is always placed on aerial cameras themselves, but practically they were only the beginning of successful photography. Innumerable sundries were required to produce satisfactory photographs. Lenses, paper, plates, chemicals, tanks, trays, printing machines, stereoscopes, together with the traveling dark rooms to do the work in, were all required to properly equip the field forces. Much of the material on the market was unsuitable.

The magnitude of these matters is indicated by the October shipments of some of the principal items of supply.

Over a million and a half sheets of photographic paper were shipped in October.

Over 300,000 dry plates.

Over 20,000 rolls of film, with 20 tons of photographic chemicals.

Traveling dark rooms, trucks, and trailers were specially developed to provide dark rooms at any and every point. Seventy-five complete units of these machines were shipped. These are mobile photo laboratories, having all equipment necessary for the rapid production of prints in the field. The truck body is equipped with a Dyneto generating outfit for generating current used in dark-room lamps, enlargers, etc. An acetylene generator is also provided. This may be used when the electric unit is for any reason rendered inoperative. The trailer body is equipped with sinks, tanks, enlarging camera, printing box, and other necessary photographic apparatus.

ENLARGING LANTERNS.

At the time of the signing of the armistice 460 enlarging lanterns had been furnished for use in the field in connection with the 4 by 5 inch negatives made by the aerial form of camera.

CONCLUSION.

The fact that should not be overlooked is that provision had to be made on airplanes shipped to France for the installation of all of the various types of photographic apparatus. The vast personnel, possibly somewhat skilled in photography, nevertheless had to be trained for aerial photography. All of the development work, every portion of it technical to a degree, had to be done in America practically during the last 12 months of the war. Such results as have been obtained are extremely creditable to the American manufacturers of photographic equipment.

AVIATORS' CLOTHING.

Aviators are commissioned officers and when not at work wear the regular uniform which, as in the case of all officers, is furnished by the officers themselves.

When at work in the air the clothing equipment is highly special and is loaned by the Government to the fliers.

When the United States entered the war we had no standards to work from, we knew little of the problems involved and how far reaching were these problems. Yet the work covered a multitude of problems reaching from securing 400,000 dog skins in China to determining conditions 20,000 feet above the western front.

There had been no standard styles established, or rather there was a chaos of conflicting styles, many of which were good by themselves, but would not function with other equipment that was necessary.

PURCHASE PROBLEM.

The purchase of aviators' clothing for the Army was at first made by the committee on supplies of the Council of National Defense, in charge of Mr. Julius Rosenwald and Mr. E. Tyner. From there it was taken over and for a short time was done by the Quartermaster Department, when it was again transferred to the Bureau of Aircraft Production, and put in charge of Maj. John E. Hays.

In purchasing this material there were several points to be considered. First, that it should be as warm as possible without being so cumbersome as to interfere with the movements and efficiency of the aviator, for when a man is up 20,000 feet, flying at a speed of 100 or more miles per hour, in a temperature well below zero, he can not be clad too warmly; also that it should be of such sturdy construction as to withstand hard usage and all conditions of weather; and finally that each part should function properly with all of the other parts.

After many tests and much development, the following outfit was used:

HEADGEAR.

On the head was worn, in moderate weather, first, a woolen hood or helmet so designed as to fit closely over the entire head and neck, extending down well over the forehead to the eyes and around the neck to the shoulders. In extremely cold weather, or for high-flight work, a silk hood of double thickness and like design was worn, having between its layers an electrically heated unit connected with a generator on the engine of the plane by copper wire cables that extended through the suit proper. Over this was worn a soft leather helmet, lined with fur, and extending down over the back of the head and covering the ears and sides of the face, fastening under the chin. The face was entirely covered with a leather face mask, lined with wool, and with an opening for the eyes, over which was worn a pair of goggles.

At times when communication with either the ground or other airplanes was essential, the radio helmet replaced the fur-lined helmet. This was made of leather and somewhat similar in design to the other, but so fashioned as to contain the receivers of a wireless telephone, enabling a flier to hear what was spoken to him in an ordinary tone of voice many miles away.

Oxygen masks were worn for high-flight work in addition to the above equipment. The oxygen mask was made of rubber, which contained a transmitter allowing him to speak as well as hear by wireless. This mask was attached by a flexible tube to a tank of oxygen carried in the plane and so arranged as to feed automatically a different amount of oxygen as different altitudes were reached.

It was found by a series of tests, made in a room so designed as to create the exact and various conditions that would exist at any known height, that a man's faculty to respond at sight, sound, or touch became more dormant as the air became rarefied, and consequently the man in combat who could remain in a normal condition by the use of oxygen could begin firing his gun sooner than one not so equipped.

BODY CLOTHING.

Over the body was worn a one-piece flying suit, extending from the feet to the throat, belted and buttoned tight at the anxles and wrists; this being made of waterproof outer material so arranged as to leave no opening or crevice when buttoned and lined throughout with fur.

The question of obtaining fur for these linings was a problem. Vast quantities of fur were required and had to be of extreme warmth, with a pelt or skin sufficiently strong to withstand rough usage and still not be of too great bulk, and at a price not over extravagant. It was determined that a Chinese Nuchwang dog skin met these requirements better than any other, and they were consequently used. This required practically all of these skins that could be obtained in both this country and China, and necessitated the lifting of an embargo to bring these skins into this country, which, through the cooperation of the War Trade Board, was accomplished.

When it is considered that the last purchase before the armistice was signed was for a quantity of between 450,000 and 500,000 of these dog skins, it may safely be said that, at least, it is not the dogs that are making the nights hideous in China.

Through these suits, between the fur and outer covering, were placed wire cables terminating in snap fasteners at the wrists, ankles, and neck, to which could be attached a silk-covered wire leading to electrical heating units, placed in silk gloves, moccasins, and helmets, all of which were warmed by an electric current drawn from the generator on the engine.

CLOTHING FOR HANDS AND FEET.

On the hands were worn, besides the electrically heated gloves, a pair of muskrat fur gauntlets, extending well up the arms and of a special design which allowed the fingers of the glove to remain in a fur-lined pocket or be withdrawn from it when necessary without removing the glove.

On the feet were worn, in addition to the electrically-heated moccasins, a leather moccasin extending well up the calf of the leg and lined with heavy sheep wool. These were fastened with straps and buckles.

MISCELLANEOUS EQUIPMENT.

In addition to the above, there were many other items furnished, such as sweaters, leather coats of various lengths, a fur-lined coat, two styles of hard helmets, used mostly by students and observers, and many styles of goggles.

CONCLUSION.

The air clothing problem involved not only quantities of special material and workmanship far beyond existing resources, but endless attention to detail.

Many returning fliers state that it was generally acknowledged that our fliers were by far the best and most efficiently equipped of any nation.

The magnitude of the clothing problem can perhaps be best understood by a few figures. The initial allotment of funds for this purpose was $2,509,000. This was still further increased from later appropriations, and on November 11 the work in hand for air clothing involved over $5,000,000.

Items of over 50,000 fur-lined flying suits ($36.25 each), over 100,000 leather helmets of all kinds (about $4.50 each), over 100,000 leather coats (from $10 to $30 each), and over 80,000 goggles ($3.50 each), reflect the major items.

OXYGEN FOR THE AVIATOR.

The oxygen apparatus furnished to the American Expeditionary Forces was developed and produced by the Bureau of Aircraft Production under the direction of Brig. Gen. T. C. Lyster of the Medical Section of the Department of Military Aeronautics. These notes are formulated from information from Capt. E. A. Hults, who had charge of the production, and are approved by Brig. Gen. Lyster.

Coincident with development along other lines, the maximum altitude attained by airplanes has increased enormously during the war. The record for altitude in 1914 was 26,246 feet, and to-day, January, 1919, the record is 30,500 feet. (Accuracy questionable.)

In 1915, over the western front pilots worked at 7,000 feet without fear of attack from the ground and few machines would fly above 10,000 feet. The "ceiling" with the early equipment was about 12,000 feet.

In the closing months of the war antiaircraft guns on the ground made 15,000 feet necessary for safety over the enemy lines and tactics of the air made that machine safest that could fly highest. Actually the working ceiling of 18,000 feet was demanded and obtained from the latest types of planes.

EFFECT OF HIGH ALTITUDE.

At 19,000 feet the pressure of the atmosphere is one-half the pressure at sea level. That means that a given amount of air in the flyer's lungs gives only half the oxygen, and this lack of oxygen, not the low pressure itself, makes men "dopey" and weak at high altitudes. The determination of these simple facts is an important result of medical research work done for the Air Service. While the fact seems clearly proved that extra oxygen is necessary at high altitudes, it is a curious phase of the flyer's psychology that most aviators still laugh at the idea.

As the altitude increases the breathing becomes quicker and deeper; the heart beats faster and faster. The body tries to obtain the requisite amount of oxygen by increasing the amount of air breathed in a given time and by exposing a greater amount of blood to the oxygen in the air cells of the lungs. While breathing rapidly and really in distress, many pilots do not feel any marked inconvenience. He may feel perfectly fit and well, but he is not as efficient as when near the ground. His reaction becomes slower, he is less prompt to judge distance, to aim his guns, to fire, and maneuver his ship, although he is not conscious of this impairment. He will feel dizzy but perfectly happy, though as a matter of fact he has lost his judgment, and if he attempts to stay at these altitudes he will gradually pass into a condition of semi and sometimes total unconsciousness.

EARLY WORK.

The great necessity of efficiently maintaining fliers was brought about through a study of the English air casualties during the first year of the war. These were about as follows: Two per cent due to the Hun, 8 per cent due to the plane, and 90 per cent due to the men, which clearly indicated that something was radically wrong with the personnel, and immediate action was necessary. A thorough study of this situation disclosed the fact that practically all of the flying personnel was suffering from what was known as oxygen fatigue or lack of oxygen, being caused by flying so many hours of the day at high altitudes and not securing enough oxygen to properly feed the body.

The first apparatus was designed for the British air service by Lieut. Col. Dreyer of the British R. A. M. C., and was made at the plant of De Lestang at Paris. The demand for these apparatus was so great that an automobile was kept waiting at the plant for each apparatus as it was finished and was especially rushed to the front. An indication of the importance of oxygen is shown by the record of the 25th Squadron 9th Wing, R. F. C. This was the first squadron to use oxygen equipment on planes in the British service. They were using the original Dreyer apparatus and found it efficient, sufficiently at least for Maj. Birley, who was in charge of the squadron to state that this squadron, in his opinion, was giving six times the service of any other British squadron.

DEVELOPMENT OF DESIGN.

To design an oxygen equipment which would be entirely automatic, one that would be reliable and efficient, necessitated the building of a device which embodied several instruments and one that would overcome many variable conditions. It was necessary to have a device that would work under variable tank pressures from 100 to 2,250 pounds per square inch with temperature varying from 80° above to 30° below zero (Fahrenheit). To overcome these variables necessitated a thorough study of temperature and pressure effects upon metals and much experiment. The apparatus must automatically deliver the proper quantity of oxygen to either one or two men at every altitude from 3,000 to 30,000 feet.

An original model of the French-made apparatus was brought to this country to start quantity production. The French apparatus was a handmade device, each part being carefully fitted by an individual workman. Under the direction of Brig. Gen. T. C. Lyster, Medical Research Board of the Medical Section of the Department of Military Aeronautics, and the Bureau of Aircraft Production, the development and engineering of an oxygen apparatus to meet American requirements and to be adapted to American methods of manufacture was undertaken.

The entire apparatus had to be redesigned, first to take care of two men instead of one; second, to reduce the weight, and third, to meet American methods of manufacture, and fourth, to make the apparatus more efficient and reliable. This work was started about the 1st of January, 1918.

The entire Air Service is under great obligations to A. C. Clark & Co. of Chicago for their untiring efforts to develop the details of the apparatus to the necessary degree of reliability and ease of manufacture.

The equipment consists of a small tank, or tanks, according to the amount of oxygen carried, the pressure apparatus, the face mask covering the mouth and nose, and the tube connected with the reservoir. The mask has combined with it either the interphone whereby the pilot and observer can talk to each other with ease while in the air, or in certain cases, the radio receiver.

A brief description of the Dreyer apparatus for regulating the flow of oxygen is as follows:

1. A high-pressure gauge calibrated in atmospheres to indicate to the aviator the supply of oxygen remaining in the high-pressure tank.
2. A reducing valve of a flexible diaphragm type, with hermetically sealed upper chamber. The sealed upper chamber acts as a temperature compensator.
3. A hand-operated shut-off valve, of a special construction, which can be set to provide a flow of oxygen to one man, to two men, or to none at all.
4. A regulating valve, the purpose of which is to automatically adjust the flow to the altitude. This is accomplished by an adjustment actuated by what is practically an aneroid barometer.
5. A flow indicator, which is simply a small fan wheel suitably mounted to tell the aviator that the oxygen is actually flowing.

In connection with the above apparatus are used the oxygen tank, various connecting tubing, and the necessary mask. The mask itself, which necessarily contains telephone or radio receivers, as well as provisions for getting the gas to the aviator, has been an intricate problem. The aviator must, while wearing the mask, be able to see and work in a gale of wind exceeding 100 miles per hour.

PRODUCTION.

On May 3, 1918, six complete equipments, including apparatus, tanks, masks, etc., were sent overseas by special messenger to be actually tried out on the front. On May 31 the first production shipment of 200 apparatus was made. To date over 5,000 apparatus have been manufactured and accepted by the Government, and over 3,786 have been floated overseas, this production ranging from a rate of about 400 per month in May to 1,000 per month in October.

ACTUAL USE.

All military planes flying over an altitude of 10,000 feet are equipped for the application of oxygen equipment. The following type of planes all use oxygen equipment: day bombing, pursuit and chasse planes and a percentage of both night bombing and army and corps observation, this percentage depending on the altitude at which these types of planes will fly.

The importance of oxygen equipment necessitated the establishing overseas of a special oxygen equipment division to take care of the application of these equipments on planes.

As previously indicated, the oxygen idea has only been partially accepted by the fliers. Actual use on the front was just starting at the signing of the armistice.

AIRPLANE RADIO EQUIPMENT.

NOTE.—The production of airplane radio equipment is handled by the Signal Corps on requisition of the Air Service.

Radio equipment for the Air Service divides itself into two principal divisions.

First, radio telegraphy, universally used for artillery fire control and other observation work.

Second, radio telephony, developed for voice command of squadrons, and just being tried by the American Expeditionary Force.

RADIO TELEGRAPHY.

Airplane radio telegraphy had reached a relatively high degree of development when the United States entered the war. The underlying principles were the same as those of any other radio telegraph equipment. Quenched and rotary spark gaps, crystal and audion detectors were all used successfully. Although the use of transmitting apparatus on military airplanes in hostile operations had been developed in Europe, many of the earlier successful experiments in transmitting from and receiving on the airplane were made in the United States.

The first successful attempt at radio transmission from airplane to ground was made August 27, 1910, at the Curtiss Aviation Meet at Sheepshead Bay, Long Island. No message was sent, but intelligible letters transmitted by the pilot were received on the ground. Capt. Harry M. Horton, now of the Air Service, designed the transmitting set, and Col. C. C. Culver, the receiving set used at the time. Flying in those days required the pilot's constant attention, the sending key had to be mounted on the control wheel, and Mr. McCurdy, the pilot, had to pay so much attention to flying his machine that he could send only detached letters of the alphabet. The apparatus was crude, as is all apparatus used in first experiments. The wires of the machine were used as the " ground " and the antenna consisted of some 60 feet of lamp cord, which was thrown overboard, trailing while in flight.

In September, 1911, at the Aviation Meet, Nassau Boulevard, Long Island, Col. Milling won a substantial prize offered by Gov. Woodruff for successfully transmitting a wireless message from airplane to ground over a distance of 2 miles. This set was designed by Capt. Horton. In the summer of 1912 a wireless message was transmitted from an Army airplane over Laurel, Md., to Washington, over a distance of about 25 miles, and in the fall of the same year, at Fort Riley, Kans., this distance was increased to 50 miles.

Receiving a message on an airplane was a later development. Six experimental flights were made in the Philippines in December, 1914, and messages were received over a distance of approximately 6 miles.

All of these earlier experiments were made on airplanes of the pusher type having the low powered engine of that period behind the pilot. The ordinary radio receiver could be heard without special difficulty. The change to the tractor type of airplanes, with the relatively high powered engine in front of the pilot, subjected him both to the noise of the motor and the blast of the propeller with its terrific roar. The designing of a receiver usable under these conditions presented new difficulties.

Serious study of these problems by the Army was initiated in the fall of 1915 at San Diego. The problem of receiving in the noise of the tractor motor was successfully solved and messages exchanged between planes in flight. For the long distance experiments, the "quenched" type of transmitting apparatus was used. Receiving apparatus employed various types of the "audion" for detection and amplification, and the operator was provided with suitable headgear to exclude the noise.

Equipment for airplane radio work is divided into three principal groups:

Power equipment, either a storage battery or preferably a generator driven by a constant speed air fan. This part of the equipment furnishes the energy.

Radio equipment, including variable induction coils, variable condensers, transformers, and sending key (flame proof). This apparatus generates radio oscillation, i. e., makes the waves.

Antenna equipment, including reel, fairlead, and wire to radiate the oscillations or waves.

At the time of our entry into the war the allies, particularly France and Great Britain, had highly satisfactory sets developed and produced for installation on airplanes. These sets were for the transmission of telegraph signals, and were one-way sets, sending messages to the ground, but they provided no means of receiving signals. The acknowledgment of receipt of signals was shown to the pilot and observer by means of indicator panels displayed from the ground stations. The radio telegraph sets were by far the most important airplane radio equipment during the war. They were used mostly for fire-control work, the airplane locating targets, reporting same to battery, and reporting results of shots.

Power equipment.—The generator of an airplane radio set is commonly driven by an air fan directly attached to the generator which is fully exposed to the blast of air. The generator must be limited to the least weight possible and still supply the necessary power. The size of the generator must be kept within certain limits to avoid excessive wind resistance. The first point was overcome by efficient design, which helped on the second point. The use of aluminum wherever possible, and the design of conical head and streamtail solved the second.

The problem of driving the generator at a reasonably constant speed by an air fan moving through the air with the varying speed of a modern airplane involved difficulties both of design and production. The constant-speed air fans vary less than 2 per cent in speed, driving the generator at 4,500 revolutions per minute on planes traveling from 40 to 200 miles per hour. The constant speed of the fan accomplishes two vital results. The tone of spark is kept at a reasonably constant pitch, and the generator is saved from destruction by flying to pieces in excessive speed encountered in a nose dive or on a very fast plane.

Radio Equipment is mounted in sets in instrument cases that are installed as a unit on the airplanes. Weight and space must be conserved as far as efficiency and necessary range will permit. To meet these conditions no detail of design can be slighted. Special rice paper is used in condensers to get a suitable capacity in a limited space. Flame proof transmitting keys are designed, with contacts entirely inclosed, removing the danger of fire from spark. These keys are made rugged for operation by a man with heavy gloves or mittens and are provided with a small electric bulb which glows when key is closed, showing operator set is operating properly.

The instruments work between the "ground" and the antenna. The "ground" on a plane consists of a connection to the engine and framework which are all electrically bonded together. Fine wires are also woven among the struts of the wings, these also being connected to the engine. A plane thus "bonded" is said to be "metallized."

The Antenna of an airplane is entirely insulated from the plane. Airplane radio antenna for telegraph work consists of about 300 feet of fine braided copper wire trailing below and behind the plane from a suitable reel and held in place by a lead weight of approximately 1¼ pounds attached to its end. Considerable experimentation took place before suitable wire was decided upon. It must have the necessary radio characteristics, be strong enough to give service under adverse conditions, and yet not be so strong as to endanger the plane or the life of its occupants in case of the antenna fouling on other aircraft or upon trees, building, etc., in case of the plane coming close to earth before the wire could be reeled in.

Difficulty was experienced in the development of a suitable reel for handling this wire used for the antenna. A reel was finally adopted which, when released, automatically allowed the wire to unwind with a centrifugal braking device which prevented excessive speed of unwinding and which admitted of rewinding readily and of using any desirable length of antenna wire. It was found that with the lead weight on the end of the wire if a plain reel were used and allowed to unwind without a governing or braking device that the force of the weight was sufficient to break the wire when it was completely unwound.

The "fairlead" for conducting the antenna through the floor of the fuselage of the plane presented another problem. The function of a fairlead is to permit the antenna wire to pass through freely, to be wound and unwound without excessive wear on the antenna wire and at the same time to insulate the antenna wire from the plane, and provide a means of suitable connection between the antenna wire and the electric circuit of the radio equipment.

A later development of the antenna consists primarily of two trailing wires of soft copper without any weights attached. This design resulted from the necessity of a trailing antenna which would not endanger the machines and their occupants during the maneuvering of close-order flying. This equipment is apparently satisfactory and has evident advantages of simplicity and economy. In fact much of the radio telephony is accomplished with antenna consisting of relatively short soft copper wires trailing from the tips of the wings.

RADIO TELEPHONY.

Radio telephony was developed in 1910 from the original conception of the value of a system of intercommunication whereby a squadron commander on the ground or flying in a machine of his squadron could direct the flight of a squadron by voice command in the same way and with nearly the same flexibility as an officer directs the movement of the infantry.

The art of radio telephony, as applied to airplanes, was developed in the United States almost entirely between April, 1917, and November, 1918. Prior to April, 1917, a few experiments had been conducted showing the possibility of this means of communication. The voice was first transmitted from airplane to ground by radio telephone in this country in February, 1917, at the San Diego school. Several successful tests of airplane radio telephone equipment occurred during the summer of 1917 and on October 16, 1917, the apparatus had been developed to a stage which, on official test, permitted radio-telephonic conversation between airplanes in flight at a maximum range of 25 miles and from airplane to ground over a maximum range of 45 miles. This test was held at Langley Field, Hampton, Va. Samples of the above set were immediately sent to France for field test, and the first order for production of airplane radio-telephone sets was placed with the Western Electric Co. December 1, 1917.

Vacuum tubes.—The history of development and production of airplane sets for communication by radio telephone is the history of the development of the vacuum tubes which, in both theory of operation and difficulty of manufacture, are highly technical. The vacuum tube is the basis for all radio-telephone communication, and in its present stage of perfection and refinement is directly responsible for the successful application of radio telephony to the airplane. The difficulties of quantity production of vacuum tubes can best be understood by comparing the ordinary electric-light bulb with the vacuum tubes of the radio telephone. The light bulb contains but one electric circuit with two terminals; the vacuum tubes contain three circuits with four terminals. The making of the tubes with these circuits involves intricate manufacturing processes, necessitating skilled glass workers and special materials to secure the essential very high vacuum.

The vacuum tube has many applications. When used for radio telephony they act as oscillators and as modulators, i. e., by proper connection with the antenna they vary the waves radiated so that they have the same form as the speech waves of the ordinary telephone transmitter.

The transmitter is another vital accessory of airplane radio telephone sets. Anyone who has heard the roar of an airplane engine at close range, or even a half mile overhead, and then stops to consider how difficult it is to understand a telephone conversation coming from an ordinary telephone in noisy surroundings, will appreciate the difficulty of hearing conversation from an ordinary transmitter exposed to the noise of an airplane engine. Two types of transmitters were designed which practically eliminate engine noise. One of the features was the cutting away of the inclosing parts of the ordinary transmitter, thus allowing engine noises to strike both sides of the vibrating diaphragm equally. Through a special mouthpiece the voice strikes the transmitter at the proper angle. The transmitter hangs on the chest or on the helmet of the user and is spoken into, after the manner of operators at ordinary telephone switchboards. The receivers were originally sewed in the aviator's helmet, but owing to the fact that aviators generally have their own helmet, the latest arrangement is to mount the receivers on a skeleton headband which is put on before the helmet. The headband and helmet holds the receivers tightly against the ears and shut out engine noise, enabling the aviator to hear perfectly.

PRODUCTION.

Previous to our entry into the war airplane radio sets had not been manufactured in the United States. The telegraph sets followed French or British principles, but required the development of details along lines obtainable in this country. The multitude of accessories involved in complete sets presented many questions. Storage batteries were a big problem and the final decision of the Air Service was the use of Edison storage batteries as far as possible. It was necessary, however, with the SCR–65 set to use the Liberty type of lead storage batteries.

Dry batteries for telephone work are an important accessory which presented engineering and production problems. The essential point to the successful operation of a vacuum tube is a dry battery of exceedingly small dimensions, containing 15 very small closely packed cells and a voltage of approximately 22 volts and which, due to the small size of the cells and their close arrangement, deteriorates very rapidly on the shelf or in use. It was finally necessary, in order to get a sufficient number of these dry batteries overseas, to make up the component parts in the factories of this country and ship these parts overseas, where they were assembled at a special plant established for that purpose. This method of supplying dry batteries had just been established when hostilities were suspended on November 11, 1918.

Production of Airplane Radio Sets from April, 1917, to November 11, 1918.

TELEGRAPH SETS.

SCR-65, spark telegraphing *transmitting* set for transmitting telegraph messages from airplane to ground. Used for instructions in fire-control work, and is a copy of the British Sterling Buzzer Fire Control Set.

Total produced to November 11, 1918........................... 1,819

SCR-73, performs the same function as the SCR-65, but is a much more efficient, more powerful, and more desirable set than the SCR-65, and resembles the French Type "Y" set, which was the most desirable set for fire-control work. It is a Rotary Spark Set.

Total produced to November 11, 1918........................... 1,000

SCR-54, for use on the ground and is a *receiving* set for telegraph messages only. This set was used almost exclusively as a receiving set for fire-control messages, as it constituted the receiving station for all telegraph messages sent from the plane to ground. It is a copy of French Artillery Type, is a crystal detector, and is the ground receiving set for both types of transmitting sets.

Total produced to November 11, 1918.......... 7,752

TELEPHONE SETS.

SCR-59, used in airplanes for *receiving voice messages only*, and has no transmitting equipment. The purpose for which it was designed was to enable the pilot to receive voice commands in formation flying and in flying instruction.

Total produced to November 11, 1918.......... 6,509

SCR-67, for use on the ground, is a radio telephone set, and capable of *transmitting and receiving voice messages*. It is somewhat more powerful than the corresponding set used in the plane.

Total produced to November 11, 1918.......... 527

SCR-68, radio telephone set used on the airplanes for both transmitting and receiving voice message to and from the plane while in flight.

Total produced to November 11, 1918.......... 3,150

Interphone sets (not radio).

SCR–57, interphone set, which is a refinement of the ordinary telephone and is used between pilot and observer during flight. This interphone set is included as a part of all airplane radio telephone sets.

Total produced to Nov. 11, 1918.......... 3,978

SCR–89 performs the same function as the SCR–57, except that it provides for five stations of intercommunication and was intended for use on large bombing planes, etc., carrying two to five passengers.

Total produced to Nov. 11, 1918.......... 485

CONCLUSION.

The highly technical nature of all radio work makes difficult of understanding the magnitude of the problems met by the radio engineers and manufacturers of this country between April, 1917, and November, 1918. Much has been accomplished to meet the military emergency, which hastened new developments and added to the degree of perfection of the art. The radio telephone has risen from the experimental stage to the commercial stage and is due to take its place among the useful arts of the world. Its particular application to airplanes will prove of greater value in peace than in war, as it will become a necessary accessory of the commercial airplane.

THE SENTINEL OF THE SKY.

These notes principally by Mr. Everard Thompson and Capt. H. W. Treat.

Development of the Military Observation or Kite Balloon.

Just 136 years before the signing of the recent armistice, Stephen Montgolfier and his brother Joseph allowed their attention to be drawn to the fact that smoke and clouds have a natural tendency to ascend.

It was in France in November, 1782, that these two brothers made their first balloon experiments and succeeded in sufficinetly heating the air in a paper bag to cause it to rise without any apparent force acting. They were so elated over their discovery that they extended their work and finally in September, 1783, at Versailles, living creatures took the first ascension in an aerostatic machine. The honored living creatures were not human, but were a sheep, a cock, and a duck. The first human beings to take such an aerial ride were M. Pilatre de Rozier and M. Girond de Vilette, who, soon after the above-mentioned experiments, made their attempts, rising successfully to a height of about 300 feet.

Aside from the military value which has developed and has been steadily emphasized since the American Civil War, the popularity of the game was increased by leaps and bounds, and during recent years balloon flights have been an essential part of the circus and carnival as well as providing a good sport for a limited number of enthusiasts. The aeronaut at side shows drew more attention and caused more hearts to temporarily stop beating than did the gayly bedecked clowns and trapeze performers.

The hot-air balloon, however, would descend when the air became cooled and when free was always subject to the action of the prevailing air currents. To overcome this latter characteristic, it either had to be held by a cable or propelled by the, yet undeveloped, portable power plant. For observation, a stationary balloon thousands of feet in the air would be ideal for many purposes, especially war operations. Practical trials were made, but the development of the art had perfected only the spherical balloon and this, hitched to a cable, bobbed aloft as does a cork on the ocean waves.

The principles of stream-line shape were not early applied to the captive balloon and although the captive spherical was used in the siege of Paris in 1870–1, and as previously stated, in the American Civil War, it was not developed along its present lines until only a few years prior to the beginning of the present conflict in 1914.

By way of contrast to the captive spherical, one of the most important and picturesque instruments of warfare developed in the great struggle of armed forces for world supremecy, recently closed, was the captive military observation or kite balloon. The term "kite balloon" describes it in a single phrase. A balloon of this type rides the air on the end of its cable much the same as the ordinary kite rides, and gives in its attached basket a fairly stable observation post thousands of feet above the earth, from which the observers may direct artillery fire on distant targets.

At the beginning of the war the artillery fire of the allies was directed principally by airplanes. In this work, however, their use left something to be desired. While the plane observers could locate targets fairly well, they frequently lost touch with their batteries through the difficulty of sending and receiving wireless or visual signals from the swiftly moving craft. Gradually the captive balloon came into use and by the end of the war had practically displaced the airplane as a director of gunfire wherever possible. It came to be the very eye of the artillery, which, through the balloon, was made infinitely more efficient than ever before in history of warfare.

Sitting comfortably aloft, the observer in the kite balloon basket had the whole panorama of his particular station spread before him and could note accurately, with powerful glasses, everything transpiring in a radius of 10 miles or more. He was constantly in touch with his batteries by telephone and could give, by coordinated maps, not only the exact location of the target and the effect of the bursting shells, but could, and often did, give most valuable information of enemy troop movements, airplane attacks, and the like. He was a veritable sentinel of the sky, with the keen, long-range vision of the hawk. He played a part less spectacular than the airplane scout or fighter in the latter's free and dazzling flights, but his duties were not less important. Nor did he suffer from ennui during his period aloft. When a kite balloon went up it became the subject of keenest attention by the enemy because it was up on business and was certain to be the cause of damage unless it was forced down. Long-range, high-velocity guns were turned on it, and planes swooped down on it from great heights seeking to pass through the barrier of shells from antiaircraft guns and get an "incendiary bullet" through the fabric of the gas bag, which meant the ignition of the highly inflammable hydrogen gas, the quick destruction of the balloon and perhaps the occupants of the basket as well, unless they could get away in their parachutes.

From the time the gas leaped into flame until the explosion and fall of the balloon was rarely over 15 or 20 seconds, so quick work was necessary for the men in the basket to jump to safety. The pilot of the airplane could dodge and slip away from the guns, not so the pilot of the kite balloon anchored to its windlass from 2 to 5 miles behind his own lines. He had to take what was coming to him without means of defense. He had to carry on his scientific calculations unconcernedly, and in his spare moments had the questionable pleasure of watching the flash of an enemy gun on a distant hill, directed on him, and then waiting 20 or 30 seconds for the whining messenger to reach him, while he pondered on the accuracy of the enemy gunner.

As a matter of fact, few direct shell hits on a balloon were recorded in the recent war. Most of the balloons brought down were brought down by "incendiary bullets" from diving planes. Some plane pilots made a specialty of hunting "sausages," a nickname given to kite balloons because of their shape, and became very expert at it. Between September 26 and November 11, 1918, 21 American balloons were lost, of which 15 were destroyed by enemy planes and 6 by enemy shells. The enemy lost 50 balloons during the same period on the same front. Balloon companies' aircraft guns drove off many enemy attacks, and one company brought down two enemy planes with machine-gun fire in two consecutive days. The importance of the work of the allied kite balloons is strongly emphasized by the fact that the Germans gave official credit to their aviators of one and a half planes for every balloon brought down.

The average life of a kite balloon on an active section of the western front was estimated to be about 15 days. Sometimes it only lasted a few minutes. There is a record of an American balloon passing unscathed through the whole period of American activity on a busy section of the front. It is generally considered that a balloon which has seen five or six months of ordinary nonwar service has done its duty, and is unsafe because of the deterioration of the fabric, but there are many cases of a longer and safe useful service. There are also many cases of the balloon fabric becoming unserviceable in a month or two, and the balloon has had to be discarded because of high permeability to gas. Such cases are generally due to rough or careless handling. Inflated balloons at the front were taken safely over open fields, through country strewn with shell holes and barbed wire. In several instances they were transported, without a windlass, a distance of 6¼ miles at a time. In the Meuse offensive between September 26 and November 11, American balloons made an aggregate advance of over 264 miles.

EUROPEAN CONDITIONS, 1914.

When the war broke out in August, 1914, Germany had, perhaps a hundred of the kite or "sausage" balloons, France and England a very few. The German type was known as the "Drachen" and consisted of a gas cylinder of rubberized cotton cloth 65 by 27 feet with hemispherical ends. For stability, a lobe, approximately a third of the diameter of the cylinder, was attached to the underbody of the gas bag and curved up around the end. This lobe, made of lighter rubberized fabric than the gas bag itself, automatically filled with air as the balloon ascended and acted as a rudder to hold the balloon in line. For further stability, three tail cups, one behind the other and with mouths open to the wind, were attached to the rear of the balloon. These cups, 10 feet apart, also filled with air and helped to keep the balloon from swinging in high winds. France, England, and the United States had a few of the Drachen balloons and variations of that type, but they had hardly passed over the experimental stage when the Germans swept over Belgium.

While the Drachen balloon was a rather clumsy affair and proved unstable in high winds, its importance as an adjunct to the artillery could not be ignored. The results of its work became daily more evident. The armies of France, England, Italy, and America all made experiments tending toward improvement of this type which should give greater stability in the air and permit higher altitudes being attained. It remained for Capt. Caquot, of the French Army, to produce a kite balloon with both of these qualities, and his name is now used as a designation of the type which he invented and which was in general use by the armies and navies of France, England, and America during the last year of the war. Italy developed a kite balloon somewhat different from existing types which was very efficient. A compliment to the efficiency of the Caquot was paid by Germany when her army adopted this type of kite balloon and abandoned the Drachen as soon as possible.

TYPE "R" KITES.

The Caquot type "R" is an elongated gas bag 93 by 28 feet in its largest diameter, made of rubberized cotton cloth and sharply stream-lined. Its capacity is 37,500 cubic feet. Hydrogen gas is the ascensive power used and lifts the cable, two men, basket, and all other equipment to a maximum altitude, in the best weather conditions, of over 5,000 feet. It has a balloonet or air chamber within the main body of the gas envelope, which, as the balloon ascends, fills automatically with air through a simple scoop placed under the nose of the balloon. The air and gas chambers are separated by a diaphragm of double-ply cloth with a film of rubber between the two plies. This diaphragm is attached to the inner side of the envelope, well down below the equator, by sewing, cementing, and taping, preventing absolutely the entry of air to the gas chamber above it.

When the balloon is fully inflated the diaphragm rests on the underbody of the gas envelope and there is no air in the balloonet. When the balloon rises, the gas, by its natural expansion, would burst the envelope, but this is prevented by a valve set to relieve the gas pressure before it reaches the danger point. When the balloon descends, lacking its several hundred feet of hydrogen which has escaped into the air, it would lose its shape and grow flabby, a condition of possible danger. Here the balloonet, or air chamber, comes into play. As the air is driven by the wind through the scoop the diaphragm rises and takes up the lost bulk in the gas envelope above; thus gas losses are taken up by air by what amounts to an elastic air envelope below the gas envelope and separated from it by the diaphragm, through which no air can pass.

Three lobes of rubberized cotton fabric, but lighter than the envelope fabric, since they have to hold only air, are spaced equidistant around the circumference of the rear third of the balloon, and give increased stability. They are filled automatically by the wind, if it blows, expand to their full extent, and act as rudders to hold the balloon steady. If there is no wind there is no need of the lobes or steadying rudders and they then hang loosely, particularly the two upper ones, like elephant ears. The Caquots are frequently called "elephants" because of the drooping lobes or "ears" when not filled with air. The Caquot has no tail cups, rides nearly horizontally, with consequently a small strain on the cable. It has sustained winds as high as 70 miles an hour.

UNITED STATES CONDITIONS, APRIL, 1917.

When the United States entered the war in April, 1917, the Army and Navy were practically without this type of craft, and the knowledge of its construction was extremely limited. Developments in Europe had been carefully watched, however, and a few balloons made by some of the larger rubber companies. During the mobilization on the Mexican border, there was but one captive balloon in service and that one was a gift to a local National Guard organization by the Goodyear Tire & Rubber Co., of Akron, Ohio. Lacking adequate plans and specifications when the call began to come for these balloons, progress in production was necessarily slow. There was a tendency to develop individual ideas, improvements, and inventions on the balloon, things disastrous to standardization. In April, 1917, the whole production of military observation balloons in the United States was two or three per month. The various rubber manufacturers, especially the Goodyear and Goodrich organizations, at Akron, Ohio, on request of the Government, went whole-heartedly into the work of quantity production, directed by the Equipment Division of the Signal Corps, United States Army, which organization eventually developed into the present Bureau of Aircraft Production. As demands increased the United States Rubber Co., the Firestone Tire & Rubber Co., the Connecticut Aircraft Co., and the Knabenshue Manufacturing Co. all went just as whole-heartedly into the problem.

THE BALLOON CLOTH PROBLEM.

There were great difficulties in the way of quantity production of kite balloons outside of the lack of accurate knowledge on the subject of actual balloon making. Principal among these was the one of cotton cloth of proper strength, texture and in sufficient quantity. Balloon cloth was a thing practically unknown in this country in April, 1917. There had never been a call for it. To make a close, smooth, strong cloth as a base for the rubberizing process, it was considered necessary to have a weave of approximately 140 threads to the inch both ways. Only a few mills had made such a cloth and only in very small quantities. To have balloons on the schedule required by the War Department, millions of yards of this high-count cloth were required. Cotton manufacturers, when called upon to produce the cloth, undertook the work at first reluctantly, because it meant practically the development of a new type of weaver and a great reduction of the output of their looms, which on this cloth, 38 to 44 inches wide, averaged less than 10 yards a day.

At first the wastage of imperfect balloon cloth ran very high—frequently 60 per cent—but by care and persistent effort this was reduced by the middle of 1918 to perhaps 10 per cent in total from the loom to the balloon. The wastage was largely caused by "slubs," knots, and other imperfections of weaving, which prevented an even surface for rubberizing and consequently impaired the strength and gas holding qualities of the balloon. Hundreds of inspectors, both factory and Government employees, were necessary to get an approximately perfect cloth, and all had to be developed for this work. The making of balloon cloth in the United States amounted to the development of a new art for which thousands of men had to be specially trained in a few months. This alone was an achievement of no mean degree.

Such was the cooperation of the cotton manufacturers and the Government that all obstacles were overcome and the manufacturers had progressed from cloth sufficient for 2 balloons a week in April, 1917, to 10 a day in November, 1918. The production of balloons, too, went forward from small beginnings, with few mistakes or delays and always up to or a little ahead of the schedule set for overseas and domestic use. The development of the balloon from nothing to its maximum is one of the bright chapters in the history of aircraft production in the United States.

To make 10 balloons a day—the point of progress in manufacture which had been reached when the armistice was signed, it was necessary for the cotton mills to weave about 600,000 yards of the special balloon cloth a month. This meant the work of many hundreds of weavers and 3,200 looms were actually in use November 11. The average yardage of a loom per day was about 10. In April, 1917, only a few hundred looms were available.

It was sometimes a desperate race between the cotton mills and the balloon cutters, but the former kept far enough ahead to prevent any serious check to the schedule of balloons called for by the Bureau of Aircraft Production. Had the war continued another year, the cloth yardage demanded by a proposed output of 15 kite balloons a day, together with other types of balloons and the Navy dirigibles, would have reached a total of about 20,000,000 yards, or enough in a single width to have reached across the continent from New York to San Francisco five times, or nearly halfway around the earth. In the actual cutting and making of a balloon a large force of inspectors was used and had to be trained specially for the work. Every step of manufacture was watched by Government inspectors to the end that there should be no possibility of hidden mistakes to endanger the lives of the pilots and observers. This was all in addition to the factory inspection. When a balloon was accepted by the chief inspector it was right for the work it had to perform.

RUBBERIZED BALLOON FABRIC.

The rubberizing process by which the cotton cloth is converted into gas-tight balloon fabric and used in the construction of the balloon envelopes was, during the war, a subject of extensive experimentation and development. Small amounts of balloon fabric had been made but quantity production was never before attempted in the United States.

The standard Enropean construction was not changed, but rubber compounds, cures and other processes had to be developed. It is interesting to note that balloon envelope fabric is made about like an ordinary sandwich, there being a thin perfect film of specially compounded rubber between two plies of the cotton cloth which has been described. The outer ply of this cloth is cut on the bias and when plied up in this way, prevents, to a very large extent, any long straight tear down the grain of the cloth. The threads of the two plies act at an angle of 45° to each other and distribute the strain sufficiently to stop a snag practically where it started.

In applying to the cotton cloth the rubber film, which is really the gas-resisting envelope, the cloth must at times be put through the spreading machines 30 to 35 times. This is necessary to build up the thin rubber films perfectly and without flaws of any kind.

The outside or bias ply of the fabric is "spread" with a rubber compound containing a coloring matter, the object being to waterproof the outer ply, to provide a camouflage for the balloon when in the air or camped on the ground, and, thirdly, to absorb the actinic rays of the sun and thus protect the delicate rubber gas film between the two plies of cloth. On the gas film depends the ordinary life of the balloon, and it must be protected in every way possible. In some cases coloring matter is also used in the gas film itself, so that both the heat and the ultra-violet rays, which are so destructive to rubber, may be more entirely absorbed without affecting the film or heating and expanding the gas in the balloon.

The developments in this field have kept pace with the other balloon developments, and the latest reports from the front stated that the American fabric was not only proving successful but had as an added feature a characteristic which was the direct means of saving life. These reports state that the American fabric burns very much slower than European fabric, giving the pilot and observer more time to get away in their parachutes and thus prevent the burning balloon falling on them.

BALLOON WINDLASSES.

Everything about the kite balloon presented more or less of a problem because it was new, and these problems had to be worked out quickly by the American manufacturer for quantity production. The mobile windlass, for instance, by which the balloon was let up and pulled down on its cable, had to be developed from nothing. The genius of the American manufacturer overcame the difficulty, as it did every other obstacle in the development of war instruments. Steam was the motive power first used for windlasses, but before the close of the war America had developed both gas and electric windlasses which were thoroughly efficient. The best known type of gasoline windlass was that having two motors, one to rotate the cable drum controlling the balloon's ascent and descent, and one for moving the windlass itself. A record pull-down speed of 1,600 feet a minute, or more than three times as fast as the fastest passenger elevator, has been attained by the gasoline windlass. The electric windlass developed a speed of 1,200 feet per minute, but was smoother in operation, thus compensating for the slightly slower speed. The mobile windlass could move on the road under its own power 20 miles an hour and could tow the balloon in the air at the rate of 5 miles an hour, or better if necessity demanded.

A satisfactory windlass had been developed in France and, to be on the safe side, it was the duplication of this machine which was first attempted for the use of the United States Army. To duplicate, with American materials and methods, a purely French machine for which there were no drawings was a difficult and very slow proposition. The James Cunningham, Sons & Co., of Rochester, N. Y., however, took this work in hand and obtained a delivery of four complete windlasses per week.

American originality of design was shown in both the windlass designed at the United States Army Balloon School and manufactured by the McKeen Motor Car Co., of Omaha, Nebr., and the windlass designed and manufactured by the N. C. L. Engineering Co., Providence, R. I. Both of these windlasses were put in quantity production, thus assuring for the Balloon Service a sufficient number of the best windlasses ever manufactured.

CABLE.

The cable which holds the balloon captive is approximately a quarter inch in diameter, weighs 1 pound for each 8 feet of length, has a breaking strength of 7,200 pounds, and is made of seven twisted strands of plow-steel wire, containing in all 133 separate wires. This cable, while it accomplished its original purpose, was early seen to have wonderful possibilities of development. The observers in the basket must be kept in constant communication with the artillery and their own windlass and this communication could best and most efficiently be obtained by the use of the telephone. The first use of the telephone, therefore, had to be an entirely individual unit with its own separate cable from the basket to the ground. In this way communication was established but only at the sacrifice of other desirable features of captive balloon work, such as a decrease in possible altitude, increased cable resistance, and the supply of an extra windlass for winding and unwinding the telephone cable.

Previous to the entrance of the United States into the war, preliminary experiments in France were being made with the view of putting the telephone wires in the center of the main cable, thus doing away entirely with the second cable and windlass. There had never been developed a satisfactory cable of this construction and American genius at the John A. Roeblings Sons Co., and the American Steel & Wire Co., was set to work, with the result that not only was a satisfactory cable developed, but a steady production was attained, 50,000 feet per week being delivered regularly by the John A. Roeblings Sons Co., alone.

The original use of two baskets suspended from each balloon necessitated a very delicate construction of three separate and thoroughly insulated conductors. Before such a cable was put into production, the double basket idea was discarded in favor of the single basket and consequently a different cable was necessary. An insulated three-wire single-conductor cable, surrounded by 6 strands of 19 wires each was the final and successful cable which was being actually produced in quantity.

This development of course meant a further development of the windlass, but without delay the necessary devices to handle this type of telephone conductor were attached and the eyes of the artillery, the captive observation balloon, had made one more advance toward perfection.

HYDROGEN GAS.

A sufficient supply of hydrogen gas was, at the beginning, another of the balloon problems. Hydrogen, before the war, was a by-product in the manufacture of commercial oxygen, and only a small quantity was used in this country. But the demand of millions of cubic feet of this gas was met promptly through the establishment of Government plants and the expansion of privately owned plants. Portable hydrogen generators for field service were developed, but by far the greater part of the gas used at home and abroad was made at permanent supply stations, and shipped to points of demand in steel cylinders, each holding about 200 cubic feet of gas under a pressure of 2,000 pounds per square inch. On November 11 there had been ordered and put into production 172,800 of these cylinders, 89,225 having actually been delivered and put into service. From these, kite balloons were filled quickly through a manifold filler, which permitted 12 to 24 cylinders to be drawn from at the same time.

The gas made by the portable hydrogen generators involved individual problems, as did practically all phases of the balloon production. In this particular case the machine itself not only had to be designed and adapted to military uses but the chemicals necessary to produce the gas had to be obtained. The electrolytic or iron contact methods were out of the question for rapid generation of gas, and the problem resolved itself into the adoption of the ferrosilicon-caustic soda process, by which it was possible to produce in the field, 10,000 cubic feet of hydrogen per hour. Caustic soda was plentiful, but high-grade ferrosilicon, a product of large electrolytic furnaces, was scarce, due to the consumption of the available supply in the steel industry. There were, however, delivered for this purpose 2,482 tons, over 2,360 tons being supplied by the Electric Metallurgical Sales Corporation alone.

When the portable hydrogen generator was not practical or necessary, the high-pressure cylinders and "nurse balloons" were used for storing gas shipped from long distances. The nurse balloon was simply a large 5,000 cubic foot rubberized fabric bag used in the same way as a common steel gasometer, which is familiar to everybody.

It is impossible to state the exact quantity of gas used by the Balloon Service, but as one item alone, there were 17,634,353 cubic feet produced and delivered by private manufacturers previous to the signing of the armistice. These manufacturers were finally in position to meet practically any demand for hydrogen in quantity. This is only a small part of the total, as it does not include the gas produced by the permanent Government stations in the United States and France, or that produced by the silicon process in the field.

HELIUM GAS FOR BALLOONS.

Hydrogen is itself an inflammable gas and when mixed with air or oxygen is dangerously explosive. It has always been a source of great concern to balloonists and their dream has been of a non-inflammable, non-explosive gas, sufficiently light to function as does hydrogen.

It was known that "helium" was such a gas, but it was, up to two years ago, so scarce and expensive that it was hardly given a serious thought. Not more than 100 cubic feet of helium had ever been produced and it was valued at about $1,700 per cubic foot. It was discovered that certain natural gases in the United States contained limited quantities of helium and the problem then resolved itself into one of extracting the helium from the gases in sufficient quantities to make its use practical. Funds were provided from the Signal Corps, Navy, and Bureau of Mines, and under the direct supervision of the Navy and Bureau of Mines the processes of gas liquefaction as used by the Linde Air Products Co. and the Air Reduction Co. and also the Norton process, were put into operation with the following result as reward:

On the day of the signing of the armistice there were, on the docks and ready for loading on board ships, 147,000 cubic feet of helium with a prewar value of about $249,900,000. Plants were under construction for the production of this gas at the rate of 50,000 cubic feet per day at a cost of approximately 10 cents per cubic foot.

This development can not be overestimated, as it opens a new era in lighter-than-air ship navigation. Under war conditions it makes nil the effects of the incendiary bullet, which has recently been the cause of the complete destruction of so many balloons and airships. Under peace conditions it opens up the possibilities of new types of construction of dirigible airships, as the dangers from lightning, static electricity, or sparks of any kind have been eliminated.

ARMY AND NAVY.

While the Army and Navy have separate organizations for the production of balloons these organizations worked hand in hand. Specifications for cloth and fabric were practically identical for both branches of the service and the procurement of this class of material was consolidated with the Army.

The type "R" kite balloon for the Army and Navy were practically identical except the Navy used two automatic gas-bag valves, one placed on each side of the balloon one-third of the way back from the nose and just above the equator. The Army retained the French and English method of a single valve in the nose. The Navy rigging was also slightly different, as was the fabric, which had to be slightly heavier to withstand the action of the salt air and the rough handling necessary in the small space available on board ship.

In October the Navy adopted the Caquot "M" type, which rides at an angle of about 25° to the horizontal and is a trifle smaller in gas capacity since great altitude is not necessary. Kite balloons in the Navy are used as submarine and mine spotters and as a high point of lookout. They are towed on a cable from the deck of a warship and are connected with the deck by telephone.

PARACHUTES.

One of the important accessories of the kite balloon is the parachute, familiar to anyone who has attended a country fair on balloon day. When balloons began to be shot down, the need for parachutes developed. At first the individual or one-man parachute was used successfully to permit the men in the basket to get away from a burning balloon, but maps and records were lost. To save these records entire, the basket parachute was invented. This was considerably larger in diameter than the individual parachute and when cut away from a burning balloon brought the basket with the men themselves and all else it contained safely and quickly to the earth. Few fatalities occurred in the hundreds of cases in which the individual and basket chutes were used in actual war service or in training. One balloon observer was forced to make four jumps from a parachute on the same day, and another made three in four hours, two balloons being burned over his head. Thirty balloon jumps were made during the Argonne offensive alone.

During the entire time the American forces were on the front only one death occurred as the direct result of a parachute drop, and in that particular instance the burning balloon fell directly on top of the open parachute, setting it on fire and allowing the observer to fall unprotected the rest of the distance to earth.

It is interesting to note that the use of parachutes is relatively new compared even with the art of ballooning. The man who developed the parachute and first descended safely to earth by its means is still active and enthusiastic over aerial development, and during this war he has had direct charge of the inspection of all United States Army balloons and parachutes. To Maj. Thomas S. Baldwin, chief of United States Army balloon inspection, may be given much credit for the material success of these new American products. From a life of aerial exploits of all kinds, under all conditions, and in all parts of the world, Maj. Baldwin knows what is and what is not safe, and when a balloon or parachute is sent into action there is, with the pilot, always a feeling of satisfaction of knowing that the best balloon talent in the world has O. K.'d its serviceability. As a balloonist or as a true American, Maj. Baldwin has no peer.

CORDAGE.

Cordage was another difficulty of the balloon production. At first balloons were shipped overseas without rigging, since the supply of cordage was short in the United States and the French believed they could furnish all the cordage necessary. But the procession of unrigged American balloons swamped the French riggers, and it was necessary to develop cordage in this country of very high quality and in great quantity. In the rigging of a kite balloon there are about 2,000 feet of different kinds of rope. Hundreds of miles of rope were made and delivered to the Government by the manufacturers without serious delay to balloon production.

CONCLUSION.

The development of Army balloons and balloon equipment has passed through various stages of development since April, 1917, when there was practically nothing to use as a nucleus for the organization necessary to meet the new demands.

The stages of experimentation, development of new ideas, and, finally, standardization, have been met with the final result of success. Up to November 11, 1918, there were produced for the United States Army alone, 1,036 balloons of all types, 642 of these being the final type R observation balloon. Propaganda and target balloons were developed and produced, as were new type parachutes, canvas balloon hangars, and 1,221,582 feet of steel cable, a sufficient length of single-strand specially manufactured wire to more than reach entirely around the globe. Hundreds of other items of no less importance were required and produced for the balloon service, but can not be mentioned at this time.

The history of balloon production in the United States during the war is a record of achievement second to none in America's war program. Beginning with little or no technical and manufacturing knowledge available in the country, the manufacturers and officers charged with the balloon program produced in a few months balloons which stood the hard test of actual service and compared most favorably in all ways with the balloons of the best factories of Europe, where the art of balloon building has been in existence for many years. There was never any shortage of balloons after the wheels of production really began to turn, and had the war continued for another year this country could have supplied our own Army and Navy and our European allies as well with all the kite balloons and equipment they needed.

ARMY BALLOON PRODUCTION.

April 6, 1917–November 11, 1918.

Balloons:	
Type R, observation	642
Type M, observation	22
Type C, observation	7
Type J, observation	1
Experimental observation	4
Supply balloons	129
Spherical balloons	10
Propaganda balloons	215
Target balloons	6
Total balloons	1, 036
Parachutes	256
Windlasses	50
Cable, feet	1, 221, 582
Gas equipment:	
Hydrogen cylinders	89, 225
Hydrogen, cubic feet produced by private manufacturers	17, 634, 353
Helium, cubic feet	147, 000

The above production for the Army provided not only for the requirements of the A. E. F. and the balloon schools in the United States, but permitted furnishing a substantial quantity of this class of equipment to the allies.